Report to the Federal Energy Regulatory Commission
for activities under the Long-Term Settlement Agreement
for the 1994 calendar year
between Fisheries Agencies and Tribes
and Public Utility District No. 1
of Douglas County

WELLS HYDROELECTRIC PROJECT

F.E.R.C. PROJECT NO. 2149

Public Utility District No. 1
of Douglas County, Washington
1151 Valley Mall Parkway
East Wenatchee, Washington 98802-4497

April, 1995

DOC # 34229

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Foreword

On January 24, 1991, the Federal Energy Regulatory Commission approved a Settlement Agreement to resolve anadromous fish issues for the Wells Hydroelectric Project on the Columbia River in Washington State. The Agreement was a product of negotiations with state and Federal fisheries agencies and Tribes on the operations of the Wells Project (No. 2149). The F.E.R.C. directed that the licensee of the Wells Project has certain reporting responsibilities. This document is intended to fulfill portion (E)(d) of the Order requiring an annual report to be filed by April 30. This is the fifth annual report under the Agreement and will cover the period between January 1 to December 31, 1994.

Report to the Federal Energy Regulatory Commission
for activities under the Long-Term Settlement Agreement
for the 1994 calendar year
between fisheries agencies and Tribes
and Public Utility District No. 1
of Douglas County

(1) Development of Studies, Plans and Evaluations

The Public Utility District No. 1 of Douglas County (District) worked closely with fisheries agencies and Tribes to carry out various studies and obligations specified in the Settlement Agreement. These included various monitoring studies and operation plans.

1.1 Annual Bypass System Operations Plan for 1994

The Settlement Agreement calls for the District to provide an Annual Bypass System Operational Plan to members of the Wells Coordinating Committee (WCC) by December each year. The District submitted the Annual Bypass Plan for 1994 to the WCC for review on November 15, 1993. The WCC accepted the Plan (94-3)[1] (Appendix A). The spring and summer migration is monitored by hydroacoustics at Wells. The level of hydroacoustic detections responds proportionally to the magnitude of the salmonid migration.

The Bypass Team for the Wells Project makes decisions on the start and end of bypass operation during both spring and summer migration periods. Representatives from the agencies, Tribes and District make up the team (Agreement II.F.3). Members selected for the team in 1994 were Brian Cates (US Fish and Wildlife Service; USFWS), Jerry Marco (Colville Confederates Tribes; CCT) and Rick Klinge (District) (94-3).

1.2 Miscellaneous Planning for the 1994 Bypass Season

The anticipated starting date of bypass operation for 1994 was April 15. This date coincided with the historical release schedule of hatchery salmon from the Winthrop National Fish Hatchery and timing of wild spring chinook in the mid-Columbia. This meant preparations for installation of bypass barriers and hydroacoustic equipment for the hydroacoustic index would need to be ready by April 1 (Agreement II.D.1.). The plan was approved in March (94-3).

1.3 Spring Chinook Passage Study

The District worked with Yakama Indian Nation (YIN) to conduct an adult spring chinook passage study from Wells Dam to broodstock collection points in the Methow River. There had been concern over how adult salmon migrated to

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[1] (94-3) refers to minutes of the Wells Coordinating Committee from the third meeting in 1994. See Appendix M.

and around trapping locations and if these traps posed some delays to migration. The WCC reviewed a draft study proposal and made several recommendations (94-1). Based upon the study design, the University of Idaho recommended at least 120 fish should be tagged above Wells (94-2). Scales would be read to minimize tagging hatchery bound fish (94-2). It was suggested that no more than 10% of the run be tagged (94-2). This meant that unless the run to Wells was 1,200 spring chinook, the necessary number of tags would not be put out. Two hundred tags were ordered and equipment put in place (94-3). Because of an extremely poor run prediction for spring chinook in 1994, the project was terminated (94-5; 94-6).

1.4 Project Mortality Study

The Settlement Agreement specified the District, along with consultation from the Joint Fisheries Parties, will develop a study of juvenile mortality associated with Wells Dam by 1990 (IV,C,5). Results from this work would adjust compensation levels of the hatchery programs. The WCC had decided not to pursue this work in 1991, 1992, 1993 and 1994. The WCC felt that due the lack of returning adults, a 1995 study would not be advisable (94-3).

1.5 Methow Trapping Facilities

The Settlement Agreement calls for adult collection facilities for spring chinook broodstock (Agreement IV.D.2.c.(3)(a)). Traps on the Twisp and Chewuck Rivers were completed in 1992.

The trap for the Methow River was scheduled for construction with the improvements to the Fog Horn Ditch intake, fish ladder and dam for 1993. The District agreed to pay the USFWS $500,000.00 for this work in exchange for 7.0 cfs of surface water rights needed for the Methow Hatchery. The fisheries agencies and Tribes had full review of the proposed project. While the USFWS sought a Shoreline Permit for the project in January 1992, the Okanogan Wilderness League (OWL), an environmental organization in Central Washington State, appealed the process on the basis that the project did not have proper environmental review. OWL contended that the project should have a National Environmental Policy Act (NEPA) review and the project had ignored recreation concerns. A Washington State Environmental Policy Act (SEPA) review had been completed and determined impacts from the project to be non-significant. The Shorelines Hearing Board held a hearing and visited the site on May 24 and 25, 1994. On July 15, 1994, the Shorelines Hearing Board found that the OWL did not have grounds for the appeal. Thus the necessary permits for the project were granted.

The District presented to the WCC several options for collection of broodstock at Fog Horn Dam (94-8; 94-9). The District was concerned that the closeness of the Fog Horn trap to the current hatchery outfall may not improve chances of collecting naturally produced brood for the supplementation effort in the Methow. Some members disagreed. The WCC allowed the District to entertain the possibility of a temporary trap to help evaluate the situation (94-9). The District later decided not to look into a temporary trap.

The estimated cost of the improvements scheduled for Fog Horn Ditch Intake and fish ladder, without the adult broodstock trap, had increased well above the agreed $500,000.00. The District worked with the USFWS and Washington Department of Fish And Wildlife (WDFW) to amend the agreement in order to cover the additional costs. The WCC fully supported this trap as being the adult brood trap specified in the Agreement (94-10). It was emphasized that the Methow Fish Hatchery and the Winthrop Fish Hatchery would need to cooperate in programs so as not to interfere with the principles each was founded upon (94-10).

The WDFW submitted a spring chinook broodstock trapping protocol for the Methow Hatchery (94-4; 94-7). The protocol took into consideration the low anticipated return size, genetic questions of adequate population size and natural escapement needs. Broodstock collection from the Methow Hatchery outfall combined with screening of hatchery and wild adults via scales was also discussed thoroughly (94-6; 94-7). Broodstock collection was discussed at length (94-4; 94-5; 94-6; 94-7). The WCC could not reach consensus on brood collection at tributary traps if the spring chinook run to Wells was less than 100 adults (94-7). It was suggested that department directors become involved (94-7). The WCC Chair prepared a summary of the events to present to agency directors. On May 26, Bill Hevlin said NMFS would not oppose WDFW plans for broodstock collection at tributary traps. NMFS strongly recommended continuation of discussion of brood collection activities (Appendix B).

The WCC discussed salvaging spring chinook eggs from sections in the Methow and Twisp rivers that de-water annually during low flow periods in October and November (94-4; 94-6). Viable eggs collected out of portions of the river that dry up could be used for the supplementation program. The YIN estimate in 1993, 40 redds were lost when the river dropped up to 12 feet from the time spawning took place (94-6). A proposal for salvage efforts was submitted by the YIN (94-7).

1.6 Evaluation of the hatchery facilities

The Settlement Agreement calls for an evaluation of the program or facilities built by the District (Section IV). The evaluation would look at the adequacy of the facility and operations to be able to implement the hatchery plan. The Evaluation sub-committee worked toward a draft plan (94-3; 94-7). A draft was distributed (94-9) for comments. The plan evolved into an enhancement plan with three guiding principles: one describing the compensation outlined in the Settlement Agreement, one relating to management of spring chinook in the Methow, and one relating to the evaluation of the supplementation plan (94-9).

1.7 Sockeye Salmon Enhancement

The Settlement Agreement calls for four phases of hatchery based compensation. The sockeye salmon pilot project started with 8,000 lbs. of production of fish at 25 fish per pound. If evaluation of the program showed success after three years, then the program would increase to 15,000 pounds of production (Agreement IV.A.3.(a)(2); IV.A.3.(b)(1); and IV.C.2).

A draft evaluation plan had been distributed to the WCC in 1993 (93-9). Comments from the draft were sent to the CCT (94-1; 94-3) and a finalized plan was made (Appendix C).

Sockeye brood from 1993 initiated the first year of a three year evaluation of the pilot program. These fish were spawned and eggs incubated and progeny reared at Cassimer Bar. Necessary permits for the net pens were received (94-3). Okanogan County sought input from the Canadian fisheries bodies, since the Lake Osoyoos straddles the International Boundary (94-5). After input from various sources, there were several conditions placed on the shoreline permit.

Adults from the 1994 sockeye return were collected for the second year of the program. A record low return of Okanogan sockeye to Wells preempted broodstock collection necessary for the 8,000 pounds of production (94-8). A total of 141 adults for the program were collected (94-10).

1.8 Okanogan Sockeye Salmon Planning

Bob Heinith (CRITFC) had submitted a draft plan for enhancement of Okanogan sockeye in 1993. Discussions of the role of the WCC and how to work with the Canadian fisheries agencies and Okanogan sockeye was held on several occasions. There was concern over the appropriateness of the WCC initiating discussion over a trans-boundary stock (94-1). The District volunteered to re-work the plan. WCC asked the Chair to assist in expediting the process (94-3). The WCC believed that discussions with Canadian fisheries parties were necessary to resolve the trans-boundary management differences with Okanogan sockeye (94-8). A sub-committee was selected to move toward this end (94-9). Comments from the District to the plan created an ad hoc group to help bring the issue to resolution (94-10).

1.9 Okanogan Sockeye Spawning Ground Surveys

The District was concerned with the opposition of the Canadian fisheries agencies over the net pen operation on the U.S. side of Lake Osoyoos. The District felt it could not support sockeye research in Canadian waters until the Canadian concerns over the pilot program and the Canadian management goal for the Okanogan basin were better understood (WCC 94-8). Several members of the WCC expressed disappointment that the District was taking that position and said they were lead to believe that the District would be behind this effort (94-8). The WCC decided to coordinate spawning ground counts in order to not miss spawning escapement data for 1994. A survey schedule and analysis of the data was developed by Bob Bugert (WDFW) (94-8).

1.10 Okanogan Sockeye Fry Emergence Study

The WCC discussed the possibility of a study of fry emergence timing of Okanogan sockeye. Proposals were received and awarded in 1994 to study the 1994 fry emergence (94-1; 94-2; 94-3; 94-5). The thrust of the study would be timing on the fry migration and possible impact from irrigation operations.

1.11 1995 Bypass Operational Plan

The District submitted to the WCC a Bypass Operational Plan for 1995, as per Section II.F.1 of the Settlement Agreement (94-10). The plan outlined scheduled hatchery releases above Wells Dam and anticipated the starting and completion date of bypass operation (Appendix D).

(2) Results of Studies, Evaluations and Monitoring Efforts

2.1 Okanogan Sockeye Fry Emergence Study

British Columbia Department of Environment contracted with the District to help understand the timing of nerkid (sockeye and kokanee) fry emergence from spawning gravels downriver to Lake Osoyoos. Field sampling was from March 18 to May 16. Early reports indicated that high flows in the Okanogan caused premature emergence of sockeye fry (94-5). The fry migration was made up of white fish followed by nerkid fry. The peak of the nerkid fry migration was on April 18. The report presented recommendations for irrigation periods and water control flows that could improve survival of nerkid fry (Appendix E).

2.2 Spring Chinook Spawning Surveys in the Methow River Basin

The YIN has conducted spawning ground surveys in the Methow basin for spring chinook since 1988. The information on abundance and distribution of spawners will be important for the evaluation of the Methow Supplementation facility.

The 1994 escapement showed for the three basins, there were 32, 27, and 64 redds found in the Twisp, Chewuch and Methow rivers respectively (94-9). This was the lowest return of adult spring chinook seen since these surveys have been done in 1988. Unusually low numbers of spring chinook were seen throughout the Columbia Basin in 1994.

2.3 Okanogan Sockeye Spawning Ground Surveys

Sockeye surveys in 1994 were coordinated among the joint fisheries parties with data analysis by WDFW (94-9). Escapement at Wells Dam was 1,662 sockeye, the lowest ever recorded. Estimated escapement to the spawning grounds was 619 (Appendix F).

2.4 Adult Passage Studies

Two reports on ladder passage research conducted at Wells were received in 1994. NMFS conducted a telemetry study with sockeye salmon in 1992 to understand passage issues at Wells Dam. The work showed travel time between Rocky Reach and Wells Dam was about 1.5 days, and that median passage time was 1 day at Wells. Once the fish was committed to the ladder, it took from four to six hours to ascend and exit the ladder. A fall back rate of 13% was identified at Wells during periods of spill. Sockeye were delayed about a month from entering the Okanogan River due to high water temperatures and held for approximately a month in Lake Osoyoos before continuing to the spawning area near Oliver, B.C. (Appendix G).

NMFS conducted a telemetry study in 1993 with spring, summer and fall chinook to identify passage problems at fish ladders in the mid-Columbia, including Wells. Fish were radio tagged at John Day, Priest Rapids and Rocky Reach dams. The results at Wells showed some difficulty of adult chinook locating the start of the ladder from the collection chamber. The overall passage time was felt to be within the levels seen at other mainstem projects (Appendix H).

2.5 Predator Index Study for the mid-Columbia

A report on predatory resident fish from the Washington Department of Wildlife and USFWS was received in 1994 on research conducted in the five mid-Columbia reservoirs, including Wells, in 1993. The work showed that Northern Squawfish were the predominate predator collected and their abundance was highest in tailrace areas of hydroelectric projects. Cool spring temperatures in 1993 suppressed predator feeding behavior and lowered the effectiveness of sampling gear. The predator index values (relative abundance times consumption index) was comparable in mid-Columbia reservoirs to the John Day Reservoir. This information will be useful for comparison during respective predator control efforts proposed by the District (Appendix I).

(3) Outline of Action taken toward fulfillment of the Settlement Agreement

3.1 Methow River Spring Chinook Facility

The Settlement Agreement called for a hatchery based compensation program for spring chinook supplementation composed of adult collection sites; a central hatchery facility for incubation, early rearing, and adult holding and acclimation facilities for final rearing (Agreement IV). Hatchery personnel reared progeny from 1992 and 93 broodstock in the facility during 1994.

Hatchery personnel operated brood collection facilities on the Twisp and Chewuch rivers and from the hatchery outfall channel on the Methow River in 1994. They collected 10 adults from the Chewuch (19,000 eggs); 17 adults from the Methow (36,000 eggs); and 5 adults from the Twisp (16,000 eggs)(94-9).

The Settlement Agreement also calls for evaluation of the hatchery program. An evaluation plan had been developed and presented to the WCC for review and comment (94-3; 94-7; 94-9). While a formal evaluation was being developed, several aspects of the hatchery were being evaluated as well as collecting baseline information on natural spring chinook populations in the Methow Basin. Final reports were received during 1994 for work done in 1993 (Appendix J and K).

3.2 Cassimer Bar Sockeye Hatchery

The Settlement Agreement calls for a pilot effort to enhance Okanogan sockeye for three years at 8,000 pounds of production (IV.A.3.(a)(2)). This effort would also have an evaluation to gauge the success of the program. Brood were collected in 1993 and 1994 at Wells Dam as part of the first and second years of the three year program. Information on culture of sockeye at the Cassimer Bar facility was collected by the CCT as part of the evaluation (94-3, 94-9). Environmental conditions of Lake Osoyoos plus some limited information of growth in the net pens was collected by Dr. J. Rensel (Appendix L). The CCT also collected information on the outmigration of native sockeye plus the net pen reared sockeye from Lake Osoyoos.

3.3 Contract professional services in implementing the Settlement Agreement.

During 1994, the District contracted with Dr. Richard Whitney to serve as Studies Coordinator for the Wells Coordinating Committee. Dr. Whitney was unable to finish the calendar year as Committee chair due to health reasons. Bob Bugert (WDFW) took notes for the last meeting of the year. The District also contracted with Dr. John Skalski to provide statistical evaluation of methods and studies. Dr. Jack Rensel provided direction for the evaluation of the net pen aspect of the sockeye pilot program on Lake Osoyoos.

3.4 Juvenile and Adult Fish Passage Operations at Wells Dam

During 1994, the juvenile bypass system operated as per conditions outlined in the Settlement Agreement (II,C,D,F). The bypass operated between April 12 and June 9 (58 days) for the spring migration and between July 11 and August 11 (31 days) for the summer migration. Index values through much of the season reflected a weak migration in progress. The bypass team recommended bypass operation for 12 hours when most of the fish that comprised the weak migration could take advantage of the protection offered by the bypass.

The ladders operated during the year at the criteria established by the fisheries agencies and Tribes (Appendix O; III. B; C; D; E; F). Annual maintenance was performed to both ladders outside of the fish passage times.

3.5 Steelhead Production at Wells Hatchery

The Settlement Agreement specified that the District will fund additional steelhead compensation of 30,000 pounds at 6 fish per pound after 1991 (IV.3.a), bringing the total obligation to 80,000 pounds. Records from the Wells Hatchery show that 420,110 steelhead at 4.8 fish per pound or 87,400 pounds of steelhead were liberated in 1994.

3.6 Other Actions toward fulfillment of the Settlement Agreement

The District funded evaluations and studies that are part of the District's responsibility in the Settlement Agreement. These were described in Sections 2 and 3.

(4) Explanation of Alternatives Chosen

4.1 Project Mortality Study

As pointed out in Section 1.4, the WCC recommended that the Project Mortality Study not be pursued in 1994 (94-3). The WCC felt that the study should wait until additional PIT tag detection points were in place in either the mid-Columbia or in the lower mainstem. The results of this study will verify the level of compensation. Compensation programs are currently in place using an assumed project mortality of 14%. The availablity of test fish is a problem with proceeding with the work.

(5) Chronology of compliance for 1993

Items (3) and (4) above contain chronology of compliance in 1993. Documentation that the Joint Fisheries Parties were consulted prior to implementation of changes is provided in the minutes of the Wells Coordinating Committee. These records are included as Appendix M.

(6) A schedule of activities for 1995

6.1 Spring Chinook Facility

Construction on the Methow Hatchery was completed in 1992. Completion of the adult collection facility on the Methow River was pending a hearing that was dismissed in July 1994. The construction of the Methow broodstock adult trap is scheduled for early fall of 1995.

6.2 Operational Activities for 1995

The following schedule of activities is planned for 1995

Dec. (94)	Develop Annual Bypass System Operation Plan between District, Agencies and Tribes
March 1	Annual Bypass System Operation Plan finalized
March 1	Determine Bypass Team members for bypass season
March 1	Develop Annual Passage Monitoring Plan between District, Agencies and Tribes
March 25	Bypass barriers in place Begin monitoring juvenile migration via hydroacoustics Field work to start on Methow Hatchery Evaluation Studies
April 15	Have sockeye net pens in Lake Osoyoos
April 15	Anticipated start of the juvenile migration
May 15	Liberate sockeye from net pens in Lake Osoyoos
May 22	Start collecting spring chinook broodstock in Methow
July 1	Start collecting sockeye broodstock for Cassimer Bar
August 1	Start spawning ground surveys for spring chinook in Methow
Sept. 15	Start spawning ground surveys for sockeye in Okanogan
October	Production Plan annual review between District, Agencies and Tribes
on going	Planning sockeye enhancement strategies
on going	Planning for operations and protocols of the Methow River Spring Chinook Facilities

(7) Meeting Minutes of the Wells Coordinating Committee for 1994

The Wells Project was removed from the mid-Columbia proceedings on January 29, 1991 as the Settlement Agreement between the Fisheries Agencies and Tribes was approved by F.E.R.C. Minutes from the meetings of the WCC for 1994 are attached as Appendix M.

TABLE OF APPENDICES

Commissioners:
MICHAEL DONEEN
T. JAMES DAVIS
LYNN M. HEMINGER

Chief Executive Officer/Manager:
ELDON E. LANDIN

Public Utility District No.1 of Douglas County

1151 Valley Mall Parkway · East Wenatchee, Washington 98802-4497 · 509/884-7191

April 28, 1995

Ms. Lois Cashell
Federal Energy Regulatory Commission
825 North Capitol Street N. E.
Washington, D. C. 20426

Subject: Wells Hydroelectric Project - FERC No. 2149 WA
Annual Report - Fish Settlement Agreement
Docket No.'s P-2149-002 and E-9569-002

Dear Ms. Cashell:

In accordance with paragraph E of the order approving Settlement Agreement issued January 24, 1991, we submit the enclosed annual report of activities related to our settlement agreement for the Wells Project. A copy of the January 24, 1991 order is enclosed for your reference.

As directed by the order, the annual report addresses activities during the previous year. This fifth annual report covers activities performed in 1994 and planned for 1995.

Very truly yours,

Richard Klinge for

Robert W. Clubb, Ph.D.
Chief of Environmental &
Regulatory Services

nvh

Enclosures

c: (with report, but not appendices)
Mr. John Miyashiro
Mr. James Hastreiter
Mr. Ron Boyce
Mr. Brian Cates
Mr. Mike Erho
Mr. Cary Feldmann
Mr. Stuart Hammond
Mr. Robert Heinith
Mr. Bill Hevlin
Mr. Jerry Marco
Mr. Richard Nason
Mr. Tom Scribner
Mr. Rod Woodin
Mr. Dan Ballbach
Mr. Bill Frymire
Mr. Niel Moeller
Mr. Alan Stay
Mr. Tim Weaver
Mr. Garfield Jeffers

bc: Mr. Eldon Landin
Mr. William Dobbins
Dr. Robert Clubb
Mr. Ken Pflueger
Mr. Rick Klinge

date of this order or of any other date specified in this order, except as specifically ordered by the Commission. The licensee's failure to file a request for rehearing shall constitute acceptance of the order.

By the Commission.

(S E A L)

Lois D. Cashell,
Secretary.

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WASHINGTON, D.C. 20426

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1151 VALLEY MALL PARKWAY

EAST WENATCHEE, WA 98802

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Before Commissioners: Martin L. Allday, Chairman;
Charles A. Trabandt, Elizabeth Anne Moler,
Jerry J. Langdon and Branko Terzic.

Public Utility District No. 1 of Douglas County, Washington	))	Project No. 2149-002 Docket No. E-9569-002

ORDER APPROVING SETTLEMENT AGREEMENT

(Issued January 24, 1991)

This is the most recent of a series of settlement agreements that have emerged from our consolidated proceeding on anadromous fish issues on the mid-Columbia River in Washington State. Before us today is a comprehensive, uncontested, long-term settlement of such issues arising out of the operation of Wells Project No. 2149, located in Douglas and Okanogan Counties, Washington. We will approve the settlement, with clarifications and conditions that are consistent with our approval of related recent settlements.

BACKGROUND

In 1979, the Commission consolidated and set for hearing in Docket No. E-9569 a set of related petitions seeking modification of the operation of five licensed projects on the mid-Columbia River to protect and enhance salmon and steelhead trout. 1/ The petitions were filed by various state and federal fishery agencies and Indian tribes, and sought to protect anadromous fish migration downstream through project facilities. Wells Project No. 2149 was one of the five projects. The proceeding has generated a series of interim and long-term settlements. Most recently, the Commission approved long-term settlements resolving the Vernita Bar Phase (Priest Rapids Dam) of the proceeding, 2/ and issues involving Rock Island Project No. 943-002 (Chelan County). 3/ We also have had occasion to approve a settlement of fishery issues in Project No. 2149-017, a related proceeding

1/ 6 FERC ¶ 61,210 (1979).

2/ 45 FERC ¶ 61,401 (1988).

3/ 46 FERC ¶ 61,033 (1989).

involving the raising of the surface elevation of the reservoir. 4/

On October 30, 1990, the parties in the above-captioned proceeding filed an offer of settlement with the presiding administrative law judge. On November 19, 1990, the Commission's trial staff filed comments in support of the settlement. On December 4, 1990, the presiding administrative law judge certified the settlement and the staff's comments to the Commission for decision.

The parties to the settlement are Public Utility District No. 1 of Douglas County, Washington (the PUD); Puget Sound Power & Light Company, Pacific Power and Light Company, the Washington Water Power Company, and Portland General Electric Company (collectively, the Power Purchasers); and the Washington Department of Fisheries, the Washington Department of Wildlife, the Oregon Department of Fish and Wildlife, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Confederated Tribes and Bands of the Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Confederated Tribes of the Colville Reservation (collectively, the Joint Fishery Parties).

As summarized by the trial staff in its comments, the settlement agreement provides for the following.

The agreement has a term from its execution date to the expiration of the license (2012) plus any annual licenses. During that time, the agreement is intended to satisfy the PUD's obligations under Article 41 of the license. The agreement is not subject to modification prior to March 1, 2004. There are procedures (discussed, in part, below) for the resolution of disputes.

The PUD has agreed to provide juvenile and adult fish passage and a hatchery program. The juvenile fish passage system will be a program of controlled spills using five bypass baffles. The agreement specifies criteria for the operation, timing, and performance of the bypass system. The adult passage system will use the existing fish ladder. Criteria are established for water depth over the weirs, entrance gate settings, and jet and trashrack operations.

The PUD's hatchery program is designed to mitigate fish passage losses at the Wells Project. The physical structures include adult collection sites, a central hatchery facility and acclimation facilities. The amount of compensation is to be

4/ 30 FERC ¶ 61,285 (1985).

determined by a formula using a five-year running average of adult runs by species. In 1991, the PUD will produce spring chinook yearlings, sockeye juveniles, and steelhead smolts. The production will then be evaluated and, based on those results, the PUD will either increase sockeye production or eliminate sockeye production and add production of summer chinook juveniles.

At completion of a project juvenile mortality/survival study, adjustment will be made to production levels, except for steelhead, to reflect the differences between the mortality rate developed in the study and the mortality rate assumed in developing the original production amounts. Adjustments will also be made to compensate for any unavoidable and unmitigated adult losses.

Once the five-year rolling average estimate of the juvenile run size reaches 110 percent of the estimated juvenile production used to establish the original production, the Joint Fisheries Parties can request a compensation increase in juvenile run size, except for steelhead.

The settlement also provides for continued studies and evaluations of the program. Studies will also be conducted on the potential unutilized habitat and on establishing sockeye in new habitat. The studies will be conducted under the direction of the Wells Project Coordinating Committee, which will be composed of one technical representative of each signatory to the agreement.

The Joint Fisheries Parties agree with the PUD that the Wells Project portion of the proceeding in Docket No. E-9569 should be terminated. These parties also agree to support the PUD when it requests relicensing of the project. The Joint Fisheries Parties further are of the view that the PUD's performance of its responsibilities under the agreement satisfies the PUD's fish protection and compensation obligations under the Federal Power Act and all other applicable laws and regulations.

In their offer of settlement, the parties indicate that it represents the culmination of two years of intensive negotiation, and that it "is intended to resolve, at least until March 1, 2004, the anadromous fish issues" pending in the proceeding.

The trial staff, in its comments supporting the settlement, requests that the Commission "make clear that the Commission's authority to require changes in structures and operations, should the need arise, is preserved" during the period when the settlement is not subject to modification. The trial staff also suggests adding certain reporting requirements to enable the

Commission to monitor compliance with the settlement. The trial staff does not propose modification of any of the substantive terms of the settlement, and no party opposes the settlement.

DISCUSSION

As we noted in approving an earlier settlement in this proceeding, 5/ the issues have been thoroughly ventilated and debated, and the settlement agreement is the result of a concerted effort to resolve these important matters in a way that is acceptable to all of the participants. We commend the participants for their efforts. We believe the settlement agreement is in the public interest, and we will adopt it. The agreement balances the continued operation of the project with an effective, long-term program for protection, mitigation, and enhancement of the fishery resources affected by the project.

We will clarify the dispute resolution provisions of the settlement agreement in the same manner as we did in our above-cited 1988 and 1989 orders approving related settlements. 6/ Section I.D. of the settlement agreement provides that, if the Wells Project Coordinating Committee cannot resolve a dispute among the signatories and if the amount in controversy is less than $325,000, then any party may request the Commission to refer the dispute to (1) the presiding judge in the mid-Columbia Proceeding, Docket No. E-9569, (2) the Commission's Chief Administrative Law Judge, or (3) the Division of Project Compliance and Administration, Office of Hydropower Licensing, "in the order listed," for expedited review. For the reasons stated in our prior orders, the Commission will in most cases refer such disputes to the Division of Project Compliance and Administration, and will use its best efforts to resolve such disputes within the time frames set forth in the agreement. In appropriate circumstances, such as when there are material facts in dispute, we may refer a matter to an administrative law judge. In either event, the initial staff decision will be subject to de novo review by the Commission. And, as we emphasized in our 1989 order, any resolution by the Coordinating Committee, or a third party, pursuant to Section I.D. that contemplates a change in the license or in the operation of the project thereunder shall result in the filing of an appropriate application therefor by the licensee as soon as practicable after the dispute is resolved.

5/ See 45 FERC at p. 62,259.

6/ See 45 FERC at pp. 62,259-60 and 46 FERC at p. 61,197.

As we noted in our prior orders with respect to the settlements approved therein, 7/ approval of the settlement agreement does not affect the Commission's authority, as reserved in the license, to require, after notice and opportunity for hearing, alterations to project facilities or operations that may be warranted by changed circumstances. We intend that any such reserved authority would be exercised only after full consideration of the benefit sought to be achieved thereby, balanced against the possibility that as a consequence the settlement could be voided, thereby eliminating the benefits obtained thereunder. If any party voids the agreement, the licensee shall, within 30 days, so inform the Commission in writing.

Finally, we will adopt the reporting provisions proposed by the trial staff in its comments.

<u>The Commission orders</u>:

(A) The settlement agreement filed in this proceeding on December 4, 1990, is approved and made a part of the license for Wells Project No. 2149.

(B) The Wells Project No. 2149 portion of the proceeding in Docket No. E-9569 is terminated.

(C) The Commission's approval of the settlement agreement shall not constitute approval of, or precedent regarding, any principle or issue in these or any other proceedings.

(D)(1) Whenever a violation of the settlement agreement occurs, the licensee shall, within 30 days of the occurrence, file with the Commission, and send a copy to the Regional Office, a report containing an explanation of the circumstances surrounding the violation and the licensee's plan to avoid any repetition thereof.

(2) Whenever a dispute arises under Section I.D. of the settlement agreement that is resolved without referral to the Commission, the licensee shall, within 30 days, file with the Commission, and send a copy to the Regional Office, a report containing an explanation of the dispute and the nature of the resolution.

7/ See 45 FERC at p. 62,260 and 46 FERC at p. 61,198.

(E) The licensee: (a) shall notify the Commission and the Commission's Portland Regional Office of all meetings of the Coordinating Committee; (b) shall file functional design drawings, including all information required by 18 C.F.R. § 380.3, at least 90 days prior to construction of any facilities under the agreement; (c) shall file for approval all changes in monitoring, evaluation, study and production plans, not specified in the agreement; and (d) shall file an annual report. The annual report shall be filed on April 30 of each year and shall include:

(1) A description of plans developed during the previous year for any studies, evaluations, monitoring programs, production programs, system operations, or fish passage efforts;

(2) The results of all studies, evaluations and monitoring of the previous year;

(3) An outline of all actions taken towards fulfillment of the terms of the agreement;

(4) An explanation of the reasons for exercising specific alternatives stipulated in the agreement;

(5) A chronology of compliance for the previous year, outlining schedule changes, the reasons for the changes, and documentation that the Joint Agencies were consulted prior to implementation of the changes;

(6) A schedule of activities for the next year; and,

(7) Summaries or meeting minutes from each of the meetings of the Coordinating Committee for the previous year.

(F) This order is final unless a request for rehearing is filed within 30 days from the date of its issuance, as provided in Section 313(a) of the Federal Power Act. The filing of a request for rehearing does not operate as a stay of the effective

WELLS HYDROELECTRIC PROJECT

JUVENILE BYPASS SYSTEM OPERATIONS PLAN

FOR THE 1994 BYPASS SEASON

APPENDIX - A

WELLS HYDROELECTRIC PROJECT
JUVENILE BYPASS SYSTEM OPERATIONS PLAN
for the 1994 Bypass Season

The Wells Long Term Settlement Agreement (II.F.1) specifies that Douglas PUD will submit an Annual Operations Plan for the bypass to the Wells Coordinating Committee by December prior to the spring migration. This plan will be reviewed and approved by the Committee by March 1.

The Bypass System

The PUD will install five bypass barriers in spill gates of the Wells Project. The bypass will operate per criteria in the Settlement Agreement (II.C, E).

Operation Criteria

The operation criteria includes operation of the bypass in partnership with adjacent turbine units, the amount of water required for bypass operation and criteria for full bypass system operation.

Bypass Operations Timing Criteria

The bypass will be in place from two weeks before predicted start of the migration until two weeks after the migration is complete.

Projected Hatchery Releases above Wells Dam

Hatchery releases for 1994 above Wells Dam are as follows:

Facility	Species	No. (thos.)	Dates
Winthrop (USFWS)	Spr. Chinook	920	4/15
Methow (WDF)	Spr. Chinook	77	4/15
Carlton (WDF)	Sum. Chinook	400	4/15
Similikameen (WDF)	Sum. Chinook	560	4/15
Lake Osoyoos (CCT)	Sockeye	200	5/15
Wells (WDW)	Sum. steelhead	400	4/20

Starting Dates and Ending Dates

Bypass barriers will be in place between March 27 and August 29. Hydroacoustic and fyke net sampling will start on March 27 and be collected until August 29.

The bypass team will decided the start and end of bypass operation. Hydroacoustics and fyke net information at Wells will be used to show the start and completion of the spring and summer migrations. Preseason dates for bypass operation for spring and summer migration are April 10 through May 30 and July 1 through August 15.

LETTER FROM BILL HEVLIN,

NATIONAL MARINE FISHERIES SERVICE,

CONCERNING SPRING CHINOOK BROODSTOCK COLLECTION,

JULY 13, 1994

APPENDIX - B

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
ENVIRONMENTAL & TECHNICAL SERVICES DIVISION
911 NE 11th Avenue - Room 620
PORTLAND, OREGON 97232
503/230-5400 FAX 503/230-5435

F/NWO3

JUL 13 1994

Dr. Richard Whitney
Chairman, Wells Project Coordinating Committee
16500 River Road
Leavenworth, Washington 98826

RE: Spring Chinook Broodstock Collection on the Twisp and Chewuch Rivers in 1994

As I stated on the May 26, 1994, Mid-Columbia Coordinating Committee conference call the National Marine Fisheries Service will not oppose Washington Department of Fish and Wildlife's (WDFW) plans for broodstock collection on the Twisp and Chewuch Rivers in 1994. It is our understanding that a maximum of 20 adults will be collected at each of the trapping sites. We are concerned with the practice of maintaining broodstock collection regardless of the run strength. Although this may be justifiable in certain specific instances, we do not believe this to be best course of action in all cases. In general, we continue to support an approach such as that outlined in the April 6, 1994, Wells Committee decision to collect no broodstock on the Twisp and Chewuch Rivers should the estimated run size for each river be less then 100 fish. We strongly urge additional discussion on this subject prior to 1995 broodstock collection activities.

To document the reasoning behind our initial opposition and facilitate further discussion, our analysis of the 1994 situation in the Methow Basin is presented in the following paragraphs.

With the adult return counts potentially as low as 40 fish to each of the two Methow River tributaries, taking as many as half of each population to the hatchery substantially reduces natural production and encumbers the spawning success of those fish left in-stream. To spawn successfully, the remaining adults must locate suitable substrate and a mate somewhere in the nearly 20 river miles upstream of the traps. Males must locate females prior to ripening, and individual females ripen at differing times within an approximate 30 day period. Hence, as the population reaches a critically low level the risk that individual fish may not locate a mate at the proper time increases. Reductions of the in-stream population via broodstock collection, pre-spawning mortality, or spawning displacement exacerbates this situation.

This will be the third season that the Twisp River weir and trap has been used for spring chinook broodstock collection. In 1992, the first year of broodstock collection, the annual spawning survey (Meekin, 1992) reported that during June, 4 females and 6 males were killed by stranding on the weir. Pre-spawning mortality occurred in the hatchery that year, consisting of 3 each for males and females or 17% and 25% respectively for fish collected for broodstock. We have no information on any additional pre-spawning mortality which may have occurred in the wild. The 1992 survey also noted that 40 redds were located in marginal habitat downstream of the Twisp weir, a section with past sparse spawning, suggesting that the weir was a major blockage to some migrating adults. Meekin attributed the changes in the spawning distribution in 1992, both in the overall Methow Basin and within the Twisp, Methow, and Chewuch Rivers, to broodstock trapping and low steam flow. Suspending broodstock collection on the Twisp River in 1994 would have guaranteed that there would be no strandings or spawning displacement related to weir/trap use, and no pre-spawning mortalities at the hatchery.

The rationale in support of broodstock collection lies in the egg to smolt survival advantage which the hatchery has over in-stream production. However, whether this advantage will enhance or sustain these reduced stocks in their native habitat remains to be seen. Absent adult return data, it is unknown whether or not hatchery production will return more adults per parent than natural production. Furthermore, the long term effects of the hatchery program on the natural population's fitness is also unknown. Should fitness decline, potential advantages gained by hatchery production may be short lived. To resolve questions such as these, the Wells Settlement Agreement calls for studies and evaluation of the hatchery program. Unfortunately, a comprehensive evaluation has yet to be presented to the Wells Committee.

To reiterate, our purpose in commenting on the 1994 collection plans is to generate additional discussion and consideration of these issues prior to 1995 broodstock collection activities.

If you have any questions regarding this matter please contact me at (503) 230-5407.

Sincerely,

William A. Hevlin

William A. Hevlin
Fishery Biologist

cc: Wells Project Coordinating Committee Members

Rod Woodin, Washington Dept. of Fish & Wildlife
Tom Scribner, Yakima Indian Nation
Jerry Marco, Colville Confederated Tribes
Bob Heinith, Columbia River Inter-Tribal Fish Com.
Cary Feldmann, Puget Power
Brian Cates, U.S. Fish & Wildlife Service
Ron Boyce, Oregon Dept. of Fish & Wildlife
Rick Klinge, Douglas Public Utility District

CASSIMER BAR SOCKEYE HATCHERY
PHASE ONE EVALUATION PLAN
BY
JERRY MARCO, COLVILLE CONFEDERATED TRIBES

APPENDIX - C

CASSIMER BAR SOCKEYE HATCHERY

PHASE ONE EVALUATION PLAN

Introduction

The Wells Settlement Agreement requires an evaluation of the Phase One sockeye compensation (Sec. IV. C.2) prior to initiating the Phase Two Production Plan. The objective of this initial evaluation is to determine the success of Phase One compensation based on a review of smolt production. A determination will be made by the Wells Coordinating Committee after the third brood years production has been evaluated.

In order to facilitate the evaluation requirements contained in the agreement, the following proposal is provided. The plan identifies two major objectives which will provide the framework for short-term (3 year) monitoring of the Phase One sockeye production identified in the hatchery based compensation plan.

Goal

The Evaluation Plan will provide information necessary for determining the success of Phase One sockeye production based on smolt production.

Objectives

Objective 1:
Determine if the Cassimer Bar Sockeye Hatchery is capable of meeting the Phase One production requirements identified in the Wells Settlement Agreement (Sec. IV.A.3a).

Task 1-1:
Determine survival rates of various life stages of sockeye at the hatchery and the Lake Osoyoos Net Pens.

Subtask: 1-1-A:
Monitor pre-spawning mortality of adult broodstock.

Subtask 1-1-B:
Determine egg-to-fry and fry-to-smolt survival rates for sockeye salmon prior to release.

Task 1-2:
Determine if the hatchery can produce accelerated sockeye smolts.

Subtask 1-2-A:
Monitor growth and feed conversation rates of sockeye juveniles reared at both hatchery and net pens.

Subtask 1-2-B:
Document hatchery techniques applied during each life stage. Records should include, but not be limited to, broodstock collection dates, time of spawning, thermal uniTS during incubation, hatching dates, early rearing temperatures, density at splits, ponding dates and densities, feeding schedules, net pen loading rates and lake temperatures.

Task 1-3:
Monitor fish health and develop cultural methods to alleviate fish health problems.

Subtask 1-3-A:
Conduct routine (monthly) fish health monitoring by qualified fish health experts to assess the presence of specific pathogens that are known to occur in sockeye salmon.

Subtask 1-3-B:
Develop recommendations/protocol on means to segregate eggs/progeny based on levels of Rs Antigen, which allows for protection of negative progeny from potential horizontal transmission of disease from positive progeny. Progeny of any required segregation will also be tested by ELISA at the first opportunity and prior to movement to net pens.

Subtask 1-3-C:
Summarize fish health measures designed to improve sockeye culture and include as part of the reporting requirement.

Task 1-4:
Provide monthly and annual reports which summarize task results and include recommendations for improving salmon culture techniques necessary for achieving phase one production.

Objective 2:
Evaluate Phase One Sockeye Smolt Production.

Task 2-1:
Monitor smolt outmigration from Lake Osoyoos during the phase one period. Subyearling sockeye juveniles that have been accelerated to smolt size will be released from lake Osoyoos net pens in late-May during the next three years. The ability to monitor smolt migration at release will assess whether hatchery fish migrate as accelerated smolts or rear an additional year in the lake prior to migration. In addition, baseline data can be collected on the estimated yield, timing and duration of the natural smolt migration.

Subtask 2-1-A:
Select smolt trapping site on the upper Okanogan River and secure necessary permits. Strategy: Locate a rotary screw trap in the upper Okanogan River between Zosel Dam and the Similkameen River confluence. This should allow for a range of river flows that can be handled by the trap,while sampling sockeye smolts released and/or produced in Lake Osoyoos.

Subtask 2-1-B:
Install and operate a smolt trap on the upper Okanogan River. Strategy: Initiate the operation of a rotary screw trap on the Okanogan River for smolt trapping purposes on or about April 25 and continue operation through June 10 or until it has been determined that the migration has ended.

Subtask 2-1-C:
Mark one-hundred percent of hatchery sockeye juvniles with a right pelvic fin clip prior to net pen distrubution. Strategy: A marking schedule will be developed which includes: a) the amount of time required to mark the fish b) a quality control window, c) the estimated size of the fish during the marking period based on a) and b) and d) an estimated date for initiating the marking program.

Subtask 2-1-D:
Determine trapping efficiency using a mark/recapture effort. Strategy: Conduct replicate mark/recapture efforts throughout the trapping season. Periodic releases of previously trapped sockeye smolts will be made upsteram of the trap. For identification pruposes, these fish will be marked with colored ink applied from a pan-jet applicator plus a caudal lobe clip. The upstream release site location will be determined by the ability or marked smolts to randomly distribute within the stream and the concern of predation between the trap/release sites.

Subtask 2-1-E:
Collect hydrologic informatinduring the trapping period. Strategy: Install thermograph to record water temperature, obtain daily flow recordings from gauging station at Oroville and collect turbidity measurements using a trubidity meter.

Subtask 2-1-F:
Apply trapping data to estimate smolt yield of natural and hatchery smolts and compare migrational characteristics with hydrologic parameters.

Subtask 2-1-G:
Compile results for presentation in a report.
Strategy: At the conclusion of the trapping period, a draft report will be prepared and submitted to Douglas County PUD for review by August 15, 1994 and a final report 30 days after comments have been received on the draft report.

WELLS HYDROELECTRIC PROJECT

JUVENILE BYPASS SYSTEM OPERATIONS PLAN

FOR THE 1995 BYPASS SEASON

APPENDIX - D

WELLS HYDROELECTRIC PROJECT
JUVENILE BYPASS SYSTEM OPERATIONS PLAN
for the 1995 Bypass Season

The Wells Long Term Settlement Agreement (II.F.I) specifies that Douglas PUD will submit an Annual Operations Plan for the bypass to the Wells Coordinating Committee by December prior to the spring migration. This plan will be reviewed and approved by the Committee by March 1.

The Bypass System

The PUD will install five bypass barriers in spill gates of the Wells Project. The bypass will operate per criteria in the Settlement Agreement (II.C.E).

Operation Criteria

The operation criteria includes operation of the bypass in partnership with adjacent turbine units, the amount of water required for bypass operation and criteria for full bypass system operation.

Bypass Operations Timing Criteria

The bypass will be in place from two weeks before predicted start of the migration until two weeks after the migration is complete.

Projected Hatchery Releases above Wells Dam

Hatchery releases for 1995 above Wells Dam are as follows:

Facility	Species	No. (thos.)	Dates
Winthrop (USFWS)	Spr. Chinook	800	4/15
Methow (WDFW)	Spr. Chinook	625	4/15
Carlton (WDFW)	Sum. Chinook	845	4/15
Similikameen (WDFW)	Sum. Chinook	600	4/15
Lake Osoyoos (CCT)	Sockeye	200	5/15
Wells (WDFW)	Sum. Steelhead	550	4/20

Starting Dates and Ending Dates

Bypass barriers will be in place between March 27 and August 28. Hydroacoustic and fyke net information at Wells will be used to show the start and completion of the spring and summer migrations. Preseason dates for bypass operation for spring and summer migration are April 10 through May 30 and July 1 through August 15.

(Draft 11/18/94)

SOCKEYE AND KOKANEE

FRY MIGRATION STUDY MIGRATION STUDY

OKANOGAN RIVER ABOVE OSOYOOS LAKE, 1994,

BY B. G. SHEPHERD

APPENDIX - E

SOCKEYE AND KOKANEE FRY MIGRATION STUDY

OKANAGAN RIVER ABOVE OSOYOOS LAKE, 1994

FINAL REPORT

by

B.G. Shepherd and G.A. Inkster

Ministry of Environment, Lands and Parks
Okanagan Fisheries Section
3547 Skaha Lake Road
Penticton, BC
V2A 7K2

January, 1995

Southern Interior Region
Okanagan Sub-Region
Fisheries Project Report No. OK-18

TABLE OF CONTENTS

<u>NOTE</u>: Appendices are under separate cover, and are available for inspection from: R. Klinge, Public Utility District No. 1 of Douglas County, 1151 Valley Mall Parkway, East Wenatchee, WA, 98802-7191 (<u>or</u> B. Shepherd, BC Environment, 3547 Skaha Lake Rd, Penticton, BC, V2A 7K1).

ABSTRACT

Fyke nets were fished from Vertical Drop Structure 13, located in the Okanagan River just north of Oliver, during the spring of 1994. A total of 6199 fish were caught: 5499 sockeye/kokanee (Oncorhynchus nerka) fry, 692 whitefish (Prosopium williamsoni) fry, and minor catches of longnose sucker, yellow perch, longnose dace and tench juveniles. Nerkid fry tended to be found mid-river, while whitefish fry were captured more often near shore. The whitefish fry migration ran from mid-March through the end of April, peaking at the end of March. The nerkid fry migration began March 1, peaked April 18 and ended by May 21. Once fry had accumulated sufficient thermal units to begin emergence, the main environmental trigger for migration appeared to be increases in discharge, possibly also affected by turbidity and moon phase. Although nerkid fry migration started at dusk and continued until dawn, 75% of the fry were caught between 2000 and 2300 hrs PDT. Nerkid fry lengths ranged from 23-39 mm and averaged 28 mm for live samples; preserved lengths were 5% smaller, averaging 26.5 mm. Wet weights of preserved nerkid samples averaged 193 mg. Whitefish samples averaged 16 mm (live samples) and 15 mm and 67 mg (preserved samples). Total nerkid trapping mortality was around 34% of the catch, but less than 0.1% of the total run, which was conservatively estimated at 2.9 million fry. Length-frequency data were of no use in separating kokanee from sockeye fry, but differences in pigmentation were observed that might be of value in discriminatiing between races (further studies would be required to determine this).

It was concluded that there is potential for nerkid fry to be entrained in irrigation diversions located along the Okanagan River above Osoyoos Lake. Recommendations regarding ways to minimize such entrainment, as well as improvements to sampling gear and further studies were suggested.

ACKNOWLEDGEMENTS

On behalf of the Wells Coordinating Committee, the Public Utility District No. 1 of Douglas County (PUD) requested and funded this study on a contract basis (P.O. No. W943088) to the Okanagan Fisheries Section of the BC Ministry of Environment, Lands & Parks (BCE). Rick Klinge, the PUD technical monitor for this contract, was most helpful in ensuring the success of this study. Shane Bickford of the PUD provided thermograph information, data and analyses in support of this study.

The BCE Water Management Engineering Section allowed the use of their Vertical Drop Structures as sampling platforms, which contributed greatly to the success and safety of trapping. Ray Jubb, the Senior Engineering Technician, was particularly helpful in providing useful advice for the operation.

Special thanks to those members from the Southern Okanagan Sportsmen's Association of Oliver, BC, who assisted in setting up the fry traps and patrolled the site when study personnel were off duty. Appreciation also goes to Don McPhail of the UBC Department of Zoology for identifying the whitefish fry caught during this study.

INTRODUCTION

The sockeye/kokanee (Oncorhynchus nerka) complex that utilizes Osoyoos Lake and the reaches of the Okanagan River below Vaseux Lake (Fig 1) intrigues many organizations on both sides of the U.S.-Canada Border. The Okanagan sockeye run is one of just two viable populations of this species left in the entire Columbia River system, and are challenged during migration to and from the sea by a chain of dams and reservoirs. This stock is also of particular interest, in that it spawns and rears under unusually warm water conditions for the species. Given the stock's unique nature and the desire to mitigate for downstream impacts, there is considerable interest in enhancing the Okanagan sockeye run.

The Okanagan Fisheries Section of BC Environment is tasked with managing the freshwater fish, fish habitat and sport fisheries of the Canadian portions of the Okanagan Valley (Region 8). The kokanee is popular with Canadian anglers in Osoyoos Lake, and the potential for in-lake competition between the juveniles of the two races is perceived to be high by this Ministry.

Certainly the spawning distribution and timing of kokanee appear to overlap considerably with sockeye in the Okanagan River above Oliver, although data are scanty (Mullen, 1986). Data on fry migration are similarly sparse for both races of nerkids present in this system (Pratt et al, 1991). If the migration timings are similar for the two races, then it follows that they will face the same hazards during their downstream migration.

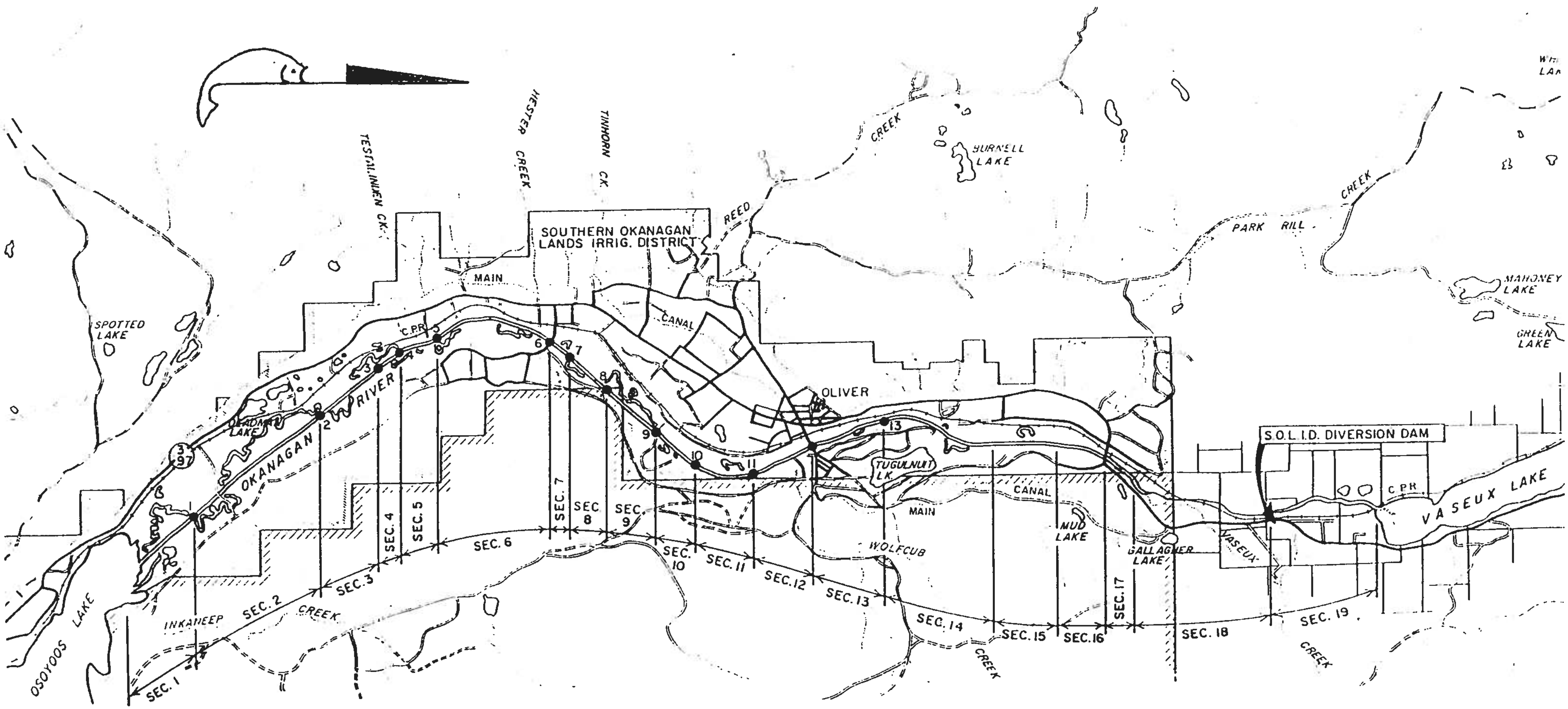
For example, it has been often suggested that nerkid fry may be entrained into the many irrigation diversions located along the river. In order to scope the severity of the problem, it was seen as essential to determine fry migration patterns. The degree of overlap of fry migration with the irrigation season could then be ascertained, and the need prioritized for further studies, such as survey of irrigation intakes for compliance with Federal fish screening requirements (DFO, 1990 MS)

In order to fill this data gap, the Public Utility District No. 1 of Douglas County issued a Request for Proposals regarding the migration of sockeye fry into Osoyoos Lake. As BC Environment also had a vested interest in seeing the study done on behalf of kokanee, the Ministry offered to undertake the study (Appx 1).

Although the focus of the study was on describing the timing of the downstream migration of nerkid fry, some information on the cross-sectional distribution of fry was collected, and a rough estimate of the magnitude of the fry migrant population was attempted. In addition, basic biological data were collected and used in attempts to separate the two races of nerkids. Monitoring also included various physical factors that could have affected migration patterns.

FIGURE 1. Map of Okanagan River between Vaseux Lake and Skaha Lake (closed circles indicate VDS locations; SOLID diversion dam is now known as McIntyre Dam).

Approximate scale 1 cm = 1 km.



METHODS

Trapping. The general sampling strategy was to use a fyke net to fish the uppermost portion of the water column passing through each of the three westernmost bays of the first Vertical Drop Structure (VDS 13) downstream of the "natural" section of the Okanagan River (Fig 2). This site was selected because it is the closest to the spawning grounds, and should have minimal losses of emergent fry due to predation or diversion into intakes.

A fyke net and frame prototype was constructed and tested in early March of 1994. The frame materials were found to be too lightweight for the flow conditions, and the frame was redesigned and successfully tested in the following week (March 11). While two more frames were being fabricated, the single fyke net was fished on alternate nights in the second bay on the west side of VDS 13 (designated as Net #2).

On March 18, all three frames and nets were deployed, and sampling settled into a dawn-to-dusk, Mon-Wed-Fri routine thereafter (see the series of photos provided as Fig 3, and the materials specification sheets in Appx 2). Nets normally were fished on the hour for a maximum of 30 minutes. When catches became too high (ie, more than 50 fry/net), sampling times were decreased, aiming for a target sample size of 10-50 fry/net. At times, the sampling interval was as short as two minutes.

Because the frames had to be more substantial than originally thought, they could not be shifted by one person and were left fixed in the three westernmost bays of VDS 13 (the bay near the centre of the river was designated Net #1, and the bay nearest the western shore was designated Net #3). After the completion of each night's sampling, the frames were lifted clear of the water using a pulley arrangement in order to avoid damage from logs or other debris.

There were some interruptions to the routine sampling schedule due to various minor problems. These gaps were filled by interpolation, using the observed relationships between nets and sampling intervals ("calibration" tables are provided in Appx 3).

By May 9, catches at VDS 13 had dropped to low levels, and the traps were relocated approximately 15 km downstream to VDS 2, which was the first drop structure above Osoyoos Lake that was not backwatered. The purpose behind this relocation was to check that nerkid fry were not "hanging up" along the river channel during their migration, and thus extending the migration period in the lower reaches of the river. Catches remained low at VDS 2 for the period ending May 16, and trapping was terminated after that date.

FIGURE 2. Views of VDS 13 looking downstream and upstream. Note the three net frames (lifted into the stored position) on the right side of the upper photo:, one fyke net has been set in fishing position in the lower photo

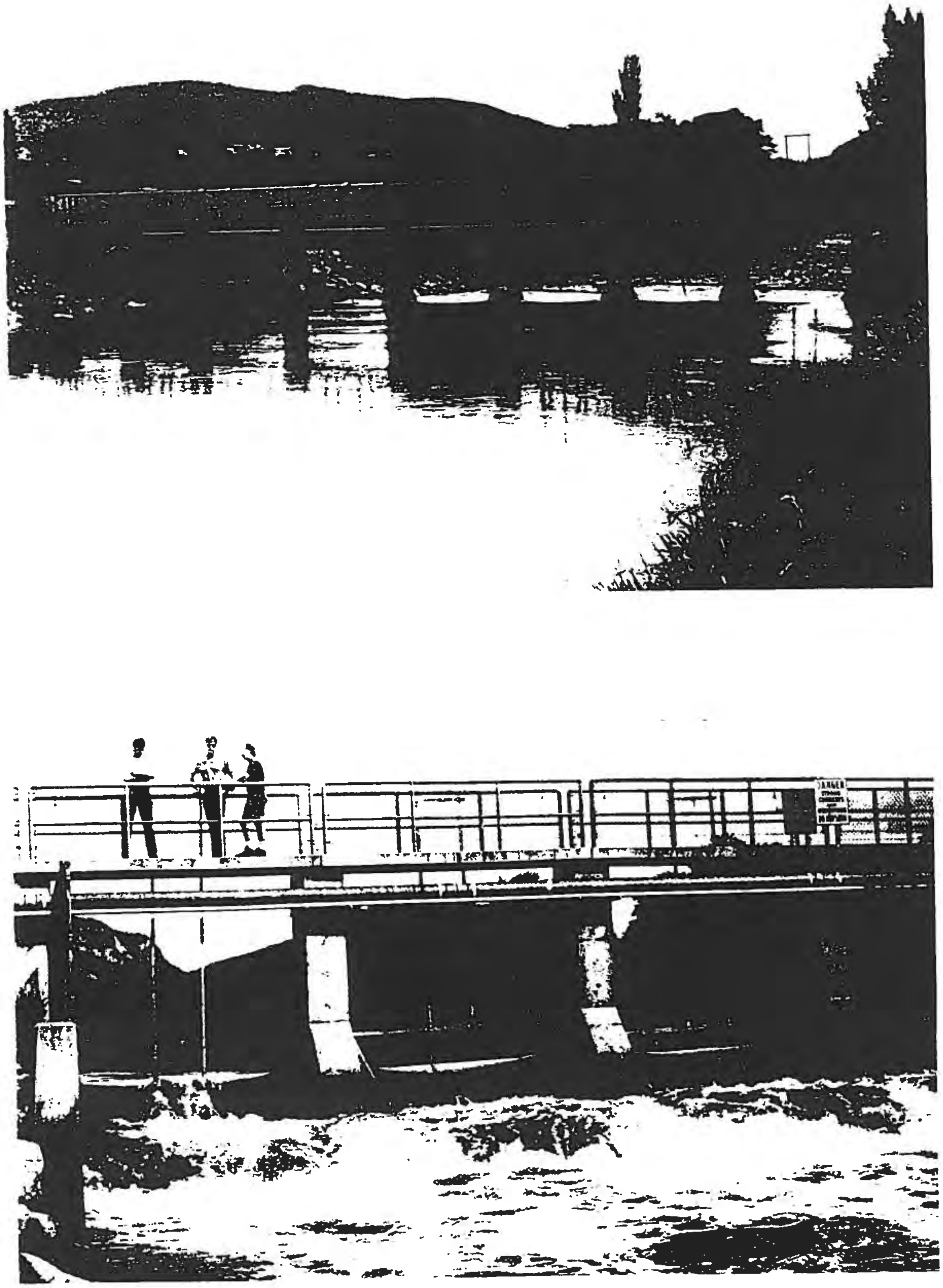
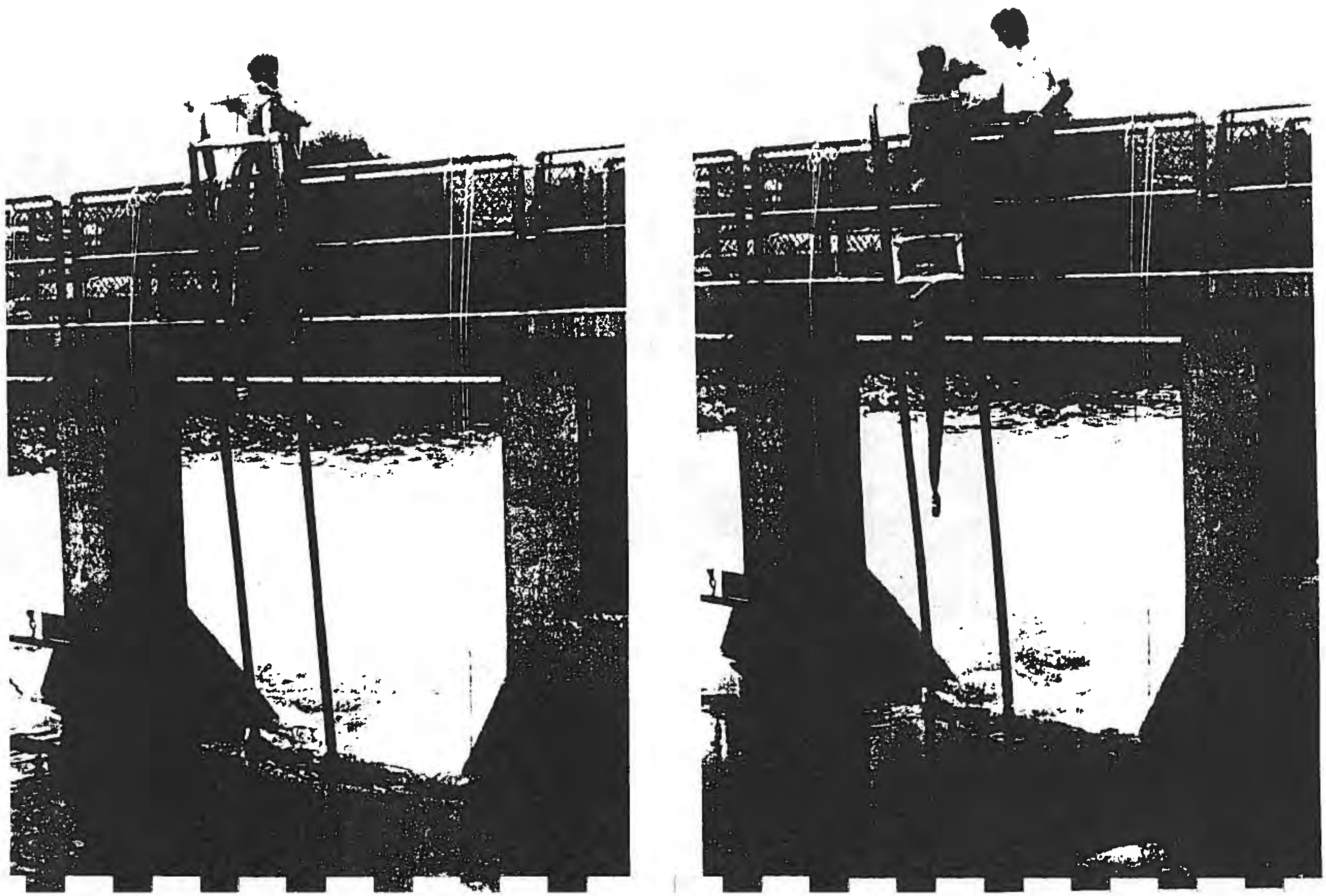


FIGURE 3. Closer views of the net frames in the lifted and stored position. Note the pressure plate, lifting eye and block arrangement in the lower photo.

(FIG 3 Cont'd). Installation of fyke net. Left hand photo shows net being inserted into guide rails (note wheels on net); right-hand photo shows net being dropped into fishing position with retrieval rope attached (note screw-top collection jar clamped into tail of net)



Biological Sampling. All fish caught were identified as to species. All fry were anaesthetized and nose-forklengths were measured to the nearest mm live in the field. At the same time, the fry were categorized as to stage of development (Appx 4) and checked for obvious anomalies or variations in morphology or pigmentation. Save for subsamples (see below) and handling mortalities, all fry were allowed to recover fully in a screened bucket and the majority were released during darkness to continue their migration downstream.

A nightly subsample of at least 10 fry representing the observed range of sizes was preserved in 10% formalin; whenever possible, dead fry were chosen for the subsample, and preserved samples were augmented with any additional mortalities experienced during the trapping period. These samples were held in preservative for at least 30 days, in order to ensure that preservative-induced changes in length and weight had stabilized before processing the samples (Anderson and Gutreuter, 1989). Samples were measured to the nearest mm, blotted dry and weighed on an electronic scale to the nearest 10 mg, categorized as to stage of development (Appx 4) and checked for anomalies and differences in morphology or pigmentation.

Using the individual length and weight data from the preserved fry samples, development index (Bams, 1970) and Fulton's condition factor (Anderson and Gutreuter, 1989) were calculated.

A second subsample of at least 10 live fry/night were frozen and are being held at the BCE Penticton office as archival samples. These samples could be made available to interested researchers wishing to pursue more sophisticated analyses (eg morphometric truss, otolith microchemistry, or genetic analyses).

Physical Monitoring. Water temperature was measured with pocket and maximum-minimum thermometers at the start of each evening's trapping (initial checks indicated that there was little fluctuation overnight in water temperatures). Air temperatures were measured with the same thermometers at both the start and end of each night's trapping.

Additional daily water temperature data for the 1993-94 spawning and incubation period were provided by the PUD, who had installed and maintained a Ryan TempMentor Model RTM thermograph at the McIntyre Dam upstream of the natural reach. These data were used to generate Accumulated Thermal Unit (ATU) estimates for various timing segments of the 1993 spawning run (taken from Hagen and Grette, 1994).

Water level was measured at the VDS during the start of each night's trapping; in addition, the Water Survey of Canada's gauging station near Oliver (Station No. 08NM085) was queried as to instantaneous water level by phone, and converted to discharge using an established stage-discharge conversion table provided by the BCE Water Management Engineering Section (it should be noted that these discharge figures differed from those collected by the Engineering Section in the morning of the same day; the difference was routinely 5-10%, but went as high as 22% during early May).

Weather observations were noted in a daily log, especially those aspects such as cloud cover, reflected light, and moon phase that could have had an effect on downstream migration. Any other conditions that could have affected trapping efficiency, such as debris and turbidity, were also noted in the log.

RESULTS

SPECIES OF FISH CAUGHT

The following species of fish were caught during the Mar 4 - May 16 trapping period:

Common Name	Scientific Name	Total Caught
Sockeye/Kokanee Salmon*	Oncorhynchus nerka	5499
Whitefish	Prosopium williamsoni (?)	692
Longnose Sucker(?)	Catastomus catastomus	3
Yellow Perch	Perca flavescens	3
Longnose Dace	Rhynichthys cataractae	1
Tench	Tinca	1
	TOTAL	6199

*the complex is referred to as "nerkids" in this report

With the exception of the dace, all of the fish caught were fry or juveniles (see the section on biological sampling for further details).

The whitefish fry were sent for species identification to Dr. J.D. McPhail of the UBC Department of Zoology, and he confirmed them to be whitefish, most probably mountain whitefish (Prosopium williamsoni).

MIGRATION TIMINGS

Nerkids. Nerkid fry were caught during testing of the prototype trap on March 4, and continued to be caught in variable numbers on all trapping nights up to the termination of trapping on May 17 (catch data are tabulated in Appx 5). Because hourly trapping times varied from 2-30 min in order to keep catches down to less than 50 fry/net, catches were expanded to a fry/hr estimate for each net. The fry/hr estimates were then summed for the three nets and over all hours fished each trapping night (the resulting estimates are termed "actual catches" in Figure 4A).

For those nights where there were no data gaps, the expanded catch data were summed and used to calculate calibration factors (Appx 3) that would allow holes in the data to filled (these estimates are termed "adjusted catches" in Fig 4A). Because the data gaps were relatively minor, the adjusted-catch migration pattern was not significantly different from the actual-catch pattern.

Further expansion of the estimates incorporated the proportion of the wetted cross-section that was fished, and interpolation for non-fishing days (Appx 6). These estimates were used to generate the following fry migration milestone dates:

% of Fry Passed	Milestone Date
Start	Mar 01 (Estimated)
10%	Apr 04-05
25%	Apr 13-14
50%	Apr 17-18
Peak	Apr 18
75%	Apr 19-20
90%	Apr 23
End	May 21 (Estimated)

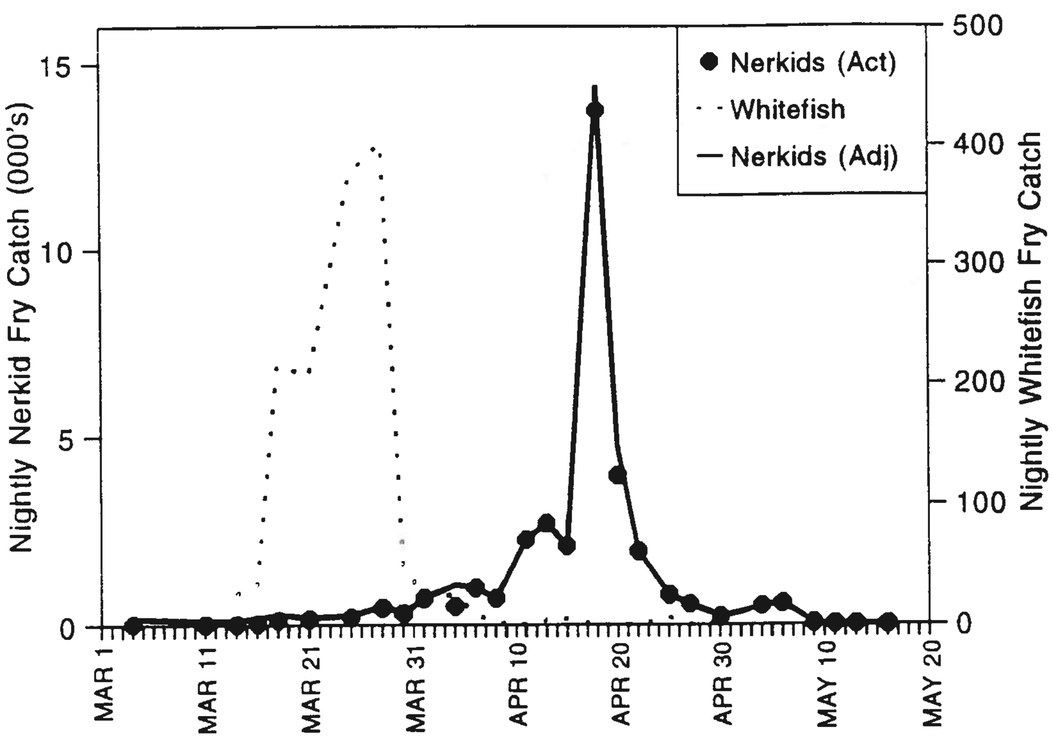
Once catches dropped to low levels on May 9, the traps were relocated downstream to VDS 2. Subsequent trapping on May 11, 13 and 16 at VDS 2 produced even lower catches, suggesting that most migrants had moved out of the system.

Other Species. Whitefish fry were captured from March 14 through April 30, and peaked March 28 (Fig 4A and Appx 5).

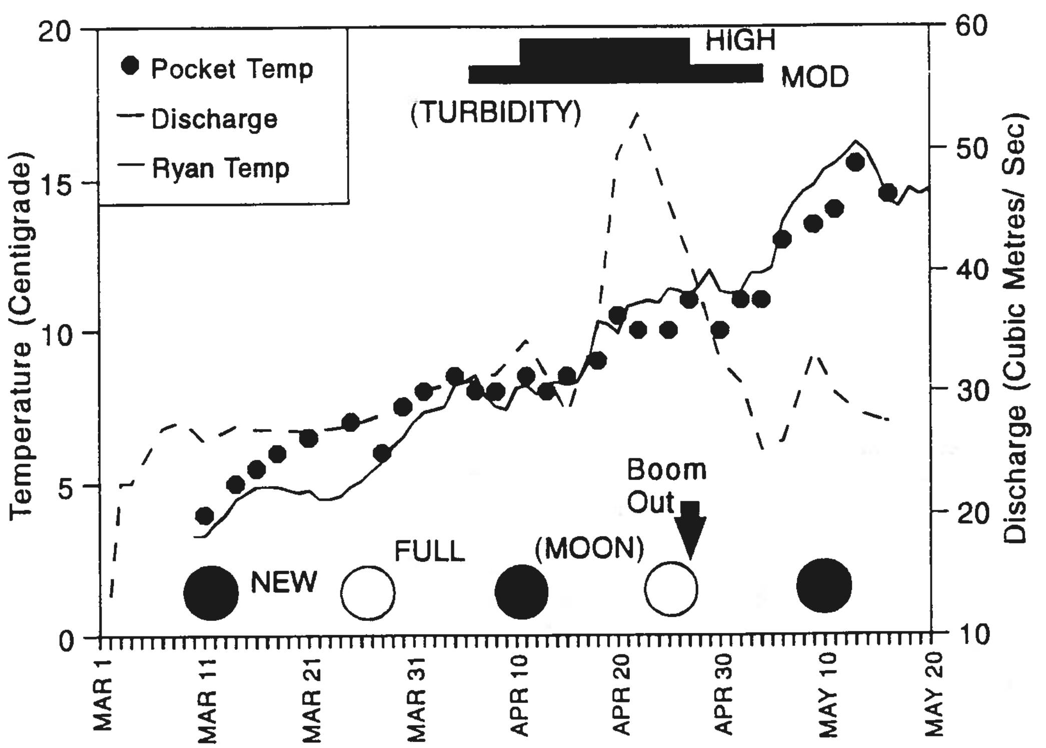
Captures of other species were confined to individual fish: yellow perch were caught on April 4, April 30 and May 13; longnose suckers on April 30, May 2 and May 16; longnose dace on May 6; and tench on April 30.

FIGURE 4. Okanagan River fry migrations

A. Expanded total nightly fyke net catches:



B. Collation of physical observations:



PHYSICAL MONITORING

The various physical observations made during trapping have been consolidated in Table 1. Considering that the pocket thermometer readings were spot temperatures taken in the early evening about 8 km downstream from the location of the thermograph, readings were similar (Fig 4B). The spring of 1994 was unusually warm, and thus water temperatures may not have been indicative of a "normal" year.

Using the McIntyre Dam thermograph data, ATUs were estimated for five spawner die-off dates and cumulated through to June 6, 1994 (Appendix 7).

BIOLOGICAL SAMPLING

Nerkids. For the 3726 live nerkid samples, lengths averaged 28 mm (this was also the modal length - see Appendix 8) and ranged from 23 mm to 39 mm. For the 551 preserved nerkid samples, mean length was 26.5 mm (std dev of 1.73 and std error of 0.07), or 95% of the live-length value. Approximately 8% shrinkage in 10% freshwater formalin was expected (Anderson and Gutreuter, 1989), but some of this shift probably was masked by the measurement accuracy, which was only to the nearest millimetre.

Fry size and development statistics for formalin-preserved samples are summarized in Table 2. Although Fulton's K was calculated and presented in Table 2, its use as an index of condition is not valid for fry that have not initiated feeding (ie, fry that are at or beyond Stage 5). Instead, Bams' Kd, which is interpreted as an index of development (Bams, 1970), was used in further analyses. It might be noted that the patterns of daily variation for these two indices turn out to be identical. This is because the formulae are very similar, and really differ only in scaling; K values for salmonids normally rotate about 1.00, while Kd values range around 2.00.

Looking at daily variations in these statistics for nerkids (Figs 5A-D), there were significant shifts in weight but not in length (Fig 5A) during migration. Weights were significantly higher during the first two weeks of migration, then dropped in the next two weeks to levels that were significantly lower than were seen during the remainder of the migration period (Fig 5B).

Similarly, nerkid development factors started high, dropped sharply and then rose and fell around intermediate levels for the rest of the migration period (Fig 5C). With regard to stage of development (Fig 5D), Stage 1 fry were seen only during the first three weeks of monitoring; the proportion of Stage 2-3 fry peaked in late March and early April, then were steadily replaced by Stages 4-5 over the rest of the study.

TABLE 1 - Physical observations made during Okanagan River fry trapping, 1994.

DATE	VDS #	WATER °C AT START	WATER LEVEL AT VDS (M)	VDS X-SECT (M^2)	DIS-CHARGE M^3/SEC	WEATHER	WIND	WIND DIRECTION	MOON PHASE	AIR °C START END	WATER TURBIDITY	DEBRIS	COMMENTS
MAR 4	13					CLEAR	BREEZE	N	NEW	8°/-2°	CLEAR	HIGH	
11	13	4	1.32	15.6	25.9	CLEAR	BREEZE	N	NEW	7°/-1°	CLEAR	NIL	
14	13	5	1.35	15.9	27.2	CLEAR	CALM	N/A	NEW	6°/0°	CLEAR	NIL	
16	13	5.5	1.34	15.9	26.9	CLOUDY	WINDY	N	OBSC	6°/-2°	CLEAR	NIL	
18	13	6	1.34	15.9	26.9	CLOUDY	BREEZE	N	OBSC	7°/-1°	CLEAR	NIL	
21	13	6.5	1.33	15.8	26.7	CLEAR	BREEZE	N	1/2	3°/-1°	CLEAR	NIL	
25	13	7	1.35	16.0	27.2	CLEAR	CALM	N/A	1/2		CLEAR	NIL	
28	13	6	1.35	16.0	28.1	CLEAR	CALM	N/A	FULL		CLEAR	NIL	COTTON WOOD CATKINS
30	13	7.5	1.35	16.0	28.3	CLEAR	CALM	N/A	1/2	12°/2°	CLEAR	NIL	PLUGGING NETS
APR 1	13	8	1.39	16.3	29.98	CLOUDY CLEAR	WINDY CALM	S	1/2	10°/2°	LOW	HIGH	PLUGGING NETS
4	13	8.5	1.39	16.3	30.07	CLOUDY CLEAR	WINDY CALM	S	1/4	12°/3°	MOD	MOD	PLUGGING NETS
6	13	8	1.39	16.7	30.8	RAIN	BREEZE CALM	N	OBSC	8°/6°	MOD	HIGH	PLUGGING NETS
8	13	8	1.41	17.1	31.38	CLOUDY	BREEZE CALM	N	NEW		MOD	MOD	PLUGGING NETS
11	13	8.5	1.45	17.9	34.2	CLOUDY	WINDY BREEZE	N	NEW	11°/8°	HIGH	HIGH	LOGS & LARGE DEBRIS
13	13	8	1.40	16.9	31.3	CLOUDY	WINDY	N	1/4	11°	HIGH	LOW	
15	13	8.5	1.36	16.2	28.08	CLOUDY	BREEZE 'ALM	S	1/4	14°	HIGH	MOD	

(Table 1 cont'd)

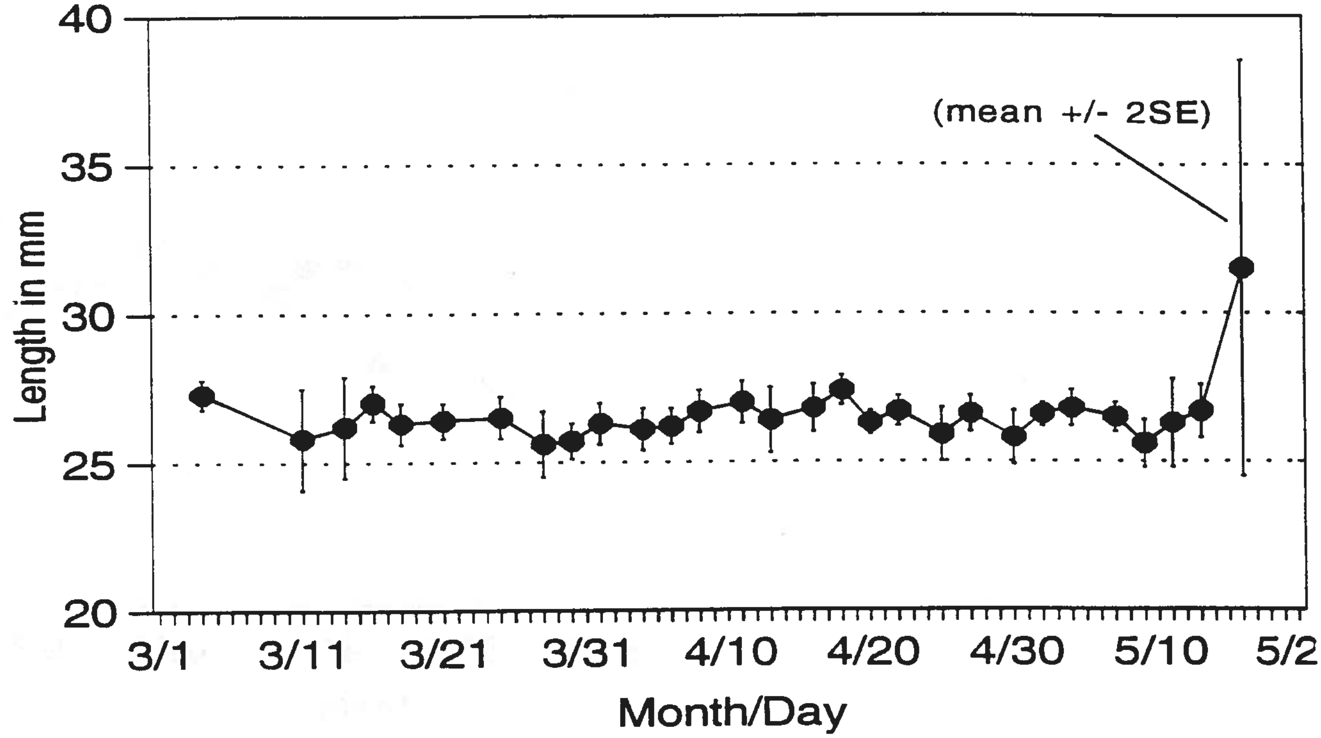
DATE	VDS #	WATER °C AT START	WATER LEVEL AT VDS (M)	VDS X-SECT (M^2)	DIS-CHARGE M^3/SEC	WEATHER	WIND	WIND DIRECTION	MOON PHASE	AIR °C START END	WATER TURBIDITY	DEBRIS	COMMENTS
18	13	9	-	20.4	35.25	RAIN	WINDY CALM	N	1/4	14°/11°	HIGH	HIGH	LOGS AND DEBRIS
20	13	10.5	1.68	21.8	49.51	CLOUDY	BREEZE	S	1/2	13°/10°	HIGH	HIGH	
22	13	10	1.78	23.9	52.8	CLEAR	BREEZE	S	3/4	14°/9°	HIGH	HIGH	NETS 1/2 FULL OF DEBRIS
25	13	10	1.68	21.8	45.73	CLOUDY	CALM	N/A	OBSC	14°/10°	HIGH	MOD	
27	13	11	1.60	20.6	41.00	CLEAR	CALM	N/A	1/2	14°/9°	HIGH	MOD	LOG BOOM REMOVED
30	13	10	1.42	17.3	32.5	RAIN	CALM	N/A	OBSC		MOD	LOW	
MAY 2	13	11	1.38	16.4	30.7	CLEAR	WINDY	N	NEW	17°/10°	MOD	LOW	
4	13	11	1.29	15.1	25.2	CLEAR	CALM	N/A	NEW	14°/6°	MOD	MOD	
6	13	13	1.42	17.3	25.88	CLEAR	CALM	N/A	NEW	18°/8°	LOW	LOW	
9	13	13.5	1.53	19.3	33.25	CLOUDY	WINDY	N	OBSC	19°	LOW		
11	2	14	1.40	16.9	29.75	RAIN	CALM	N/A	OBSC	18°/12°	LOW	HIGH	ELM SEEDS A PROBLEM
13	2	15.5	1.36	16.2	28.33	CLOUDY	BREEZE	N	OBSC	19°/7°	LOW	MOD	ELM SEEDS A PROBLEM
16	2	14.5	1.34	16.1	27.45	RAIN	BREEZE	N	OBSC	14°/9°	LOW	MOD	ELM SEEDS A PROBLEM

TABLE 2. Statistics on nose-forklength, wet weight and developmental stage for formalin-preserved fry samples taken from the Okanagan River above Osoyoos Lake, Mar 4 - May 16, 1994.

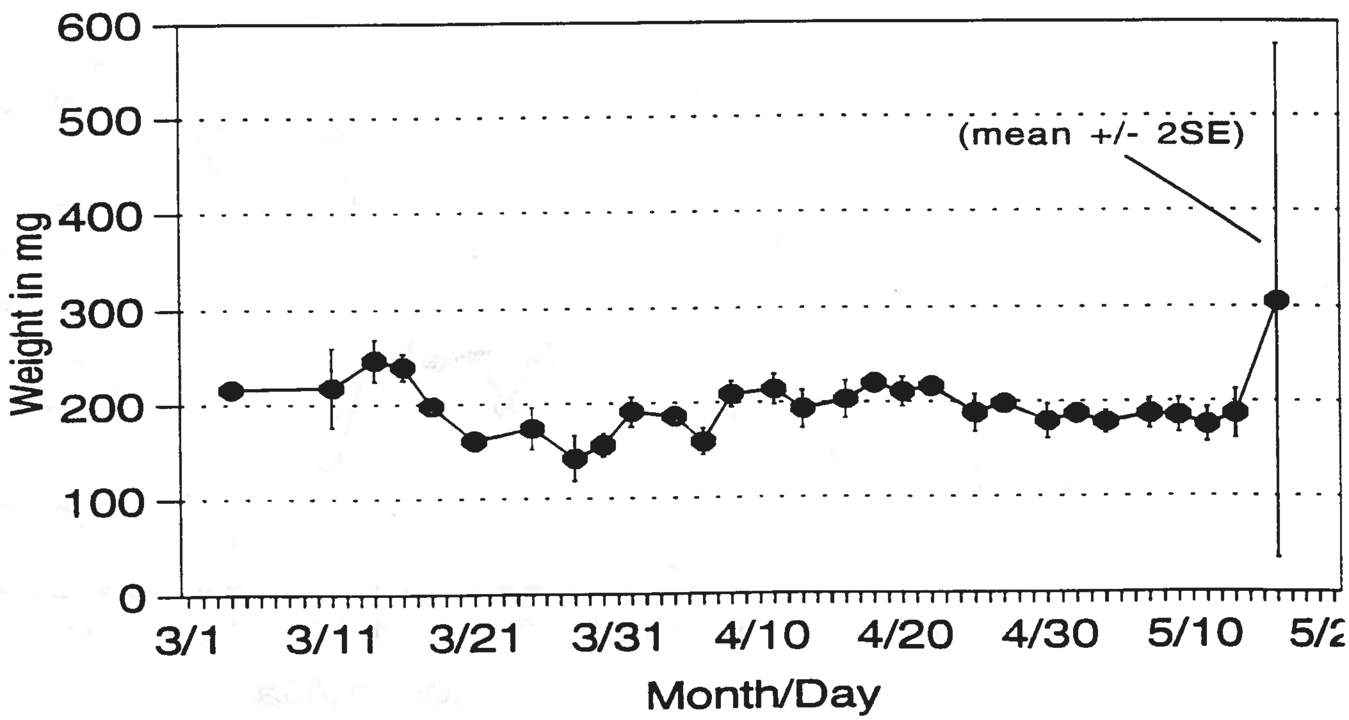
Species	Stage of Development	n	Nose-fork length in mm (Mean ± 2 SE)	Wet Weight in mg (Mean ± 2 SE)	Bams' Kd (Mean ± 2 SE)	Fulton's K (Mean ± 2 SE)
Nerkids	Stage 1	2	23.5 ± 1.0	220 ± 20	2.56 ± 0.03	1.70 ± 0.06
	Stage 2	23	24.1 ± 0.5	144 ± 16	2.16 ± 0.09	1.04 ± 0.13
	Stage 3	118	25.3 ± 0.3	178 ± 7	2.21 ± 0.02	1.09 ± 0.03
	Stage 4	198	26.7 ± 0.2	195 ± 6	2.16 ± 0.01	1.02 ± 0.02
	Stage 5	206	27.2 ± 0.2	205 ± 6	2.16 ± 0.01	1.01 ± 0.02
	All Stages	551	26.5 ± 0.1	193 ± 4	2.17 ± 0.01	1.03 ± 0.01
Whitefish	Stage 1	24	14.3 s± 0.5	85 ± 19	3.00 ± 0.25	3.05 ± 0.86
	Stage 2	20	14.7 ± 0.4	77 ± 20	2.80 ± 0.25	2.46 ± 0.67
	Stage 3	20	15.4 ± 0.6	46 ± 7	2.29 ± 0.08	1.22 ± 0.13
	All Stages	70	14.8 ± 0.3	67 ± 10	2.68 ± 0.14	2.21 ± 0.40

FIGURE 5. Okanagan River Nerkid Fry Data

A. Nose-Forklength



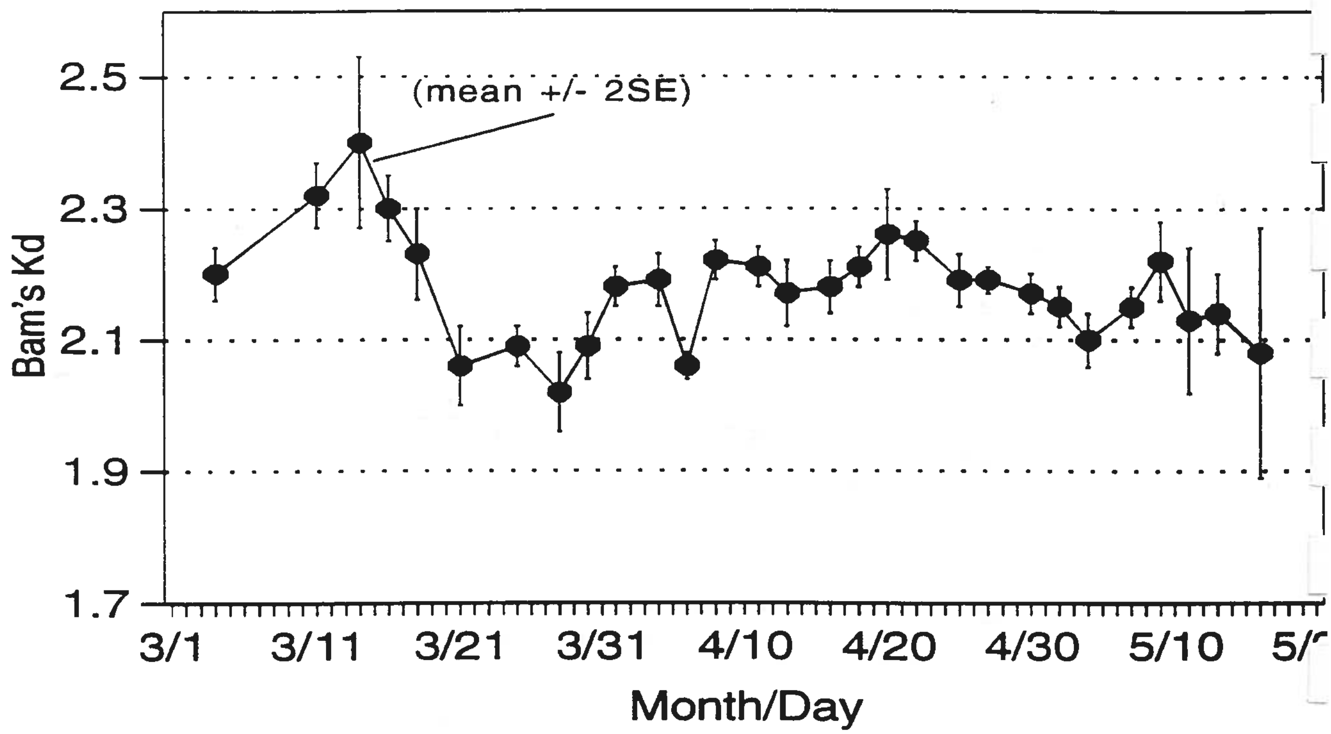
B. Wet Weight



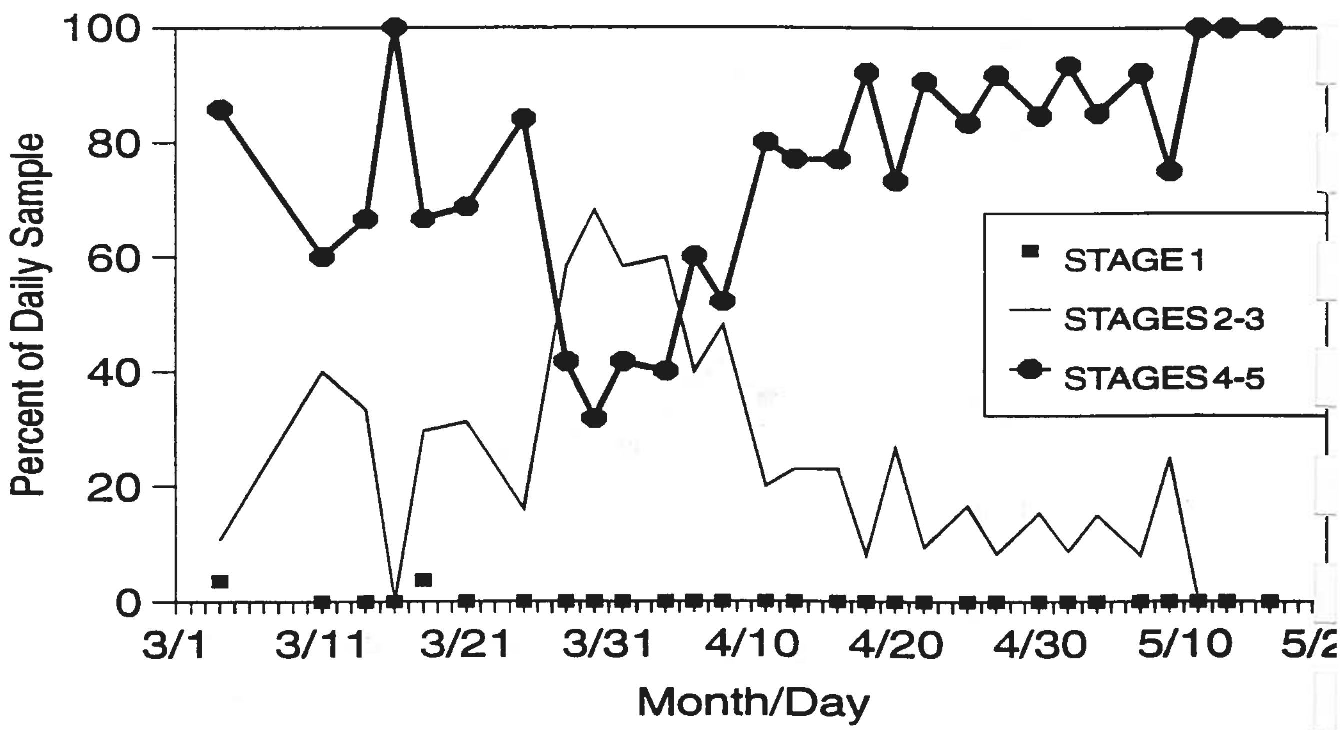
(Formalin-preserved samples)

FIG 5 (Cont'd)

C. Development Factor



D. Developmental Stage



(Formalin-preserved samples)

Much of the above-noted variation in nerkid size can be explained by an observed relationship between development and size. Both length and weight varied significantly with stage of development (Fig 6); length increased steadily as development advanced, but Stage 1 fry were heavier than all but Stage 5 fry, probably due to the large amount of unconsumed yolk present in Stage 1 fry.

There were differences noted in the pigmentation patterns of the nerkid fry. Approximately 20-40% of the fry samples had a crimson red coloration present on their fins and opercula. This coloration varied in intensity and location, but was often most apparent on the tails (including the caudal peduncle) followed next by the pectoral fins. The coloring was not uniform, and was present in the form of streaks along the fin rays, as well as splotches in the fin membranes. The body generally remained free of coloration. There was no noticeable variation in frequency of occurrence of these colored morphs during the migration period.

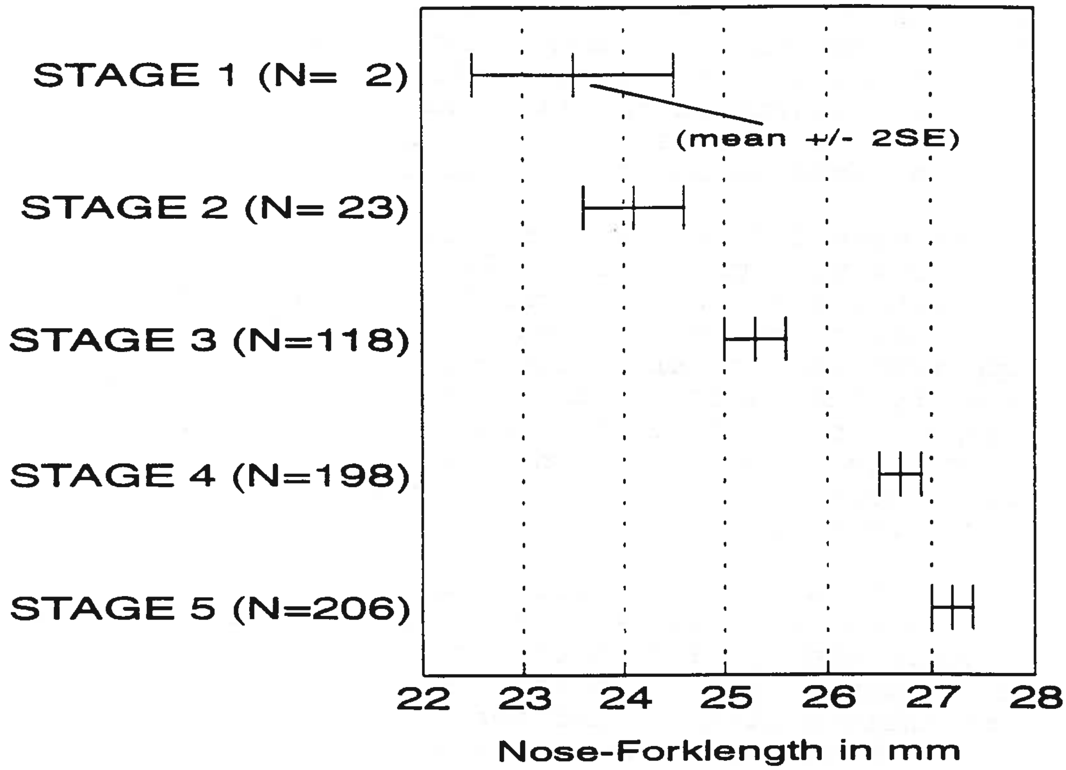
While it was not possible to sort the formalin-preserved samples on the basis of differences in pigmentation (the pigment faded rapidly upon preservation), some of the frozen archival samples have been separated on this basis. This may prove useful in conjunction with any further stock-separation techniques that might be attempted using these samples.

<u>Other Species</u>. The whitefish fry were considerably smaller than nerkid fry (Table 2 and Appx 8). Live lengths from 123 fry ranged 13-21 mm, and averaged 16 mm; the modal length was 15 mm. For the 70 preserved fry, lengths similarly averaged 14.8 mm (std dev of 1.24 and std error of 0.15). The whitefish fry were proportionally much heavier for their length - so much so, the use of both K and Kd is questionable. It should also be noted that only Stage 1-3 fry were captured; given their much smaller size, it may have been that fry nearing the buttoned stage became slim enough to slip through the mesh of the nets.

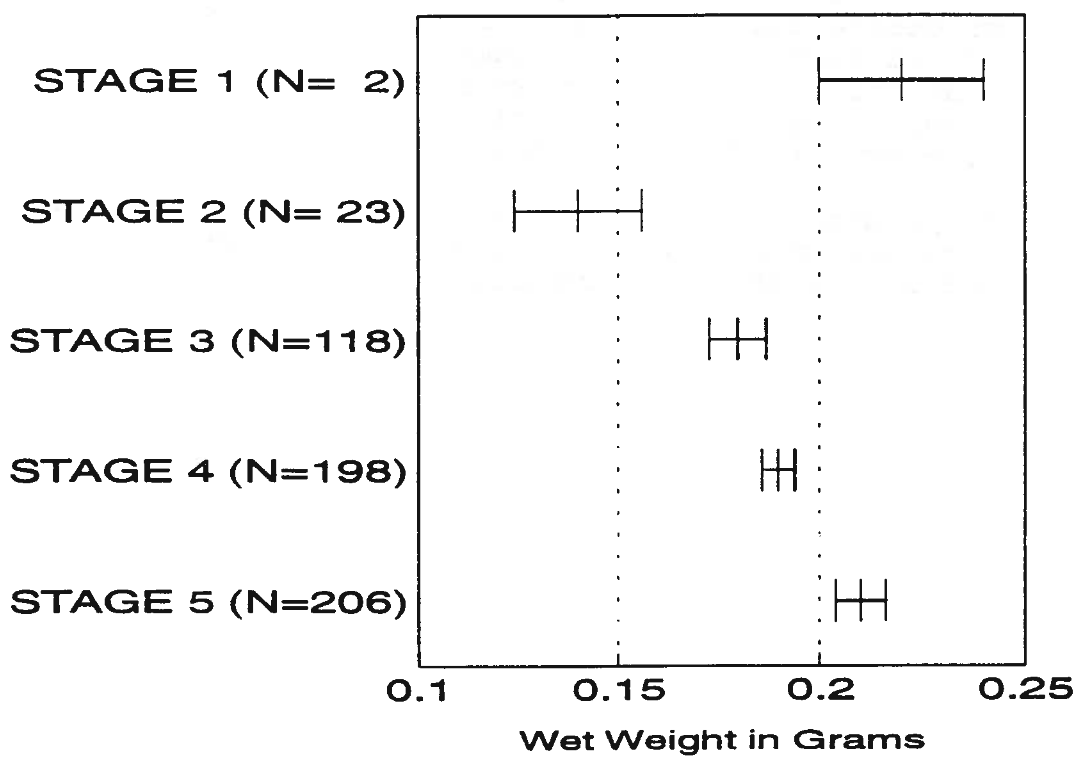
The eight specimens of the four other species that were caught were not measured, but all were estimated to be less than 125 mm and were primarily juveniles.

FIGURE 6. Okanagan River Nerkids

A. Length Vs Stage of Development



B. Weight Vs Stage of Development



(lengths and weights taken from formalin-preserved specimens)

MORTALITIES

A precise tally of nerkid mortalities was not kept, but can be approximated by examining the number of fry that were preserved. There were 28 trapping nights, and the nightly sample target was set at a minimum of 10 fry for each of the two preservation methods. Any additional mortalities were added to both the frozen and formalin-preserved samples. The estimates of sampling and trapping mortalities were:

A. Total Number of Nerkids Frozen	1,000 (approx)
B. Total Number of Nerkids in Formalin	878
C. Deliberate Sampling Mortality Target	560
D. Accidental Trapping Mortality (B + C - D)	1,318
E. (C + D) / Total Nerkid Catch (5,499)	34%

The total nerkid mortality of 34% of the catch can be broken out further into 10% deliberate sampling mortality and 24% accidental trapping mortality. In terms of the total estimated run (see the Fry Population Estimate section of this report), the total mortality probably comprised less than 0.1%.

DISCUSSION AND CONCLUSIONS

FRY CROSS-SECTIONAL DISTRIBUTIONS

Judging from actual catches, the distribution of nerkid fry was definitely skewed toward mid-river, while whitefish fry hugged the shore:

Species		(Mid-River) Net 1	Net 2	(Near Shore) Net 3
Nerkids	Caught	2740	1739	1020
	(As %)	(50%)	(32%)	(18%)
	Boom In	2393	1528	868
	(As %)	(50%)	(32%)	(18%)
	Boom Out	347	211	152
	(As %)	(49%)	(30%)	(21%)
Whitefish	Caught	69	200	423
	(As %)	(10%)	(29%)	(61%)

Doing the same breakout with the expanded net catches (Appx 3) gave similar but slightly more extreme results for nerkid fry:

Net 1 - 56%   Net 2 - 27%   Net 3 - 17%

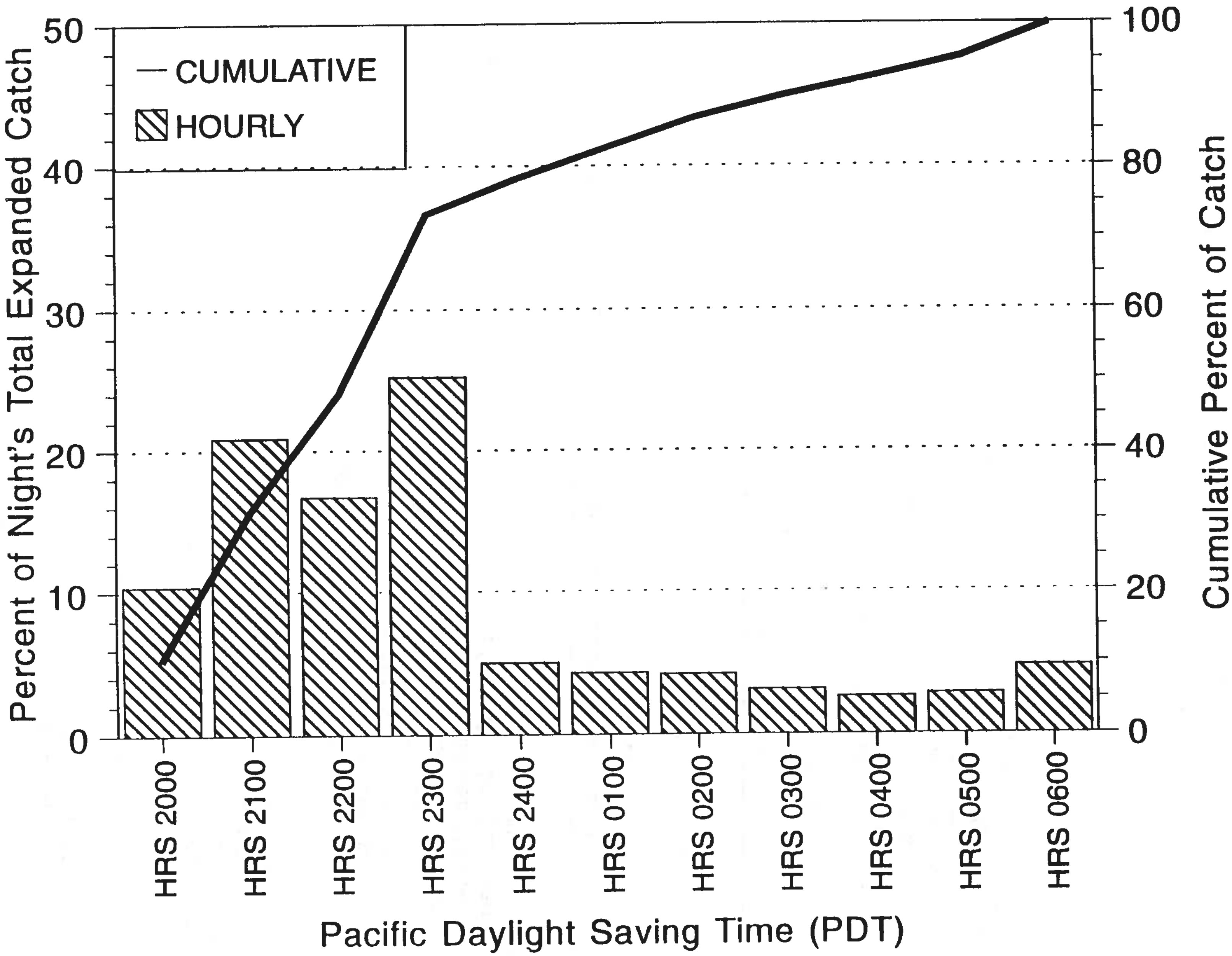
On April 27, a debris collection boom was removed just upstream of VDS 13. As the presence of this boom appeared to shunt surface water towards the shore where Net 3 was located, nerkid fry distributions were checked both before and after boom removal. The presence of the boom did not appear to markedly affect nerkid fry distribution, as the net catches varied only by 1-3% between the two periods.

The majority (seven of eight specimens) of the other species caught incidentally were taken in the net nearest to shore.

HOURLY VARIATIONS IN FRY MIGRATION

Each night, nerkid fry migration began at dusk and continued past dawn. The period of heaviest migration was 2000-2300 hrs (PDT), during which almost three-quarters of the fry were caught (Fig 7). Hourly patterns were very similar between the three nets (Appx 3).

FIGURE 7. Hourly Variation in Fry Catches



FACTORS AFFECTING MIGRATION TIMINGS

Comparing selected observations to the fry migration data (Figs 4A,B), significant numbers of nerkid fry began to migrate once water temperatures had increased to 8 C, water turbidity had become noticeable, and during the onset of the new moon period. Migration peaks coincided closely with increases in discharge, which were also associated with increases in turbidity. During the testing of the prototype trap on March 4, it was noted that the majority of nerkid fry were premature emergents; this also coincided with an increase in discharge. Thus discharge is suggested to be a primary environmental "trigger" for the migration of nerkid fry.

Another important factor in determining fry migration timing has been shown in many past studies to be the thermal regime experienced by the embryo. Emergence occurs when maximum alevin wet weight (MAWW) is reached (Heming, 1982); MAWW can be predicted from mean incubation temperatures using the Belehradec Model (Alderdice and Velsen, 1978; sockeye parameter values provided by Jensen, pers comm). Using this calculation sequence for the Okanagan River data produced the following predictions:

Spawning Date	Mean C*	Days of Incubation		Emergence Date
Oct 10	5.1 C	184 days	860 ATU**	Apr 14
Oct 25	4.5 C	197 days	954 ATU	May 09

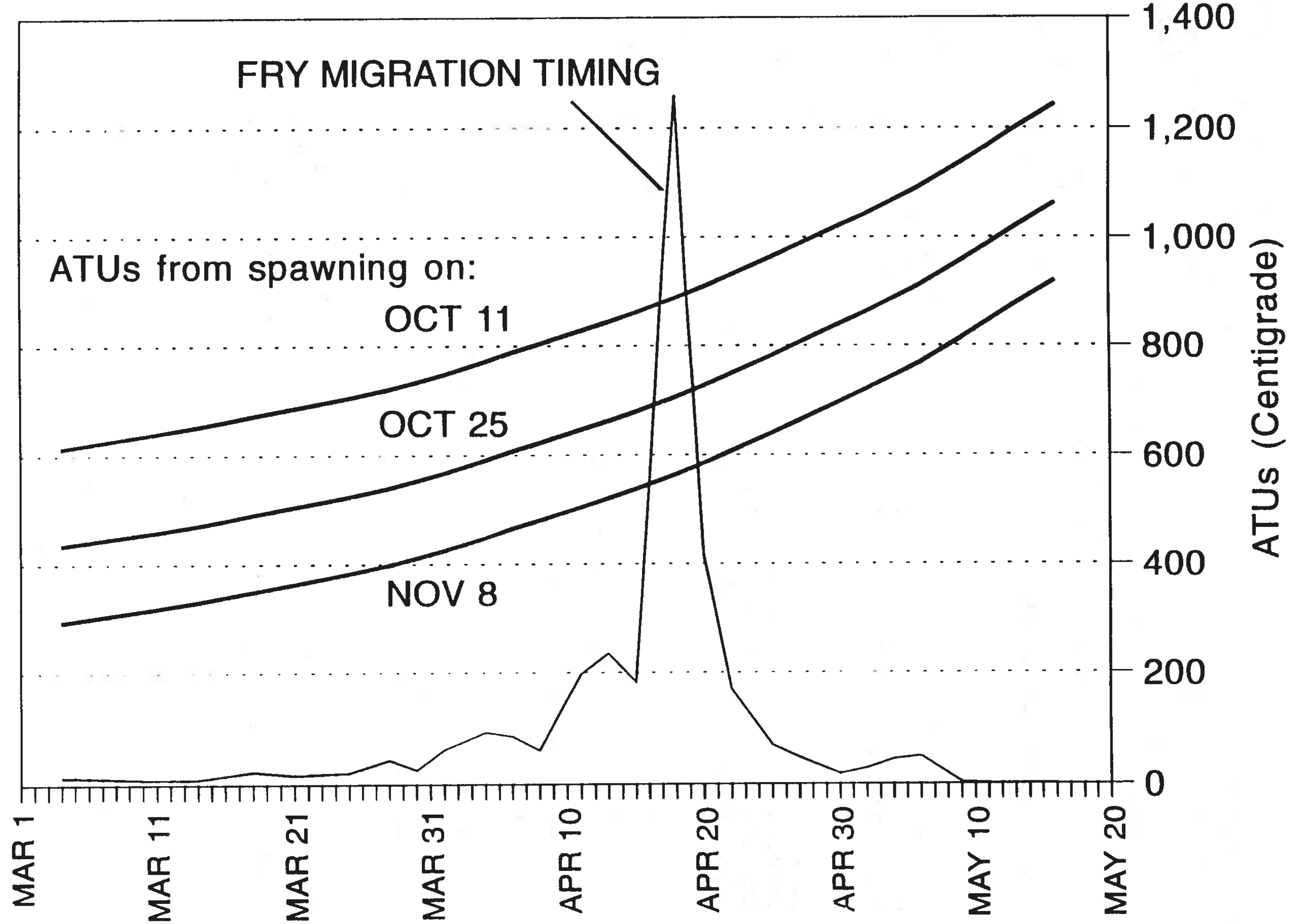
*Monthly mean surface water temperatures were corrected to reflect subgravel conditions per Shepherd et al (1986).
**ATUs calculated using surface water temperatures (Fig 8).

Judging from the spawner carcass recovery data provided by Hagen and Grette (1994), spawning probably peaked on Oct 10 or shortly thereafter; the actual peak emergence date of Apr 18 was only four days later than would be predicted for an Oct 10 spawn. As a rough rule of thumb, emergence of Okanagan River nerkid fry should start on a significant scale at around 700 ATU (using surface water temperature data) and peak around 850-950 ATU (Fig 8).

FRY POPULATION ESTIMATE

Although this was not requested as part of the study, a rough estimate of the total nerkid migrant fry population was attempted in order to provide some sense of the magnitude of the run, to assess the impact of mortalities associated with the sampling, and to assist in designing future quantitative programs.

FIGURE 8. Okanagan River Surface-Water ATU Data Compared to Total Nightly Fyke Net Catches



Nets were fished consistently such that they just broke the surface of the water, and thus fished the upper foot (0.3 m) of the water column only. When adjusted catches were further expanded on the basis of the proportion of the wetted cross-section of the river that was fished (Appx 6), the resultant population estimate was approximately 2.9 million nerkid fry.

One of the key assumptions inherent in these calculations is that fry are distributed evenly throughout the cross-section. Judging from other studies, such an assumption is unlikely to be true. McDonald (1960) checked the vertical distribution of migrating pink salmon fry in various water depth conditions, and found the following catch proportions in the uppermost foot of the water column:

(Water Depth)	2 Ft	3 Ft	4 Ft	5 Ft
If Evenly Distributed	50%	33%	25%	20%
Observed Distribution	83%	32%	2%	6%

West (pers comm) found that 57% of the sockeye fry exited the Babine Spawning Channel in the uppermost foot of a 2 ft deep channel, although upstream sills could have encouraged homogeneous mixing.

In the case of the Okanagan River study location, water depths were 4-5 ft (1.3-1.8 m) throughout the study. If nerkid fry behave similarly to pink fry, the Okanagan River fry population could be 5-10 times higher than the earlier estimate. Using available 1993 spawner data, a potential fry production figure of just over 4.5 million sockeye was calculated (Table 3). If kokanee were added to the estimate, it would be considerably higher. This reinforces the notion that a migrant fry population estimate of 2.9 million nerkids should be viewed as conservative.

SEPARATION OF RACES

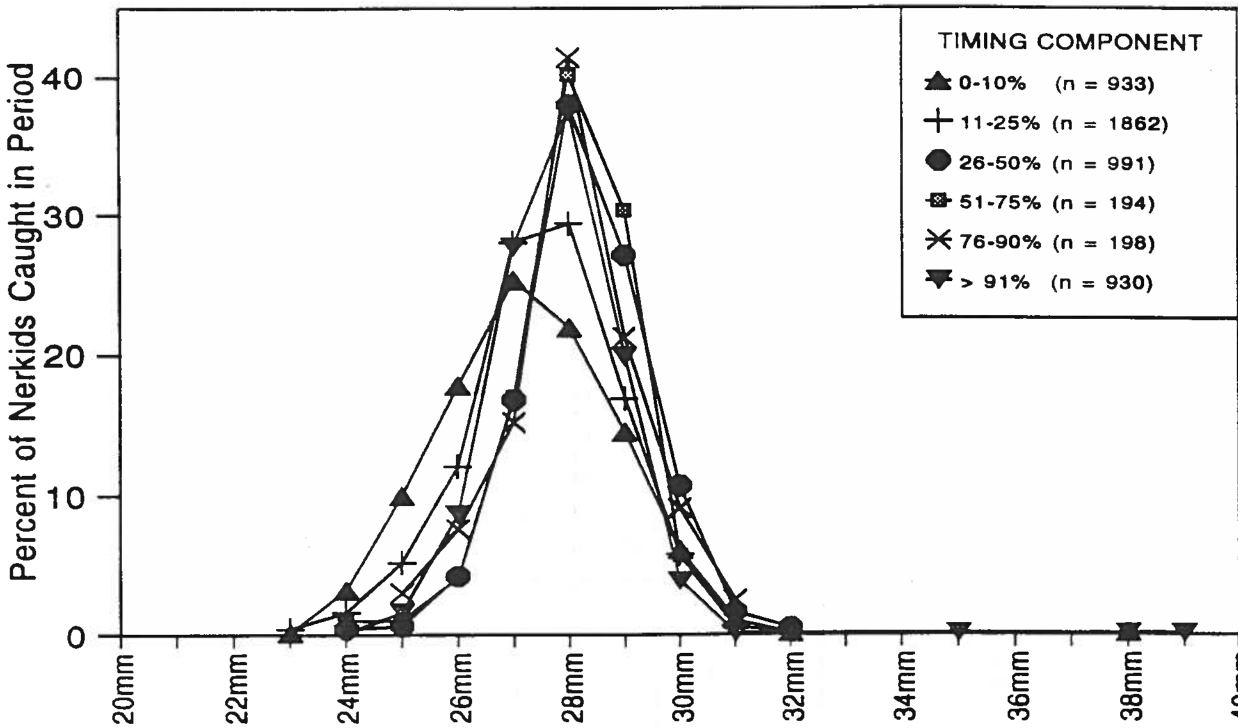
Using the live-sample data, length-frequency analyses were done in an attempt to separate the two races of nerkids. Such a separation technique appeared possible from work done on Shuswap River sockeye and kokanee fry by Wood and Foote (1990). While there was no bimodal pattern to the Okanagan River length-frequency data (Fig 9), breakouts by run timing segments indicated that early migrants were smaller than later migrants (Fig 9B). As detailed in the Biological Sampling section of the results, it appears that this is related to developmental stage, rather than race.

TABLE 3 - Egg deposition and fry production estimates for the 1993 Okanagan River sockeye brood

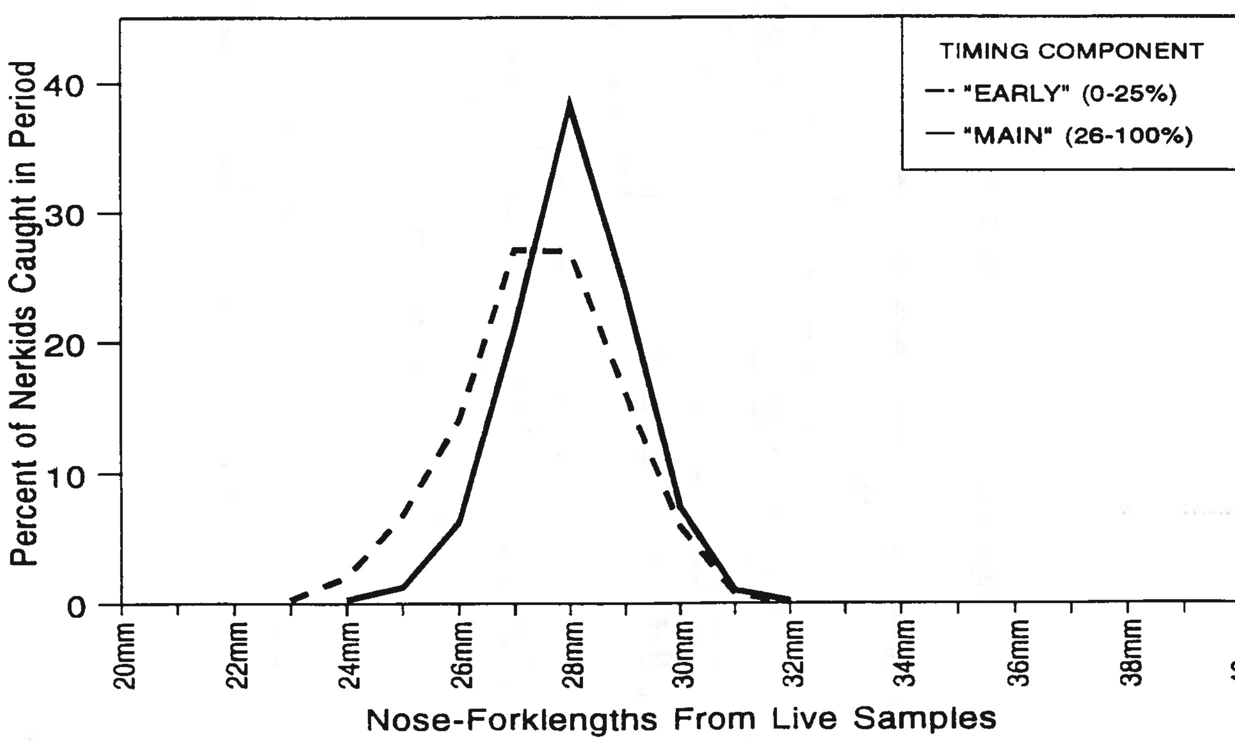
	Item	Value	Source of Information
1	Spawner Escapement	21,505 adults	Hagen and Grette (1994)
2	Sex Ratio	55% female	Hagen and Grette (1994)
3	Number of females	11,828 females	Calculated from (1) and (2)
4	Fecundity	2,763 eggs/female	Cassimer Bar Hatchery 1993 data (R. Klinge, pers. comm.)
5	Total Deposition	31.7 million eggs	
6	Egg Retention/ Pre-Spawning Mortalities	- 5%	Hagen and Grette (1994)
7	Egg Deposition	30.0 million eggs	Calculated from (5) and (6)
8	Egg-Fry Survival	15%	BC sockeye biostandard (Shepherd, 1984)
9	Fry Production	4.5 million fry	Calculated from (8) and (9)

FIGURE 9. Length-Frequencies Vs Migration Timing

A. Various Run Timing Components:



B. Combined Timing Components:



As was also noted in the Results section, it may be possible to separate the two races on the basis of different pigmentation patterns. However, this would require confirmation using more sophisticated analyses such as electrophoretics or otolith microchemistry. Archival samples stored at the BCE Penticton office will be made available for any such analyses (specimens with differing pigmentation patterns have been separated).

COMPARISONS WITH PREVIOUS STUDIES

Fry Size. Okanagan River nerkid fry were considerably larger than kokanee fry taken from Okanagan Lake tributaries (Table 4). The average preserved length of 27 mm and weight of 0.2 g falls within the normal size range for sockeye fry of 25-31 mm and 0.1-0.2 g, as determined in a recent literature review by Burgner (1987). As mentioned earlier, Wood and Foote (1990) found Shuswap River sockeye to be larger than kokanee fry, with modal length differences of 1 mm and weight differences of 40-60 mg; however, both races in the Shuswap study were considerably smaller (22.5-23.5 mm and 120-180 mg modal sizes) than seen in the Okanagan River (26.5 mm and 193 mg). Stock-specific size differences thus could outweigh race-specific differences, and cautions against using the larger size of the Okanagan River fry to conclude that they are sockeye.

Migration Timing. The estimate of ATUs to emergence for Okanagan River nerkids was very similar to those found in other studies of both kokanee and sockeye stocks (Table 5). Despite this strong similarity in ATU estimates, the migration timing for Okanagan River fry was on average 2-4 wks earlier than observed for Okanagan Lake kokanee runs (Table 4). This is most likely the result of a warmer incubation water temperature regime for the Okanagan River, at least in 1994. As noted earlier in this report, the spring of 1994 was unusually warm and may have advanced the migration timing compared to a "normal" year.

Media coverage of the project (see Appx 9) resulted in the uncovering of some additional information regarding the frymigration studies reputed to have been done in the 1950s. Mr W.B. (Bill) Kreller, a resident of Oliver (tel 498-2513; 38002 -73rd St, Oliver, V0H 1T0) since 1946, confirmed that he helped the Canadian Department of Fisheries to sample fry in the area downstream of the Hwy 97 bridge. Three fyke nets were deployed at mid-river sites from the Hwy 97 Bridge to 0.5 mi downstream. The nets were set nightly from mid-April through mid-May (the trapping terminated with the start of freshet) over a four-year period in the latter part of the 1950s. Mr Kreller sent all data to DFO in Vancouver, and thought that DFO had forwarded the information to a U.S. agency. His recollection of the trapping results was somewhat fuzzy, but he thought that catches usually

TABLE 4 - Comparison of Okanagan River nerkid fry size with data from other studies of *Oncorhynchus nerka*

SPECIES	REFERENCE	LOCATION	SAMPLE YEAR	LENGTH in mm	WEIGHT in mg	Kd	METHODS/COMMENTS
Mixed Nerkids	**Present Study**	**Okanagan River**	**1994**	**28 (23-39)**	-		average (range); live nose-fork length
				27	**193**	**2.17**	average; preserved nose-fork length and weight
Sockeye	Burgner (1987)	Pacific Northwest	N/A	25-31	100-200	N/A	observed range
	Wood & Foote (1990)	Shuswap River	1986	24 (22-25)	160 (150-210)	N/A	mode (range); standard length
Kokanee	Wood & Foote (1990)	Shuswap River	1986	23 (21-24)	120 (110-170)	N/A	mode (range); standard length
	(Okanagan Lake Tributaries)						
	Dill (1993)	Mission Creek	1993	25	95	1.85	average; preserved nose-fork length
	Dill (1992)	Mission Creek	1992	24	97	1.89	average; preserved nose-fork length
	Dill (1991)	Mission Creek	1991	25	89	1.80	average; preserved nose-fork length
	Shepherd (1990)	Mission Creek	1990	25	88	1.80	average; preserved nose-fork length
	Shepherd (1990)	Peachland Creek	1990	24	88	1.83	average; preserved nose-fork length

TABLE 5 - Comparison of Okanagan River nerkid fry ATU and migration timing estimates with data from other studies of <u>Oncorhynchus nerka</u>

SPECIES	REFERENCE	STOCK DESCRIPTION	SAMPLE YEAR	ATU TO EMERGENCE	MIGRATION DATES			METHODS/COMMENTS
					START	PEAK	END	
Mixed Nerkids	**Present Study**	**Okanagan River**	**1994**	**890-940**	**Mar 01**	**Apr 18**	**May 21**	using subgravel correction; mean incubation temp of 4.5 - 5.1°C
				(860-950)				(using surface temp data)
Sockeye	Brannon (1987)	Various Fraser R	N/A	740-930	-	-	-	incubated @ 3.4°C
		tributary stocks		880-1100	-	-	-	incubated @ 5.6°C
	WDFW (unpub)	Wenatchee Lk (East Bank Hatchery)	N/A	840	-	-	-	mean incubation temp of 4.7°C
Kokanee	Shepherd (MS 1993)	Powers Cr	1993	-	<Apr 06	Apr 25	May 15	
	Dill (1993)	Mission Spawning Ch	1993	750	Apr 07	May 10	May 31	mean surface T = 3.2°C
	Dill (1992)	Mission Spawning Ch	1992	760-790	Mar 22	Apr 22	May 25	mean surface T = 3.7°C
	Dill (1991)	Mission Spawning Ch	1991	760	<Apr 15	May 18	>Jun 17	mean surface T = 3.3°C
	Shepherd (1990)	Mission Spawning Ch	1990	740	Apr 12	May 10	>Jun 12	mean surface T = 3.3°C
		Peachland Cr	1990	-	Apr 07	May 07	May 30	
	Smith (1987)	Okanagan Lk - hatchery	N/A	880	-	-	-	shore spawners - incub T
		- natural	N/A	750	-	-	-	shore spawners - incub T

peaked in the first week of May. It would be extremely useful to track down these lost data, as they were collected prior to the improved flood control system coming into full operation.

FRY ENTRAINMENT AT INRIVER IRRIGATION INTAKES

Traditionally, a standard start date of April 1 has been written into Water Licences for irrigation withdrawals from the Okanagan River in the Oliver-Osoyoos area. Given that the period of significant nerkid fry migration would encompass the entire month of April, the potential is high for entrainment of nerkid fry (the potential would be low for whitefish fry, as their migration is largely complete by early April). Certainly nerkid fry have been captured in an oxbow located just above Osoyoos Lake (Shepherd, MSS 1991, 1992a, 1992b; 1994 unpub data).

However, nerkid fry entrainment may not be as high as these results would indicate, for two reasons. First, most irrigators do not actually start their pumps until early May; at this time, the majority of the nerkid fry should have already migrated (keep in mind that the 1994 migration may have been advanced, due to warm water temperatures). Second, nerkid fry tend to migrate mid-river, rather than along the margins.

The potential for kokanee fry entrainment into irrigation intakes is unlikely to be eliminated even if all intakes were in full compliance with the screening specifications established by DFO (Appx 10). It was found during kokanee trapping projects on Okanagan Lake tributaries that screening with the 2.54 mm (0.10") mesh openings specified by DFO were approximately four times larger than that required to prevent passage of fry.

It is recognized that the much finer screening required to physically separate kokanee fry from the water would be logistically very difficult to maintain. Instead, more attention has to be paid to designing intakes that work with fish behaviour to encourage avoidance. Possible design features worth investigating might include structures that enhance bypass velocities, or horizontal screens flush with the river bottom.

The majority of the Water Licensees are probably unaware of the need for fish screens, as their licences were issued long before the first Fish Screening Directive was ever written. There is a strong need to educate the licensees as to this need, and to check compliance rates. In 1993, fisheries agencies in the northwestern U.S. inspected irrigation intakes in the Columbia system, and found that only 29% complied with state screening regulations (Anonymous, 1994). Given the lower awareness of Canadian licensees and a lack of any prior compliance checks, it is suspected that the level of compliance in BC would be even poorer.

RECOMMENDATIONS

1. McIntyre Dam water temperatures should be monitored for at least one more year for September through May, in order to better define the normal thermal regime for the nerkid spawning-incubation period.

1. Egg-to-fry survival rates for the Okanagan River nerkid complex would be relatively easy to determine. The VDS are excellent sampling platforms for this type of study, and are spaced at intervals throughout the lower reaches of the river. Sampling at the various VDS locations would offer the capability to determine fry losses during the riverine portion of their migration.

2. The pressure plates on the lower beam of the net frame should be modified so that they can be removed at higher flows (it may be possible to operate without the pressure plates at all flows).

3. In order to gain sufficient accuracy to estimate the in-river fry population and losses between reaches, the number of traps would have to be increased at each site. A frame would have to be mounted in each bay of the VDS, and either the frames would have to be strengthened to allow more than one net to be fished within each frame (needed to determine fry distribution with depth) or the mouth openings of the nets would have to be reduced.

4. In order to conduct cross-section and depth checks, as well as provide greater crew safety, each VDS trapping operation should have at least two crew members.

5. In order to obtain egg deposition estimates to incorporate into egg-to-fry survival rates, more attention would also have to be paid to enumeration and sampling of both sockeye and kokanee spawners in the previous fall. Sampling of both races should include determination of sex ratio, fecundity, egg retention and pre-spawning mortality.

6. Further testing of the 1994 fry samples would be helpful in determining the proportions of the two races present, as well as examining the utility of the different pigmentation patterns in separation of the two races in the field. Types of tests that could be helpful would include morphometric truss and genetic analyses, and otolith microchemistry.

7. An attempt should be made to find the migration data that was collected during the 1950s; this would require the assistance of the Canadian federal Department of Fisheries and Oceans in a search of their archive records.

8. BCE Water Allocation staff should be requested to revise the standard irrigation start-up date from April 1 to May 1 for Water Licences on the Okanagan River between McIntyre Dam and Osoyoos Lake.

9. BCE Water Engineering staff should be made aware that nerkid fry can be prematurely flushed from the spawning gravels with rapid increases in discharge; they should be encouraged to avoid such releases during the earlier phases of incubation, and to slowly ramp increases during the later phases; this might allow the more mobile alevins to burrow back into the gravel if exposed.

10. All Water Licensees should be sent an information package advising them of their responsibility to install fish screens if they are withdrawing water from fish-bearing systems. Subsequent to this mail-out, compliance checks should be undertaken in the most critical areas (the Okanagan River being one of these), licensees notified if found non-compliant, and enforcement action taken if a follow-up check finds the intake still non-compliant.

LITERATURE CITED

Alderdice, D.F., and F.P.J Velsen. 1978. Relation between temperature and incubation time for eggs of chinook salmon (Oncorhynchus tshawystscha). J. Fish. Res. Bd. Can. 35(1): 69-75.

Anderson, R.O., and S.J. Gutreuter. 1983. Chapter 15. Length, weight and associated structural indices. pp 283-300 In: L.A. Nielsen and D.L. Johnson (Eds), Fisheries Techniques, Amer. Fish. Soc., Bethesda, MD.

Anonymous. 1994. Fisheries agencies take closer look and salmon problem. Fisheries (Amer. Fish. Soc.) 19(3): 38.

Bams, R.A. 1970. Evaluation of a revised hatchery method tested on pink and chum salmon fry. J. Fish. Res. Bd. Can. 27(8): 1429-1452.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing. pp 120-124 In: H.D. Smith, L. Margolis and C.C. Wood (Eds), Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Burgner, R.L. 1987. Factors influencing age and growth of juvenile sockeye salmon (Oncorhynchus nerka) in lakes. pp 129-142 In: H.D. Smith, L. Margolis and C.C. Wood (Eds), Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Dill, P.A. 1991. Outmigration of kokanee salmon fry from Mission Creek Spawning Channel and estimate of egg-to-fry survival, 1991. Contractor Report prep. for Okanagan Sub-Region Fish. Sect., Fish. Proj. Rep. OK-6, BC Env., Penticton, BC.

Dill, P.A. 1992. Outmigration of kokanee salmon fry from Mission Creek Spawning Channel and estimate of egg-to-fry survival, 1992. Contractor Report prep. for Okanagan Sub-Region Fish. Sect., Fish. Proj. Rep. OK-9, BC Env., Penticton, BC.

DFO. MS 1990. Fish Screening Directive (Revised May 1990). Dept. Fish. Oceans, Vancouver, BC.

Dill, P.A. 1993. Outmigration of kokanee salmon fry from Mission Creek Spawning Channel and estimate of egg-to-fry survival, 1993. Contractor Report prep. for Okanagan Sub-Region Fish. Sect., Fish. Proj. Rep. OK-9, BC Env., Penticton, BC.

Hagen, J.E., and G.B. Grette. 1994. 1993 Okanagan River sockeye salmon spawning ground population study. Prepared by Parametrix Inc. for Public Utility District No. 1 of Douglas County, E. Wenatchee, WA.

Heming, T.A. 1982. Effects of temperature on utilization of yolk by chinook salmon (Oncorhynchus tshawystscha) eggs and alevins. Can. J. Fish. Aquat. Sci. 39(1): 184-190.

McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Bd. Can. 17(5): 655-676.

Mullan, J.W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880's-1982: a review and synthesis. U.S. Fish Wildl. Serv. Biol. Rep. 86(12).

Pratt, K.L., D.W. Chapman and M. Hill. 1991. Potential to enhance sockeye salmon upstream from Wells Dam. Prepared by Don Chapman Consultants for Douglas County Public Utility District, E. Wenatchee, WA.

Shepherd, B.G. 1984. The biological design process used in the development of federal government facilities during Phase I of the Salmonid Enhancement Program. Can. Tech. Rep. Fish. Aquat. Sci. 1275.

Shepherd, B.G., G.F. Hartman, and W.J. Wilson. 1986. Relationships between stream and intragravel temperatures in coastal drainages, and some implications for fisheries workers. Can. J. Fish. Aquat. Sci. 43(9): 1818-1822.

Shepherd, B.G. 1990. Kokanee fry production assessment of Mission Spawning Channel and Peachland Creek, 1990. Okanagan Sub-Region Fish. Sect. Fish. Proj. Rep. OK-4, Min. Env., Penticton, BC.

Shepherd, B.G. MS 1991. Okanagan River oxbow intake. Memo to C.J. Bull dated 27 May 1991, on File 40.5012, BC Env., Penticton, BC.

Shepherd, B.G. MS 1992a. Electroshocking survey of Osoyoos Oxbow, April 22, 1992. Memo to C.J. Bull dated 24 April 1992, on File 40.5012, BC Env., Penticton, BC.

Shepherd, B.G. MS 1992b. Electroshocking survey of Osoyoos Oxbow, May 14, 1992. Memo to C.J. Bull dated 2 June 1992, on File 40.5012, BC Env., Penticton, BC.

Shepherd, B.G. MS 1993. Powers Creek kokanee fry trapping results, 1993. Memo to C.J. Bull dated 17 August 1993, on File 39080-25 (Powers Creek).

Smith D.R. 1978. A summary of existing data on kokanee (O. nerka) in Okanagan Lake. Okanagan Sub-Region Tech. Rep. 224, BC Min. Env. Penticton, BC.

Wood, C.C., and C.J. Foote. 1990. Genetic differences in the early development and growth of sympatric sockeye salmon and kokanee (Oncorhynchus nerka) and their hybrids. Can. J. Fish. Aquat. Sci. 47(11): 2250-2260.

MEMORANDUM FROM BOB BUGERT,

RESULTS OF SOCKEYE

SPAWNING GROUND SURVEYS,

1994

APPENDIX - F

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES
Post Office Box 43135 • Olympia, Washington 98504-3135 • (206) 902-2200 • SCAN 902-2200 • TDD 902-2207

17 November 1994

MEMORANDUM

TO: Wells Coordinating Committee

FROM: Bob Bugert Bob

SUBJECT: Okanogan sockeye spawning ground surveys

Here's the results of the surveys for sockeye salmon on the Okanogan River in 1994. As per schedule, surveys were made seven times over a five-week period, beginning 12 October and ending 8 November.

Surveys from McIntyre Dam to Vertical Drop Structure 13 in 1994:					
Survey date	Live sockeye	Dead sockeye	Live kokanee	Dead kokanee	Flow (cfs)
12 October	201	0	- -	- -	452
19 October	193	5	166	0	388
20 October	225	1	- -	- -	- -
26 October	180	8	182	41	388
1 November	85	26	- -	- -	247
8 November	9	11	- -	- -	- -

Supplemental survey from Vertical Drop Structure 13 to Vertical Drop Structure 6 in 1994:				
Survey date	Live sockeye	Dead sockeye	Live kokanee	Dead kokanee
27 October	7	9	13	34

Conditions for the surveys were variable, yet in general fairly good. I looked at these data three ways:

1) I used the maximum spawner count derived from the individual surveys (sum of the 20 October count and the supplemental 27 October count). This value is about 15% of the 1994 Wells Dam count (242 escaped/1,665 at Wells).

2) I used the areal spawner curve method developed by Ames (1984) and others to estimate the spawning population at 619 sockeye salmon. This estimate of abundance is 37% of the Wells Dam count (619/1,665). Calculation of this estimate required three assumptions: a) the salmon were on the spawning grounds at least one week prior to the first count, b) the "survey life" of the salmon was about ten days, and lastly, c) we was 90% of the actual number of salmon on the spawning gravels on a given survey. The 1994 Wells Dam count was less than 5% of the ten-year average--our survey detection rate should have been high.

3) The "Factor 5" method was used in the initial upper Columbia salmon surveys, which Allen and Meekin (1973) applied to Okanogan sockeye. This method uses similar assumptions to that of Ames (1980). The estimate of spawner abundance derived from this method is 779 sockeye, which converts to 47% of the Wells Dam count.

All three conversion values are lower than the 1992 conversion rate of 54% (41,950 counted at Wells Dam, of which 22,587 escaped to the spawning grounds) and the 1993 rate of 77% (27,843 at Wells, and 21,505 escaped). These escapement estimates were derived through multiple mark/recapture surveys. The conversion rates from the areal curve estimate (37%) and "Factor 5" estimate (47%) are roughly comparable to an average of 45.2% from the 1969-1974 period, reported by Allen and Meekin (1980). These two methods to estimate abundance are burdened with some rather subjective assumptions, yet I feel the first estimate is too conservative, and suggest we use the second estimate (619 sockeye spawners).

Two conclusions are apparent: 1) the single index count for live fish (taken on 20 October) is taken at an appropriate date, and 2) multiple live counts have the potential to yield markedly different estimates of spawner escapement than multiple mark/recapture. When I contacted those biologists familiar with multiple live counts of sockeye, several individuals indicated a concern over the validity of multiple mark/recapture surveys. This debate is out of my area of expertise, yet I feel it may be prudent to revisit these techniques when the sockeye evaluation plan is carried out.

c: Fuller
LaVoy
Shepherd, BCME
Carson, CDFO

References:

Allen, R.L., and T.K. Meekin. 1973. Columbia River sockeye salmon study, 1971-1974. Progress Report Number 120, Washington Department of Fisheries, Olympia.

Allen, R.L., and T.K. Meekin. 1980. Columbia River sockeye salmon study, 1971-1974. Progress Report Number 120, Washington Department of Fisheries, Olympia.

Ames, J. 1984. Puget Sound chum salmon escapement estimates using multiple surveys. *in* Symons and Waldichuk (editors). Proceedings of the workshop on stream indexing for salmon escapement estimation. Canadian Technical Report, Fish and Aquatic Sciences, Number 1326.

WELLS DAM RADIO-TELEMETRY STUDY, 1992
PREPARED BY
G. A. SWAN, et. al.

APPENDIX - G

Wells Dam Radio-Telemetry Study, 1992

Coastal Zone and Estuarine Studies Division

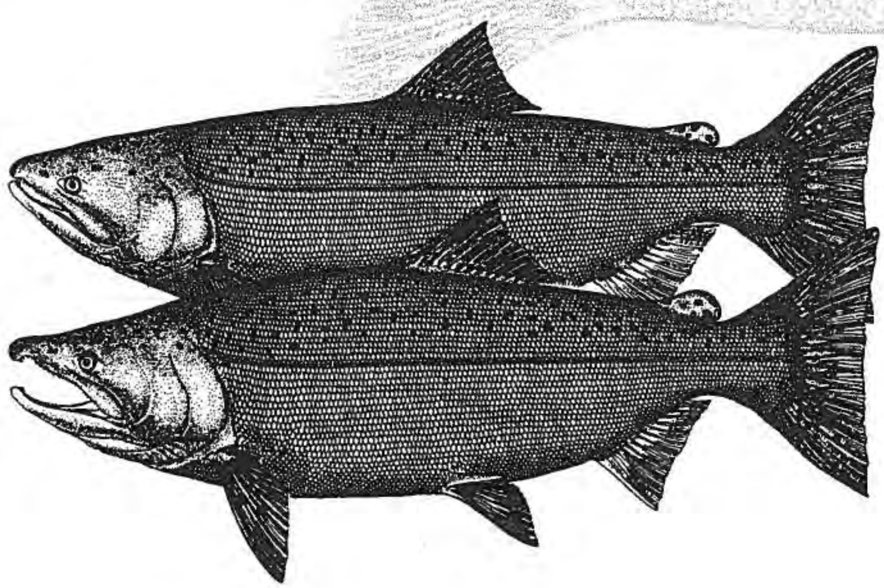
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
George A. Swan, Leslie K. Timme, Robert N. Iwamoto, Lowell C. Stuehrenberg, Eric E. Hockersmith, Byron L. Iverson, and Benjamin P. Sandford

September 1994



WELLS DAM RADIO-TELEMETRY STUDY, 1992

by

George A. Swan
Leslie K. Timme
Robert N. Iwamoto
Lowell C. Stuehrenberg
Eric E. Hockersmith
Byron L. Iverson
and
Benjamin P. Sandford

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Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

September 1994

EXECUTIVE SUMMARY

In 1992, the National Marine Fisheries Service conducted a radio-telemetry study to determine migration rates and timing of adult sockeye salmon (*Oncorhynchus nerka*) between Rocky Reach Dam and Wells Dam in the mid-Columbia River and to the spawning grounds in British Columbia, Canada. Particular emphasis was placed on identifying fish passage problems and determining the extent of delay for fish at Wells Dam and at the mouth of the Okanogan River.

Ninety-six fish were collected and radio tagged at Rocky Reach Dam. Travel time between Rocky Reach Dam and Wells Dam was about 1.5 days. The overall median passage time at Wells Dam was 1 day with the majority of the delay occurring prior to fish-ladder entry. Tagged fish spent a median of 2 hours between arrival at the dam and first attempting fish-ladder entry. Once in the fish ladders, median time for fish passage was 5 hours. Median passage time through the right-bank fish ladder was 4 hours compared to 6 hours for the left-bank fish ladder. Fifty-six percent of the fish passed between 1100 and 1700 h, with the remainder divided equally between morning and evening hours. Fishway entrance efficiency was highest for the left-bank fish ladder. For each fish ladder, the end (downstream) entrance was selected more frequently than the side entrance.

A fallback rate of 13% was found during periods of spill. A correction factor of 0.853 to adjust inflated adult sockeye

salmon counts for fallback at Wells Dam was determined. No fallback was recorded during no-spill periods.

Sockeye salmon entry into the Okanogan River began when water temperatures dropped and river flow decreased. Most of the radio-tagged fish entered the river during early morning hours between 23 and 28 August. Median migration time for the 117 km reach from river entry to Zosel Dam was 4.6 days (about 25 km per day).

The median migration time from Wells Dam to Zosel Dam (150.6 km) was 36.4 days (4.2 km per day). A portion (15%) of the radio-tagged sockeye salmon were exposed to the fishery at Chief Joseph Dam. About half of these fish appeared to range between the tailrace at Chief Joseph Dam and the mouth of the Okanogan River until proceeding to the spawning grounds.

No appreciable delay prior to passage was found at Zosel Dam. Most fish passed over Zosel Dam during the early morning hours. Some fish may have passed Zosel Dam by swimming under spill gates.

Median residence time in Osoyoos Lake before entry into the spawning area was 28 days. Sharply decreasing water temperature and slightly increasing river flow appeared to trigger the migration from the lake to the spawning area on about 1 October.

CONTENTS

FIGURES

FIGURES--continued

TABLES

INTRODUCTION

In recent years, the number of sockeye salmon (*Oncorhynchus nerka*) counted at Rocky Reach Dam, River Kilometer (RKm) 762.2 [River Mile (RM) 473.7] on the mid-Columbia River (Fig. 1), have differed from counts at Wells Dam, RKm 829.4 (RM 515.5). In 1990, for example, the count at Rocky Reach Dam was 18% higher than the count at Wells Dam. Numerous factors could have contributed to the disparity: 1) there may have been direct mortality associated with Rocky Reach Dam passage or the Wells Dam fishway entrance, 2) high spring and summer flows may have caused delay and mortality, 3) spill may have caused increased fallback through the spillways which in turn resulted in inflated counts in the fishways, 4) counting techniques, species identification, and numbers of days or hourly counting periods may have differed between the dams, and 5) delay in the Wells Dam ladders (possibly due to trapping operations) may have led to rejection of the ladder and to subsequent mortalities.

Limited data exist concerning adult sockeye salmon migration timing and survival from Wells Dam to the spawning grounds. Major and Mighell (1966) concluded that the delay of sockeye salmon near the mouth of the Okanogan River was due to a thermal block or associated factors when water temperature was greater than 21.1°C.

As part of the enhancement plan for sockeye salmon stocks upstream from Wells Dam, Pratt et al. (1991) recommended a

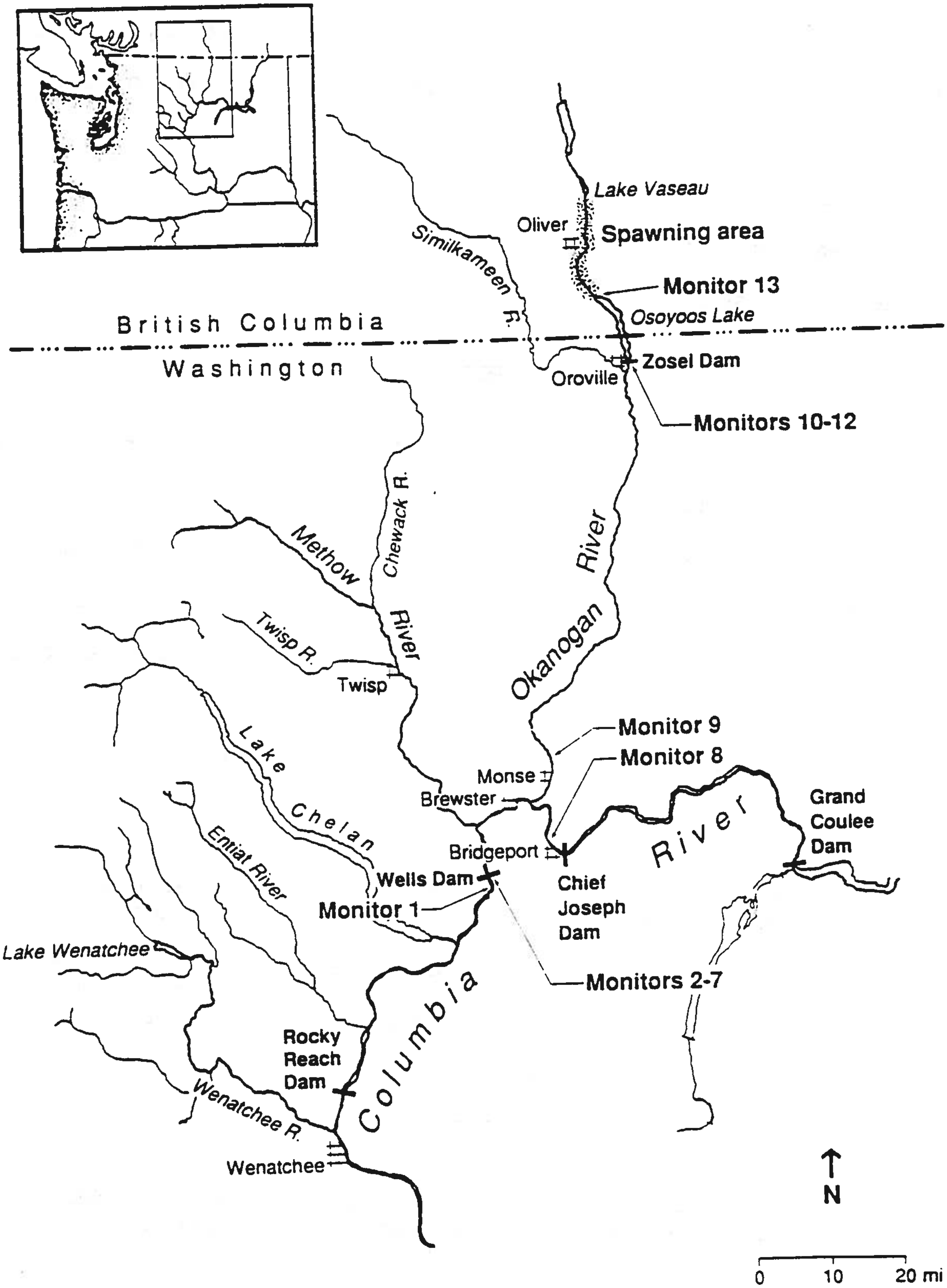

Figure 1.--Map of study area showing fixed-site monitor numbers and locations and spawning area (adapted from Major and Mighell 1966).

radio-tracking study to assess pre-spawning mortality and to assess spawning distribution. In late 1991, the National Marine Fisheries Service (NMFS), in cooperation with the Douglas County Public Utility District, conducted a radio-telemetry study of the sockeye salmon migration in the mid-Columbia River. The results of the 1992 research are presented in this report.

OBJECTIVES

The overall objective of the Wells Dam radio-telemetry study was to identify problem areas that might be associated with adult sockeye salmon passage between Rocky Reach Dam, Wells Dam, and the spawning grounds. Major goals were to collect information on 1) passage times at Wells Dam and at the mouth of the Okanogan River, 2) migrational behavior, and 3) run timing.

Specific goals for this study were covered by the following research tasks:

Task 1. Determine passage time at Wells Dam under existing spill, flow, and powerhouse operating conditions.

- **Task 1.1.** Determine the median time between at-dam arrival (entering dam tailrace) and fish-ladder entrance at Wells Dam.

- **Task 1.2.** Determine the median fish-ladder entrance to exit time at each Wells Dam fish ladder.

Task 2. Evaluate fish-ladder entrance efficiency at Wells Dam. Determine fish-ladder entrance preferences under various operating conditions.

- **Task 2.1.** Determine percentage of fish entries associated with each of the four fish-ladder entrance locations.

Task 2.2. Determine percentage of fish entries associated with successful fish-ladder passage.

Task 3. Determine the fall-back rate and routes under various conditions of spill, flow, and powerhouse operation.

Task 4. Determine percentage of the tagged population exposed to the fishery at Chief Joseph Dam.

Task 5. Determine spatial and temporal factors associated with sockeye salmon entry into the Okanogan River.

Task 5.1. Determine flows and temperatures.

Task 5.2. Determine dates and diel timing.

Task 5.3. Determine behavioral patterns of fish that approach Chief Joseph Dam before entering the Okanogan River.

Task 6. Determine overall timing and rate of migration of sockeye salmon from Wells Dam forebay to Zosel Dam.

Task 7. Determine rate of movement of sockeye salmon in the Okanogan River between river entry and Zosel Dam.

Task 8. Determine delay and passage time of sockeye salmon at Zosel Dam.

Task 9. Determine residence time of sockeye salmon in Osoyoos Lake before entering the spawning area.

Task 10. Determine river flow and temperature during the period sockeye salmon leave Osoyoos Lake for the spawning area.

MATERIALS AND METHODS

Study Duration

Field work began in June 1992 at Rocky Reach Dam and ended in mid-November with adult spawning.

Study Area

Sockeye salmon were trapped and radio tagged at Rocky Reach Dam, released about 5.3 km upstream, and tracked to spawning grounds in the Okanogan River system (Fig. 1). The study area included the Columbia River from Rocky Reach Dam to Chief Joseph Dam, RKm 877.1 (RM 545.1) and the Okanogan River to the spawning areas near Oliver, British Columbia, Canada, Okanagan River RKm 159.5 (RM 99.1).

Radio-Telemetry Tags

Radio-telemetry tags were sized for the smallest anticipated adult sockeye salmon. In 1990, the proportion of 3-year-old fish [mean fork-length (FL) = 37.9 cm] among the Okanogan River fish sampled at Wells Dam was 45% (Fryer and Schwartzberg 1991). Four- and 5-year-old fish were the only other age groups found in significant proportions--26% (mean FL = 50.1 cm) and 23% (mean FL = 57.2 cm), respectively. Stomach-implant tags were sized to fit fish as small as 35-cm FL.

Radio tags for the study were purchased from Lotek Engineering Inc.[1], of Newmarket, Ontario, Canada. Each tag was powered by one 3.5-V lithium battery with a life span of about 5 months. The transmitter and battery were sealed in a cylindrical plastic capsule 4.4-cm long x 1.4-cm diameter. Tags weighed about 10.7 g in air and had a 40-cm, 22-gauge flexible-whip antenna attached to one end. Each tag transmitted a unique identification code (20 per frequency) on one of five frequencies spaced 20 kHz apart (149.720 mHz to 149.800 mHz).

Radio-Tagging

Radio tagging of adult salmon involved three major procedures: trapping, tagging, and releasing. Fish were radio tagged on week days from 8 July to 4 August.

Trapping

The adult trap in the fish ladder at Rocky Reach Dam was used to collect fish. The trap was lowered over the weir orifices in the fish ladder. The trap floor in front of the right-side (facing downstream) orifice was covered with a sheet of white plastic to facilitate viewing fish from above water as they entered the trap. The left-side orifice was closed by a slide gate to prevent escape. The trap was raised as soon as the daily quota (four to six sockeye salmon) was collected (approximately 0.5 hour during most of the fish migration). Fish

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[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

were then transferred from the trap to a tank located on a 3.05 X 6.1-m barge in the forebay via a 46.1-cm diameter pipe. Non-target fish were immediately removed from the collection tank and released into the forebay.

Tagging

Sockeye salmon ranging from 40- to 60-cm FL were radio tagged. For tagging, sockeye salmon were individually transferred by dipnet from the collection tank to an anesthetic tank containing a 50ppm MS-222 solution. After examination for marks, tags, or injuries, fish were weighed, measured, and had a scale sample removed. Each fish was then placed on its dorsal surface in a vinyl tagging cradle, and a radio tag was inserted through the mouth and into the stomach of the fish. During the entire tagging procedure (approximately 2 to 5 minutes), fish were continually moistened.

The age of the radio-tagged fish was determined later from the scale samples read by Columbia River Inter-Tribal Fish Commission (CRITFC) personnel.

Releasing

After tagging, fish were placed in a aluminum holding/transport tank enclosed within a boat-shaped hull (tote boat) for recovery and holding. Tagged fish were initially held overnight for post-tagging mortality and tag regurgitation observations. Later, once tagging and holding procedures were determined acceptable, fish were tagged in the morning and released at the end of the workday (about 1500 h).

Tagged fish required no further direct handling prior to release. For the release, the tote boat was towed 5.3 km upstream from Rocky Reach Dam (to RKm 767.5), about 1 km upstream from Turtle Rock Island. The tank's interior was then reexamined for regurgitated tags. A 30-cm cap on the stern of the tote boat was removed, and fish were allowed to escape. The inside of the tank was then inspected a final time for tags. A 2.5-cm lip at the bottom prevented tags from sliding out.

Radio Tracking

Radio tracking began on 9 July when the first tagged fish was released. Tagged fish locations and instream progress were continuously recorded by fixed-site monitors (Figs. 1-3) and by mobile monitoring units that operated from auto, boat, or airplane.

Table 1 lists the location and numerical designation of the fixed-site radio-telemetry monitors. Initially, Monitor 8 was located on the left bank about 0.8 km below Chief Joseph Dam. However, the monitor was relocated downstream to the Colville Tribal Fish Hatchery (about 6.4-km downstream) after about 2 weeks due to intense radio interference, apparently from the power facilities near the dam.

Mobile tracking was used to monitor fish between fixed site monitors and to locate and recover stationary tags. On the spawning ground, tags were recovered by examining carcasses.

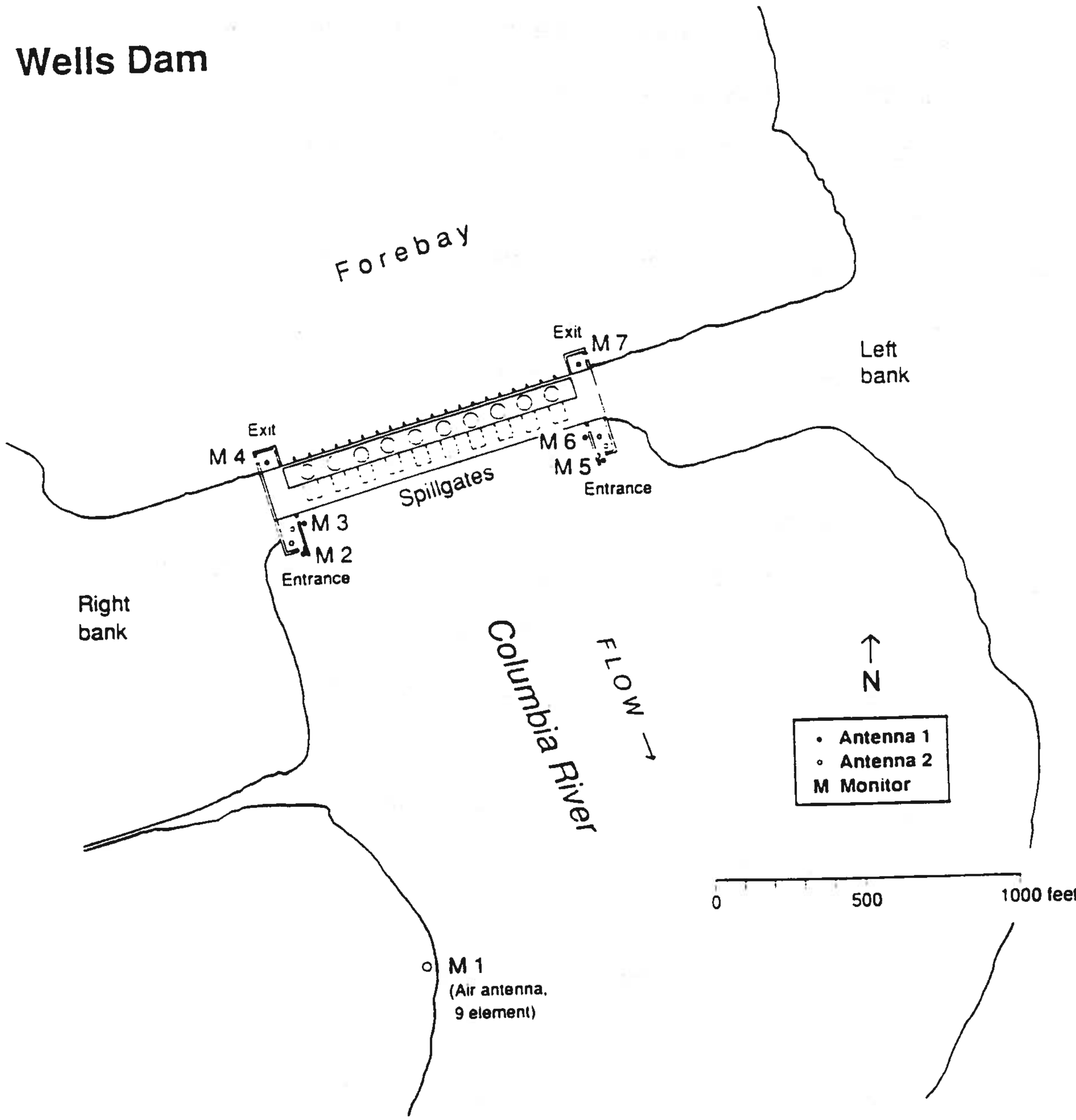

Figure 2.--Fixed-site monitor numbers and locations at Wells Dam.

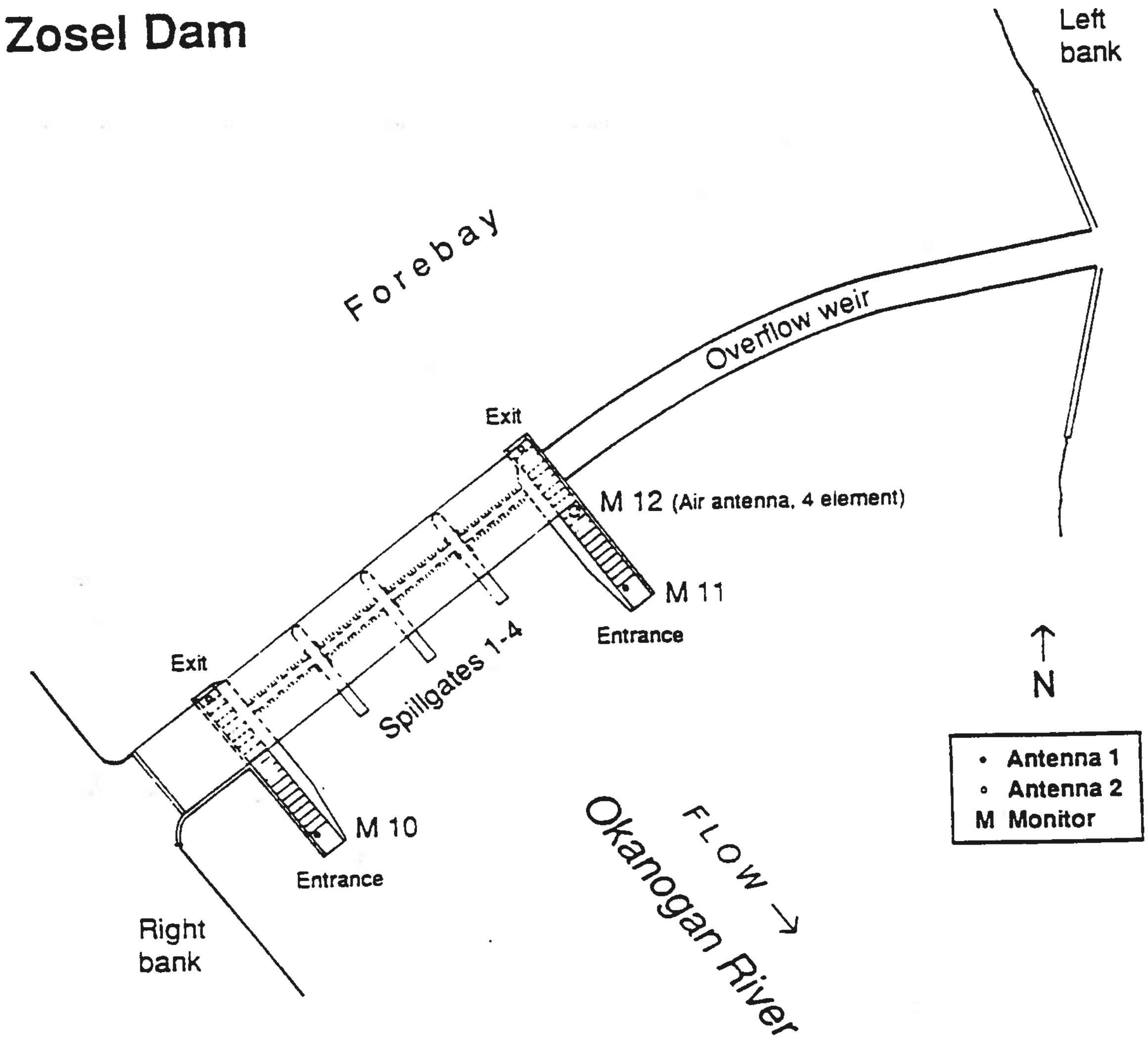

Figure 3.--Fixed-site monitor numbers and locations at Zosel Dam.

Table 1.--Fixed monitor sites, mid-Columbia and Okanogan Rivers system.

Monitor Number	Monitor Location	River	River Mile	River Kilometer	Antennae Number	Antennae Type
1	Wells Dam (tailrace)	Columbia	515.0	829.0	1	9-element Yagi (air)
2	Wells Dam (right-bank fish ladder-end entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
3	Wells Dam (right-bank fish ladder-side entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
4	Wells Dam (right-bank fish ladder-exit)	Columbia	517.0	832.0	1	Underwater coax cable
5	Wells Dam (left-bank fish ladder-end entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
6	Wells Dam (left-bank fish ladder-side entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
7	Wells Dam (left-bank fish ladder-exit)	Columbia	517.0	832.0	1	Underwater coax cable
8	Colville Tribe Fish Hatchery	Columbia	542.0	872.1	1	9-element Yagi (air)
9	Monse (Gebber's pump house)	Okanogan	6.0	9.7	1 2	4-element Yagi (air-downstream) 4-element Yagi (air-upstream)
10	Zosel Dam (right-bank fish ladder)	Okanogan	77.4	124.5	1 2	Underwater coax cable (entrance) Underwater coax cable (exit)
11	Zosel Dam (left-bank fish ladder)	Okanogan	77.4	124.5	1 2	Underwater coax cable (entrance) Underwater coax cable (exit)
12	Zosel Dam (mid-dam)	Okanogan	77.4	124.5	1	4-element Yagi (air)
13	Lake Osoyoos (0.5 mi above lake)	Okanogan	90.8	146.1	1	9-element Yagi (air)

Radio-Telemetry Monitoring Equipment and Data Collection

All fixed site monitors utilized Lotek Model SRX-400 telemetry receivers for signal detection and data processing and storage. At Zosel Dam, receivers with underwater antennae incorporated Lotek DSP-500 receiver/co-processors for simultaneous scanning of all antennas and frequencies (Fig. 3). The DSP-500 detected the signal from a transmitter (tag) and passed information concerning frequency, verification, and data storage to the SRX-400 receiver.

Four types of antennae were used for signal detection: underwater, multiple element Yagi, hand-held 3-element folding Yagi, and H antennas.

Underwater antennae consisted of coaxial cable, with about 2.5 cm of the shielding stripped from the distal end, suspended outside and within fish-ladder entrances and exits to detect the presence and passage of tagged fish within about 4.6-6.1 m. Yagi multiple element antennae were used as air antennae at fixed sites to monitor fish in a general area. Hand-held or staff-mounted three-element folding Yagi antennae were used for tracking by boat or auto. Two wing-strut-mounted H-pattern antennae were used on a high-winged aircraft for aerial tracking.

Fixed-site telemetry data were downloaded to lap-top computers at least once per week. When personnel were available, mobile surveillance was also conducted at least once per week. Aerial surveillance of the mid-Columbia River and major tributaries was conducted on 2 days.

River flow, water temperature, spill, and turbine operation data were obtained from appropriate water management and power producing agencies. Water temperature at the mouth of the Okanogan River was monitored when mobile tracking.

Fish behavior between arrival and ladder entry at Wells Dam was monitored by observing activity near and inside the fish-ladder collection system. Entrance preference was evaluated by the total number of tag-activity periods on each antenna. Tag-activity periods were also used to determine the effects of adult trap operation and spill on entrance preference.

The adult fish collection trap in the left-bank fish ladder was operated periodically by Washington Department of Fisheries, Wells Hatchery. The trap was operated 8 hours per day (0700-1500 h) on Monday, Wednesday, and Friday from 6 July through 3 August.

Working tags were located by radio signal. Non-working tags were found primarily by examining carcasses. To encourage the return of recovered radio tags and information, a $20 reward was offered.

Entrance efficiency was determined from the number of entrance attempts at each fish ladder relative to the number of successful passages.

Residence time in Osoyoos Lake before entering the spawning grounds was determined from the last time tagged fish were recorded upstream from Zosel Dam to the first time they were registered at Monitor 13 at the north end of the lake.

RESULTS AND DISCUSSION

We originally planned to radio tag a representative cross-section of the sockeye salmon population passing Rocky Reach Dam. The receipt and installation schedule of electronic monitoring gear at Wells Dam was based on adult arrival timing in 1990 and 1991. However, in 1992, adult fish arrived about 2 weeks earlier than expected. By 8 July, about 10,000 fish, representing 24% of the 1992 sockeye salmon run, had passed Rocky Reach Dam. The end of the sockeye salmon passage at Bonneville Dam also occurred much earlier than expected, requiring acceleration and completion of radio tagging about 3 weeks ahead of schedule. Appendix Table 1 lists and summarizes the fates of individual tagged fish. A detailed tag life history for each radio-tagged fish is presented in Appendix Table 2.

Sockeye salmon collected and tagged at Rocky Reach Dam ranged in length and weight from 46-60 cm (mean = 50.5 cm) and 0.64-2.0 kg (mean = 1.1 kg), respectively. The percentages of 4- and 5-year old fish were 95% and 5%, respectively. Ninety-six radio-tagged adult sockeye salmon were released upstream from Rocky Reach Dam, and 89 were subsequently recorded in the Wells Dam tailrace with 83 (86%) successfully passing the dam (Table 2). Monitors installed in the fish-ladder exits recorded 71 tagged fish passing over Wells Dam. An additional 12 fish passed Wells Dam without being recorded by the fish-ladder monitors. Seven fish were detected upstream from Wells Dam by mobile tracking, and the remainder by fixed-site monitors.

Table 2.--Activity summary at Wells Dam of 96 radio-tagged sockeye salmon released above Rocky Reach Dam.

Tagged fish recorded exiting Wells Dam	71
Tagged fish recorded by mobile tracking upstream from Wells Dam (but not recorded as exiting Wells Dam)	7
Tagged fish recorded at fixed-site monitors upstream from Wells Dam (but not recorded as exiting Wells Dam)	3
Tags within recovered fish on spawning grounds (but not recorded as exiting Wells Dam)	2
Tagged fish trapped in left-bank ladder at Wells Dam and transported to Methow Hatchery	2
Tagged fish recorded in Wells Dam tailrace (but not seen again)	8
Tagged fish never recorded after release	3
	96

Immediate regurgitation of radio tags was not a factor. During the tagging/releasing effort, one regurgitated tag was found in the tote boat.

Tables 2 and 3 summarize activity and locations, respectively, of recovered fish or radio tags. Thirty-four (35%) of the original 96 tags were recovered. Twenty-six tags, 11 of which were no longer transmitting a signal, were recovered on the spawning grounds. The average maximum life span of the 11 failed tags was less than 101 days (Table 4), well short of the desired 5-month life span. Non-recovered tags may have experienced similar battery failure.

Five tags were recovered on the river bank, well away from the river's edge, suggesting fish or tags were intentionally removed from the river.

Results for the specific research elements were:

Task 1. Determine passage time at Wells Dam under existing spill, flow, and powerhouse operating conditions.

Seventy-nine radio-tagged fish (82.3%) were detected by Monitor 1, downstream from Wells Dam (Figs. 1-2). Elapsed time from release to the monitor ranged from <1 to 10 days with a median of 1.5 days (Fig. 4 and Table 5). Seventy-one radio-tagged sockeye salmon passed over Wells Dam according to the exit monitors. However, tags in six of those fish failed to register on Monitor 1, and tags in two fish failed to register on the entrance monitors. Overall passage time for 63 tagged fish, from the first downstream monitor (Monitor 1) record to the last

Table 3.--Recovered radio tags from sockeye salmon. Abbreviations: CO - Columbia River, SI - Similkameen River, OK - Okanogan River.

Location	River	RM	RKM	Tags Recovered Active	Tags Recovered Failed
Colville Tribal Hatchery	CO	542	872	1	
Wells Dam[1]	CO	517	832	2	
Oroville, Washington	SI	3	5	1	
Below Zosel Dam	OK	47-77	76-124	4	
Spawning grounds (British Columbia)	OK	99-104	159-167	15	11
				23	11

[1] Fish were trapped at Wells Dam and transported to Methow Hatchery, Winthrop, Washington for brood stock.

Table 4.-- Longevity of failed radio tags. Abbreviations: CO - Columbia River, OK - Okanogan River.

Tag	Release date	Last active record River-RKm	Last active record Date	Recovery date	Maximum possible duration (days)
2134	14 Jul	OK - 0	27 Jul	20 Oct	98
2242	11 Jul	CO - 858	18 Aug	28 Oct	109
2247[1]	20 Jul	CO - 762	20 Jul	29 Oct	101
2328	16 Jul	CO - 872	24 Jul	21 Oct	97
2330	23 Jul	OK - 166	15 Oct	15 Oct	84
2436	17 Jul	OK - 0	03 Aug	28 Oct	103
2437	13 Jul	OK - 10	28 Aug	28 Oct	107
2447[1]	14 Jul	CO - 762	14 Jul	29 Oct	107
2534	10 Jul	OK - 10	25 Aug	26 Oct	108
2535	27 Jul	OK - 146	13 Sep	28 Oct	103
2550	17 Jul	OK - 0	31 Jul	21 Oct	96
				Average duration	101 days

[1] Never recorded after release until recovery of tag.

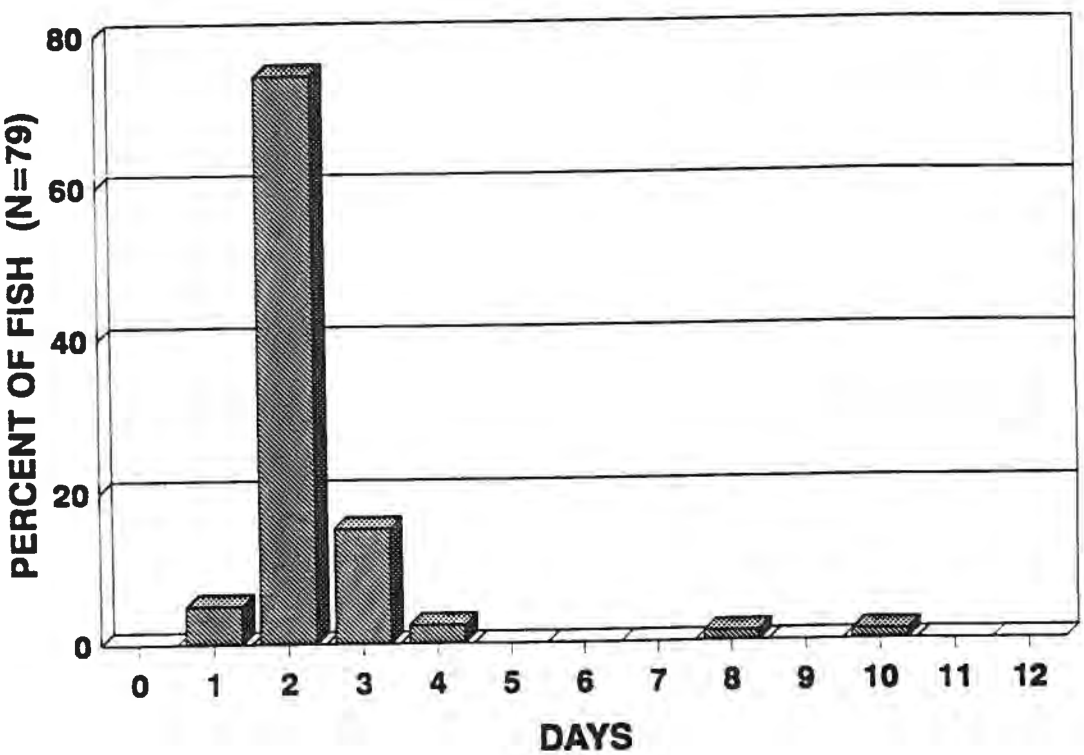

Figure 4.--Travel times of radio-tagged sockeye salmon from release above Rocky Reach Dam to Monitor 1 at Wells Dam tailrace.

Table 5.--Passage time (days) of radio-tagged sockeye salmon (with complete passage records) released 5.3 kilometers upstream from Rocky Reach Dam and monitored at Wells Dam.

	Release to Wells Dam	Monitor 1 to first ladder record	Ladder Passage			Overall passage at Wells Dam
			Overall	Right	Left	
n	79	79	69	24	45	63
Min	0.7	<0.1	0.1	0.1	0.1	0.3
Max	9.6	0.7	11.4	2.7	11.4	18.5
Median	1.5	0.1	0.2	0.2	0.3	1.3

ladder-exit monitor record, ranged from <1 to 19 days, with a median of 1.3 days (Fig. 5 and Table 5).

Due to migration rates and the time required for the monitors to scan through the five frequencies, tags were not recorded at all of the monitors.

Task 1.1. Determine the median time between at-dam arrival (entering dam tailrace) and fish-ladder entrance at Wells Dam.

Seventy-nine radio-tagged fish were detected by Monitor 1 prior to being recorded at the fish-ladder entrances (Monitors 2, 3, 5, or 6). Elapsed time between arriving at Wells Dam and the initial record at one of the four fish-ladder entrances ranged from <1 to 17 hours, with a median of 2 hours (Fig. 6). However, many of the tagged fish did not proceed up the fish ladder following the initial encounter with a ladder entrance. Time from first record at the dam (by either Monitor 1 or one of the four fish-ladder entrance monitors) until last record at the ladder entrance (duration in tailrace) for 69 tagged fish ranged from <1 to 16 days, with a median of 1 day (Fig. 7).

Task 1.2. Determine the median fish-ladder entrance to exit time at each Wells Dam fish ladder.

Passage time through the fish ladders ranged from a minimum of 2 hours to a maximum of 273 hours, with a median time of 5 hours, for the 69 fish detected at both ladder entrance and exit monitors. Median passage time through the right-bank ladder for 24 fish was 4 hours, with a range of 2 to 64 hours. Median

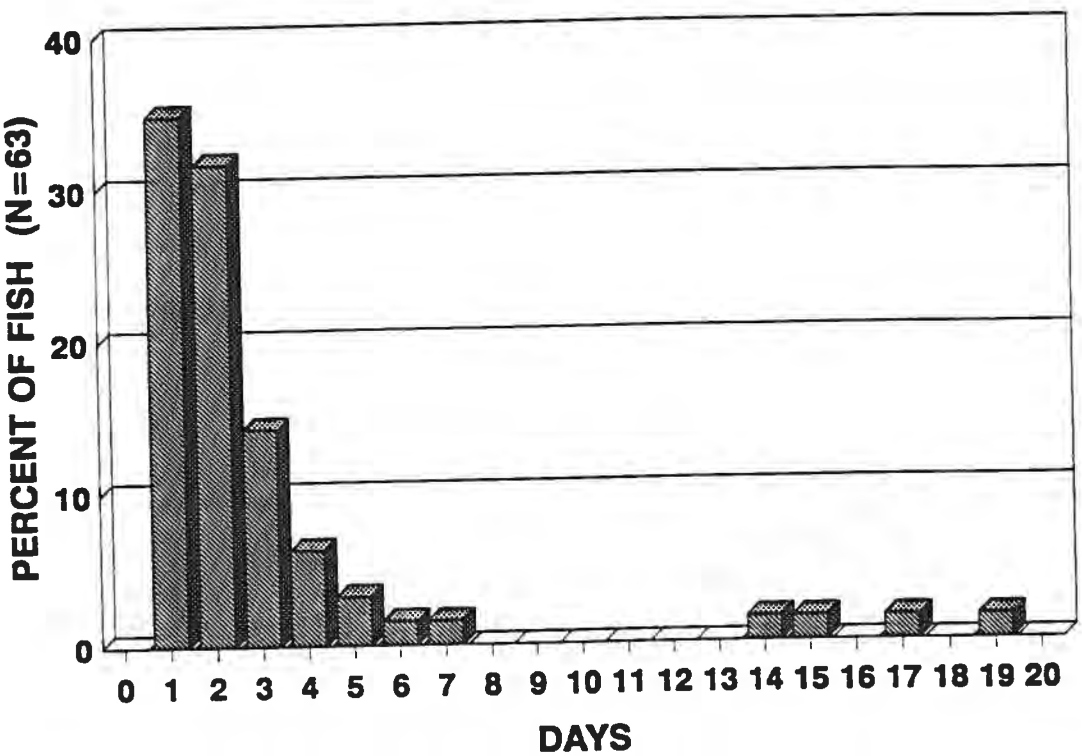

Figure 5.--Overall ladder passage times of radio-tagged sockeye salmon at Wells Dam.

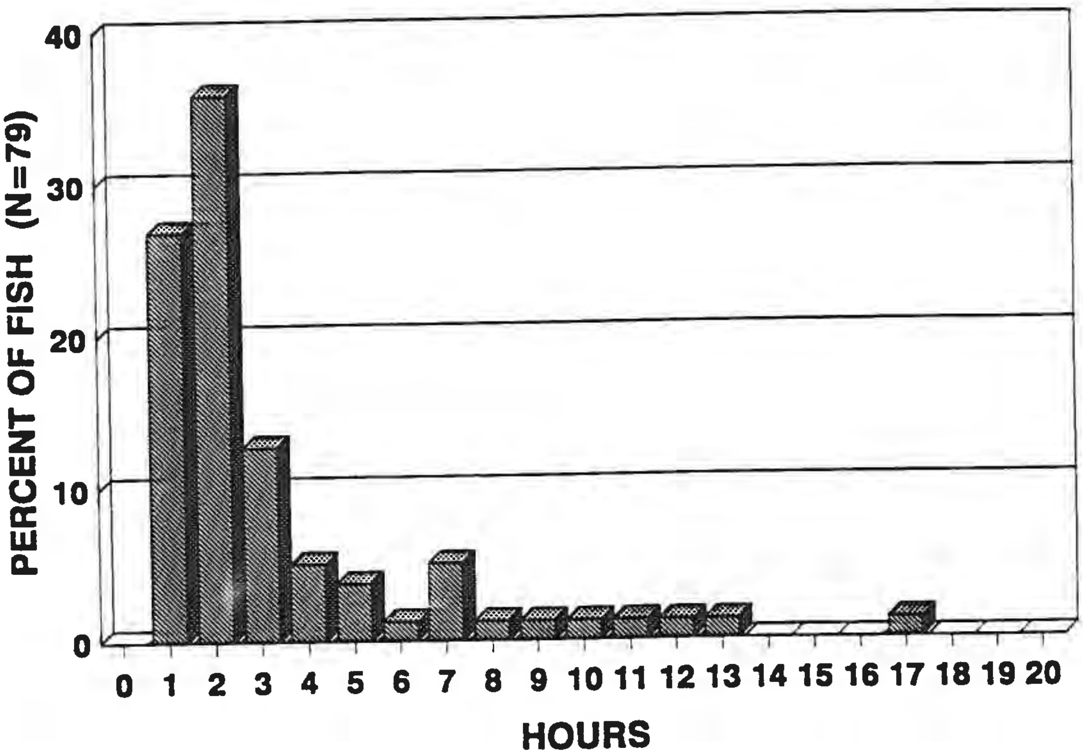

Figure 6.--Elapsed times of radio-tagged sockeye salmon between arriving at Wells Dam and the initial record at a fish-ladder entrance.

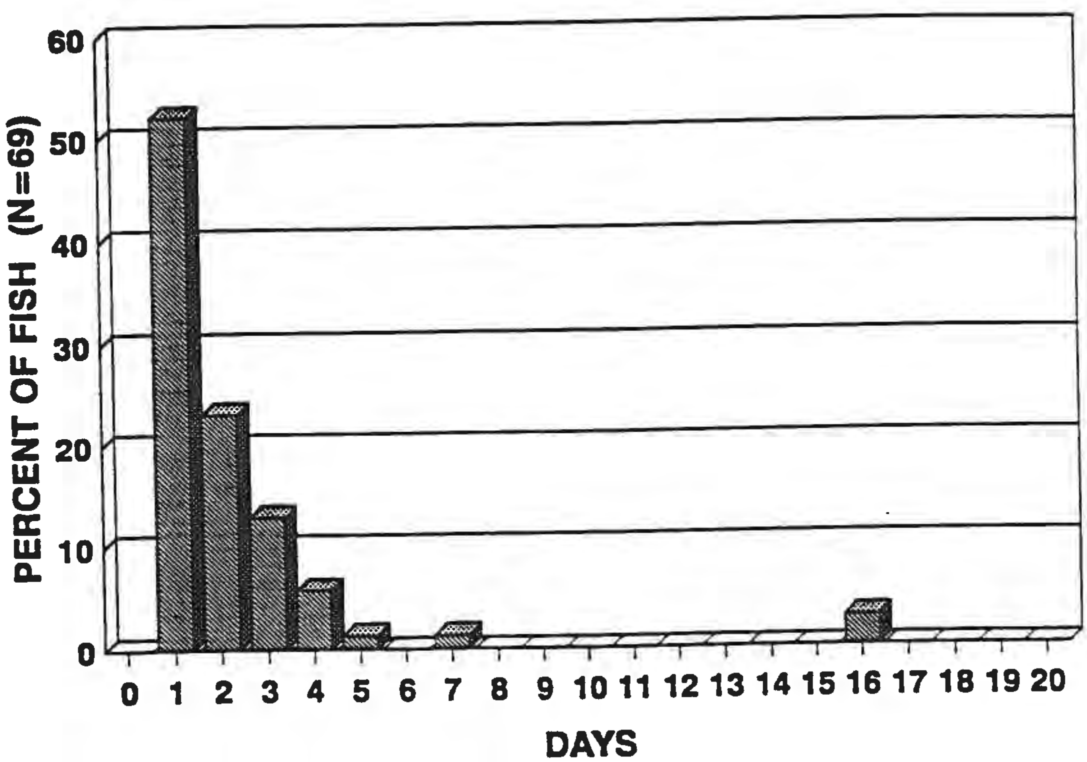

Figure 7.--Delay time in the tailrace before passage radio-tagged sockeye salmon at Wells Dam.

passage time in the left-bank ladder for 45 fish was 6 hours, with a range of 3 hours to a maximum of 273 hours (Fig. 8).

Monitoring of the 71 sockeye salmon recorded as exiting one of the two fish ladders at Wells Dam indicated that 40 (56%) of the tagged fish exited between 1100 and 1700 h, 17 (24%) exited between 0000 and 1030 h, and 14 (20%) exited between 1700 and 2329 h (Fig. 9).

Task 2. Evaluate fish-ladder entrance efficiency at Wells Dam. Determine fish-ladder entrance preferences under various operating conditions.

Task 2.1. Determine percentage of fish entries associated with each of the four fish-ladder entrance locations.

Operation of the adult trapping facility significantly (x^2 = 5.84; P = 0.0156) increased, but not substantially, left-bank entrance activity. During trapping periods, 63.9% of entrance activity was at the left fish ladder as opposed to 59.8% during non-trapping periods. For the total run, activity at the left and right entrance areas was 61.6 to 38.4%, respectively.

Fish activity increased at the left-bank entrance during trapping periods perhaps indicating indecisiveness regarding passage. However, overall passage was not affected.

At the right-bank fish ladder, the downstream entrance had 796 outside antenna records and 369 inside antenna records. The side entrance had 201 outside antenna records and 58 inside antenna records. At the left-bank fish ladder, the downstream

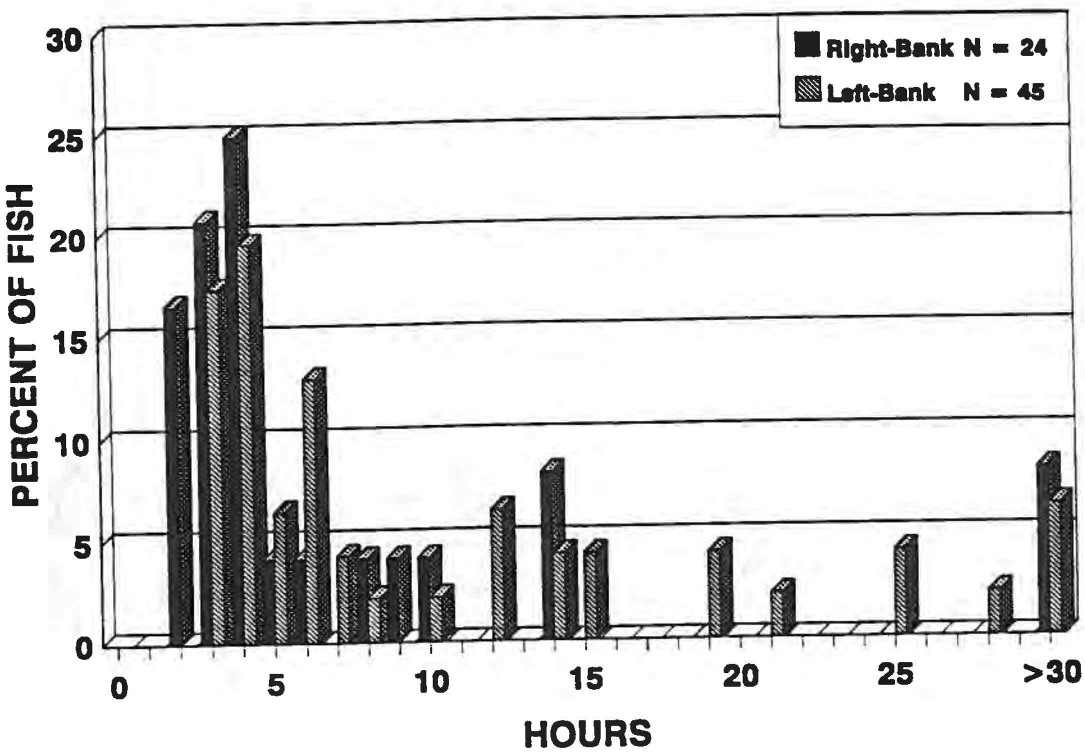

Figure 8.--Ladder-passage times of radio-tagged sockeye salmon at Wells Dam.

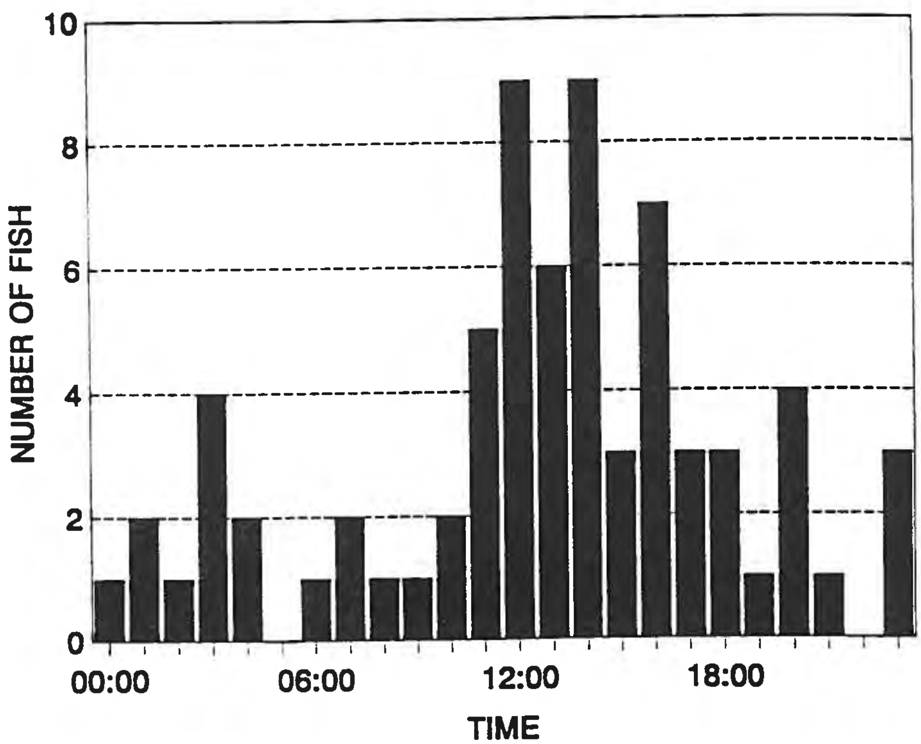

Figure 9.--Ladder-exit timing for radio-tagged sockeye salmon passing Wells Dam.

entrance had 735 outside antenna records and 1,132 inside antenna records, while the side entrance had 367 outside antenna records and 17 inside antenna records.

Task 2.2. Determine percentage of fish entries associated with successful ladder passage.

The left-bank fish ladder provided the highest passage (Fig. 10). Of the 69 radio-tagged sockeye salmon successfully passing over the fish ladders, 45 (65%) passed over the left-bank ladder and 24 (35%) passed over the right-bank ladder.

In both the right- and left-bank fish ladders, the end entrances provided much better passage than the side entrances. Thirty-one tagged fish (69%) passing over the left-bank fish ladder selected the end entrance, and 16 (67%) of those passing over the right-bank fish ladder preferred the end entrance.

Entrance efficiency was 24.5 and 41.5 entrance attempts at the left- and right-bank fish ladders, respectively for each tagged-fish passage recorded.

Task 3. Determine the fall-back rate and routes under various conditions of spill, flow, and powerhouse operation.

Spill occurred at Wells Dam during 1-27 July. Spill rate ranged from 4.1 to 7.6% of the flow (66 to 114 kcfs). Of 69 radio-tagged sockeye salmon, 52 (75%) passed during periods of spill and 17 (25%) passed during non-spill periods.

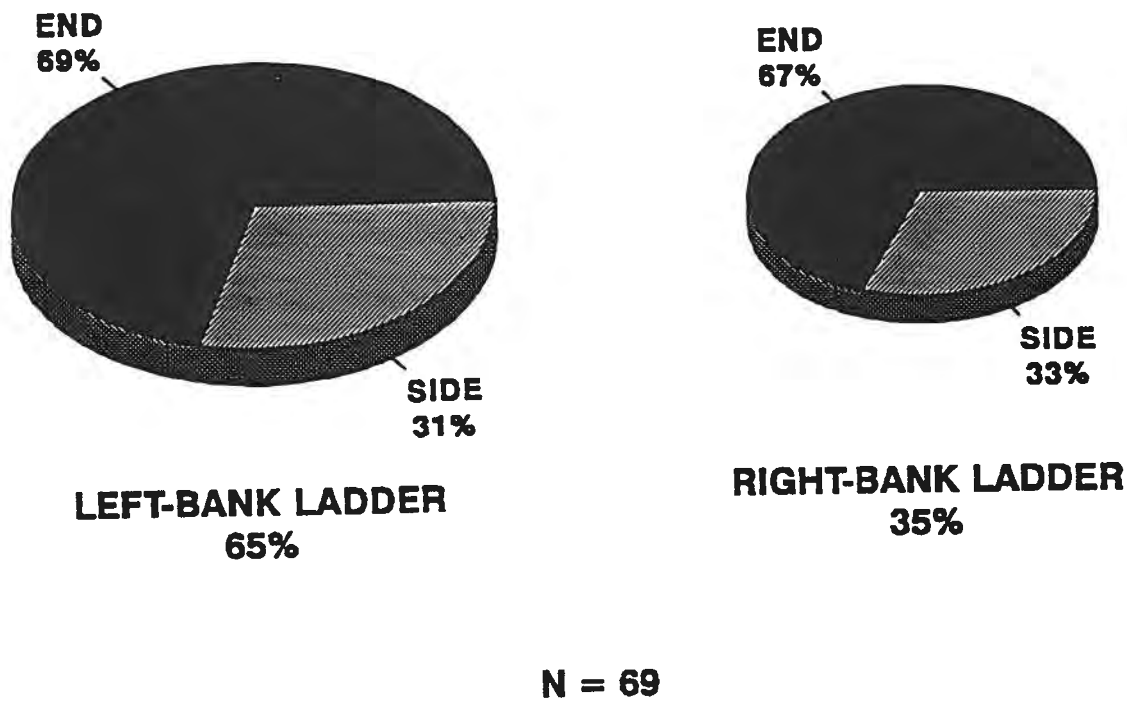

Figure 10.--Entrance selection by ladder by radio-tagged sockeye salmon at Wells Dam.

A "fallback" was defined as any fish passing the exit of a fish ladder that was subsequently found downstream in the tailrace. Nine (13%) of the 69 fish that passed Wells Dam fell back once (Fig. 11). Two of the nine fish fell back twice resulting in a total of 11 fallback occurrences. All of the fallbacks occurred during periods of spill.

One of the nine fish that fell back disappeared downstream. One fish fell back and reascended the fish ladder, but disappeared upstream from the dam. Five fish fell back, but subsequently passed the dam and entered the Okanogan River. Two fish fell back twice, before continuing upstream. One of these entered the Okanogan River and the other was recorded in the Chief Joseph Dam tailrace.

A total of 19 passes were made by the nine fish that fell back at Wells Dam, with eight fish continuing upstream after final passage. Therefore, the 52 radio-tagged sockeye salmon would have been counted as 63 fish passing the dam.

Fallback of adult sockeye salmon at Wells Dam during periods of spill appeared to inflate fish-ladder counts. The 1992 sockeye salmon passage at Wells Dam was 41,951 (U. S. Army Corps of Engineers 1992) with 35,303 (84%) passing during spill conditions, and 6,648 (16%) passing during non-spill conditions.

A correction factor to account for fallback at Wells Dam in 1992 was calculated by dividing 52 (number of radio-tagged sockeye salmon passing during spill conditions) by 63 (number of passes made by radio-tagged sockeye salmon during spill

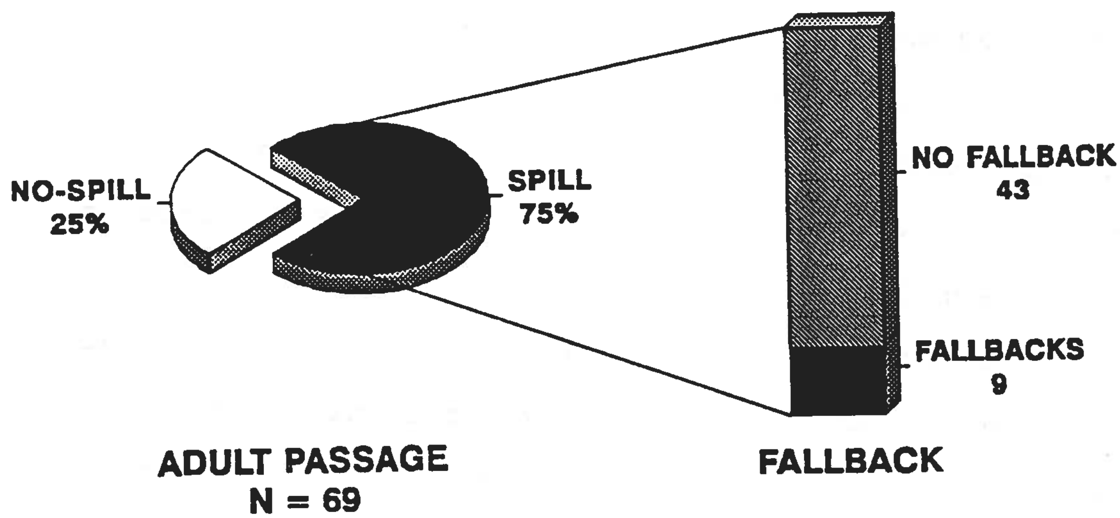

Figure 11.--Fallback rates of radio-tagged sockeye salmon during periods of spill at Wells Dam.

conditions). This factor, multiplied by 35,303 (fish count during spill), provided a corrected fish count of 29,139 fish (during spill). By adding the 6,648 (fish count during non-spill) the total adjusted run of sockeye salmon over Wells Dam in 1992 would be 35,787 fish. Dividing the total adjusted run (35,787 fish) by the total count (41,951 fish) provides a correction factor of 0.853 for the 1992 sockeye salmon count at Wells Dam.

This total adjusted run estimate was greater than Hansen's (1993) 1992 spawning population estimate of 22,587 fish. However, the comparison estimate of 34,679 fish (based on the "Factor 5" method) is relatively close. Differences in the estimates may be due to small sample size of radio-tagged fish, pre-spawning mortality, harvest, tributary escapement, etc.

In 1992, there was virtually no spill during the sockeye salmon run over Rocky Reach Dam. Therefore, fallback due to spill was non-existent. The fish-ladder count of sockeye salmon was 41,800 fish (U. S. Army Corps of Engineers 1992), 151 fish less than the count at Wells Dam, 61 km upstream. However, the adjusted count (to correct for fallback due to spill) at Wells Dam was 35,787 fish (6,013 less fish than the fish-ladder count at Rocky Reach Dam).

Based upon Bonneville Dam fallback data, increased spill rates would increase the rate of fallback (Liscom et al. 1985). Spilling at Wells Dam in July 1992 was not due to excess river flow, but was done to bypass juvenile salmonids downstream (Rick

Klinge, Douglas Co. PUD, personal communication 1994). Since 1992 was a low-flow year, migration years with high flows will have higher magnitudes of spill, potentially higher fallback rates, and inflated ladder counts. Further studies during years with mid- and high-flow conditions would provide data to develop a model for the correction of annual fish counts over Wells Dam.

Task 4. Determine the percentage of the tagged population exposed to the fishery at Chief Joseph Dam.

A portion of the sockeye salmon run may have been exposed to the fishery at Chief Joseph Dam. Fish entered the area, but radio interference prevented recordings of valid tag codes. Prior to relocating the monitor, only one tag (Tag 2328) was recorded, but never detected again. It was later recovered (non-working) on the spawning grounds. After relocation, 12 radio-tagged sockeye salmon were recorded. Of the 12 fish, 6 were subsequently recorded as entering the spawning area, and 6 were never recorded again. One additional radio tag (never recorded on Monitor 8) from a fish collected from the tailrace at Chief Joseph Dam was turned in for reward. This fish was among those recorded as successfully passing Wells Dam and was the only radio-tagged fish verified as harvested by the fishery.

In summary, 14 fish (15% of the tagged population) were potentially exposed to the fishery at Chief Joseph Dam tailrace.

Task 5. Determine spatial and temporal factors associated with sockeye salmon entry into the Okanogan River.

Task 5.1. Determine flows and temperatures.

Flows recorded at Tonasket (RKm 91.4) by the U.S. Geological Survey indicated a marked flow reduction of about 400 cfs beginning about 18 August and a substantial decrease in water temperature beginning on 22-24 August (Table 6). The migration up the Okanogan River coincided with the decreasing river flow and temperature (Fig. 12).

Major and Mighell (1966) determined that while high water temperature (above 21.1°C) in the Okanogan River was a major cause of delay for entry of sockeye salmon from the Columbia River, decreasing temperatures allow the migration to resume. Water temperature in rivers may be decreased by cool weather or through a mixing process (as at a confluence) by the addition of cooler water or reduction of warmer water. This mixing process at the confluence with the Similkameen River appears to have been instrumental in decreasing temperature in the lower Okanogan River.

Changes in flow proportions from the Similkameen and upper Okanogan Rivers appeared to directly affect water temperature in the lower Okanogan River. Prior to 17 August, 59% of the lower Okanogan River flow came from the Similkameen River. On 18 August flow over Zosel Dam was reduced by about 400 cfs resulting in an 84% contribution of Similkameen water to the lower Okanogan River flow through 25 August.

By 24 August, the temperature of the lower Okanogan River had been lowered substantially. Dennis Burton, Oroville-Tonasket Irrigation District, reported that mean daily water temperature

Table 6.--River flow and water temperature associated with radio-tagged sockeye salmon entry into the Okanogan River.

Date	Number of fish	Water temperature (°C)	River flow (cfs)
04 Aug		23.9	
06 Aug		20.9	
09 Aug	1		868
10 Aug	1		910
11 Aug		19.4	961
18 Aug		22.7	950
19 Aug		20.3	651
22 Aug	1		506
23 Aug	10		520
24 Aug	4	15.9	540
25 Aug	3		515
27 Aug		18.2	511
28 Aug	2		668
30 Aug		17.8	
	22		

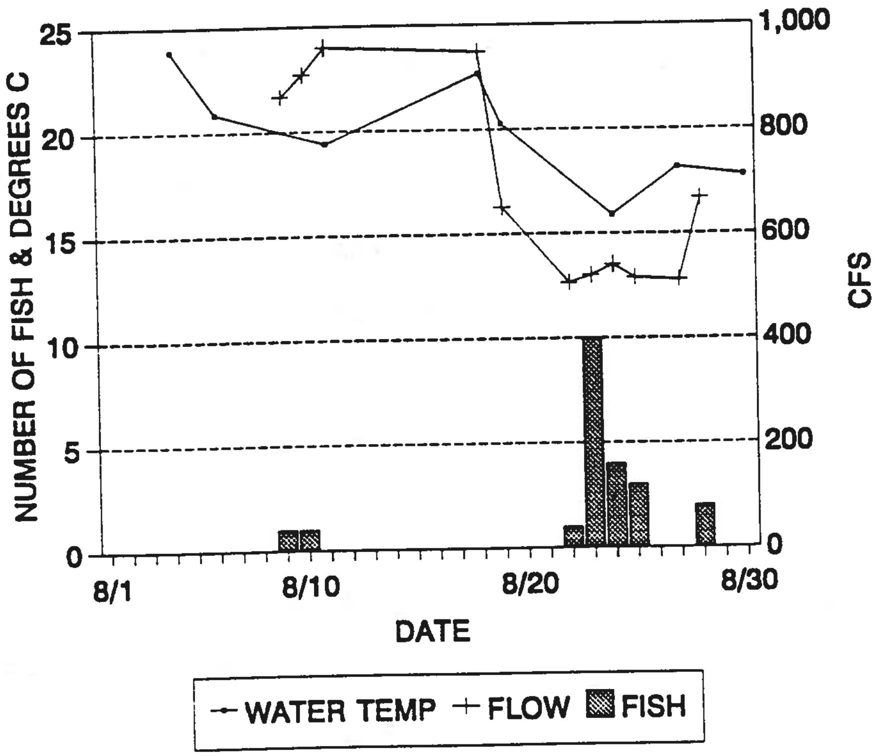

Figure 12.--Flow and water temperature during entry into the Okanogan River by radio-tagged sockeye salmon.

recorded downstream of Zosel Dam prior to 20 August was about 23.9° C, but decreased to 18.1° C by 24 August. However, water temperature in the Similkameen River was 21.8° C on 18 August, but decreased to 13.5° C by 24 August, apparently due to cool weather at the headwaters. The differences in water temperature in the two rivers and change in flow contribution resulted in the lower water temperatures of 22.7 and 15.9° C on 18 and 24 August, respectively, as measured at Ellisforde (RKm 102.5) 16.8 RKm downstream of the confluence.

Hansen (1993) also linked water flows and water temperatures at the mouth of the Similkameen River. Between 1-14 July when air temperatures would have been much higher, he found that the Similkameen River flowed cooler and apparently lowered the temperature of the Okanogan River at the confluence by as much as 2.9° C.

Task 5.2. Determine dates and diel timing.

Twenty-four radio-tagged sockeye salmon were recorded as they migrated past fixed-site Monitor 9 at Monse (Table 7). The first record was on 9 August at 1854 h, and the last record was on 28 August at 1823 h. Only three tagged fish, each on separate days, passed between 9 and 22 August. Ten fish (42%) passed on 23 August. The remaining 11 tagged fish entered the Okanogan River between 24 and 28 August.

Most movement was during the early morning hours (Fig. 13). Eleven (46%) of the 24 fish passed between 0400 and 0830 h. Six fish (25%) passed between 1600 and 2230 h.

Table 7.--Dates and diel timing of radio-tagged sockeye salmon entering the Okanogan River.

Entry date	Number of fish	Tag	Time recorded at Monitor 9
09 Aug	1	2541	1854
10 Aug	1	2444	1611
22 Aug	1	2546	1717
23 Aug	10	2349	0148
23 Aug		2229	0409
23 Aug		2237	0419
23 Aug		2250	0450
23 Aug		2342	0453
23 Aug		2335	0506
23 Aug		2346	0543
23 Aug		2143	0546
23 Aug		2243	0651
23 Aug		2439	0821
24 Aug	3	2536	0649
24 Aug		2145	1014
24 Aug		2442	2359
25 Aug	3	2430	0645
25 Aug		2138	1136
25 Aug		2339	2103
28 Aug	5	2429	1801
28 Aug		2531	1806
28 Aug		2437	1820
28 Aug		2534	1820
28 Aug		2435	1823
	24		

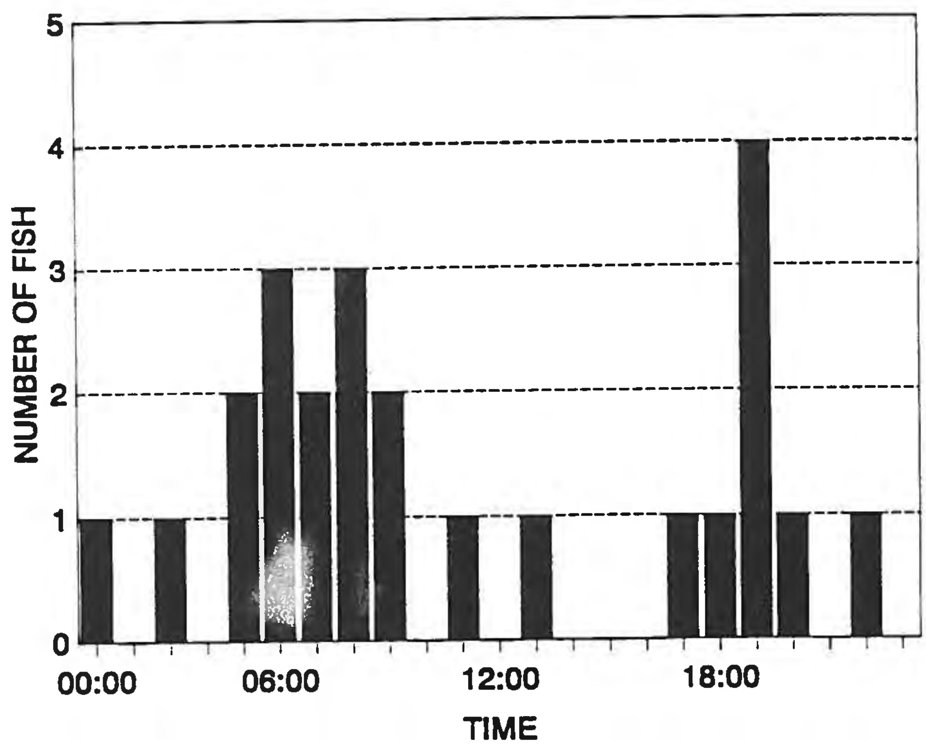

Figure 13.--Diel timing of radio-tagged sockeye salmon entering the Okanogan River.

Task 5.3. Determine behavioral patterns of fish that approach Chief Joseph Dam before entering the Okanogan River.

Three of the 14 radio-tagged fish detected near Chief Joseph Dam were monitored at the mouth of the Okanogan River by mobile tracking. Two of the three were recorded again on Monitor 9 (RKm 3.7), but only one was tracked further to RKm 69 in the Okanogan River. The tag was never recovered. The third fish was detected by mobile tracking at the mouth of the Methow River but was never seen again.

Three other fish were subsequently recovered on the spawning grounds. Two of those fish had been detected earlier by mobile tracking and remained around the mouth of the Okanogan River until the upstream migration began.

Task 6. Determine overall timing and rate of migration of sockeye salmon from Wells Dam forebay to Zosel Dam.

Twenty-six radio-tagged fish recorded as exiting a Wells Dam fish ladder were later detected at Zosel Dam. These fish took from 18.4 days to 83 days with a median of 36.4 days to migrate over the 150.6 km at a rate of 4.2 km per day (Fig. 14).

TASK 7. Determine rate of movement of sockeye salmon in the Okanogan River between river entry and Zosel Dam.

Sixteen fish entered the Okanogan River over a 4-day period (22-25 August) and arrived at Zosel Dam between 26 August and 4 October. These fish migrated upstream at a median rate of about 25 km per day, with a range of 1.7 to 41.8 days (median of

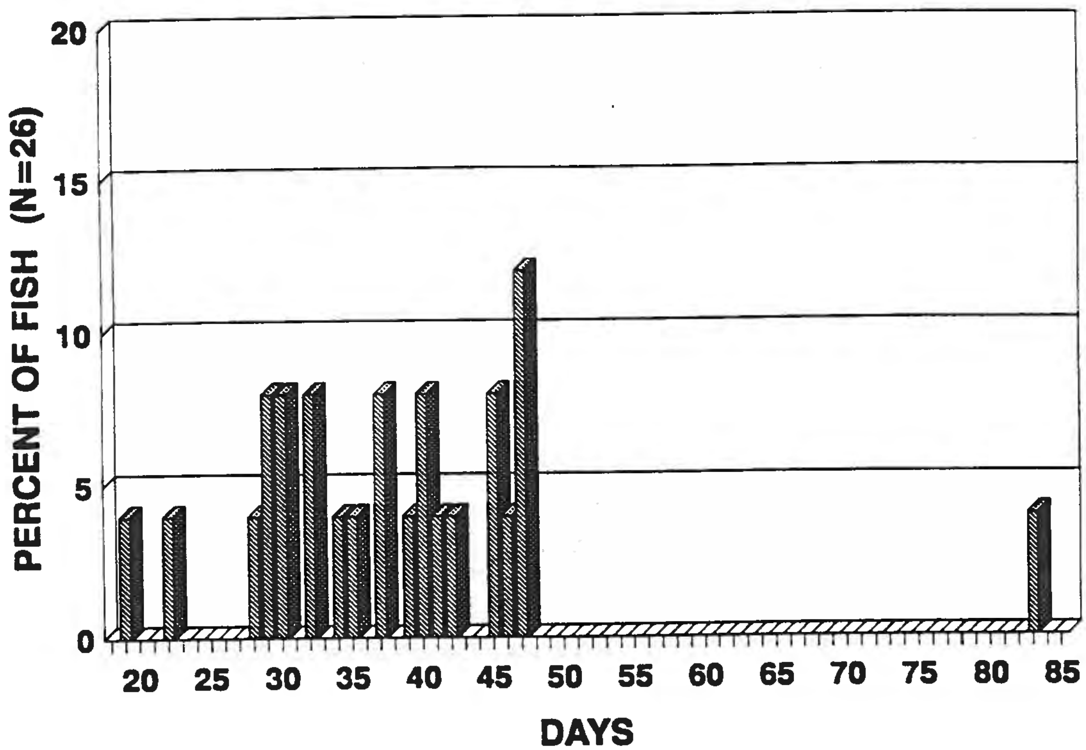

Figure 14.--Travel times of radio-tagged sockeye salmon from Wells Dam forebay to Zosel Dam.

4.6 days) to cover the 117 km distance from Monse (Monitor 9) to Zosel Dam (Fig. 15).

Task 8. Determine delay and passage time of sockeye salmon at Zosel Dam.

Twenty-nine radio-tagged sockeye salmon were detected when passing upstream from Zosel Dam. After arriving at Zosel Dam, overall time to pass ranged from 1 hour to a maximum of 240 hours with a median of 3 hours (Fig. 16). However, nine of these fish may have passed Zosel Dam by swimming under the spill gates or passing through one of the ladders without registering on either the fish-ladder entrance or exit monitors. Four fish had recorded exit times but no entrance times. Passage times for the remaining five fish ranged from 1 hour to a maximum of 111 hours with a median of 3 hours.

Twenty fish entered one of the two fish ladders (Monitors 10 and 11). These fish remained below the dam from less than 1 hour to a maximum of 235 hours with a median of 1 hour before entering a fish ladder (Fig. 17). Passage times were different between the two fish ladders. Of the 17 fish with known entrance and exit records, the nine left-bank fish ladder entries took from 2 to 28 minutes before exiting (median = 14 minutes). The remaining eight fish that entered the right-bank fish ladder took from 5 to 50 minutes (median = 18.5 minutes) before exiting (Fig. 18).

Of the 21 radio-tagged sockeye salmon with known exit records, 11 (52%) exited between 0100 and 0700 h, 2 (10%) exited between 0701 and 1400 h, and 8 (38%) exited between 1401 and 0100 h (Fig. 19).

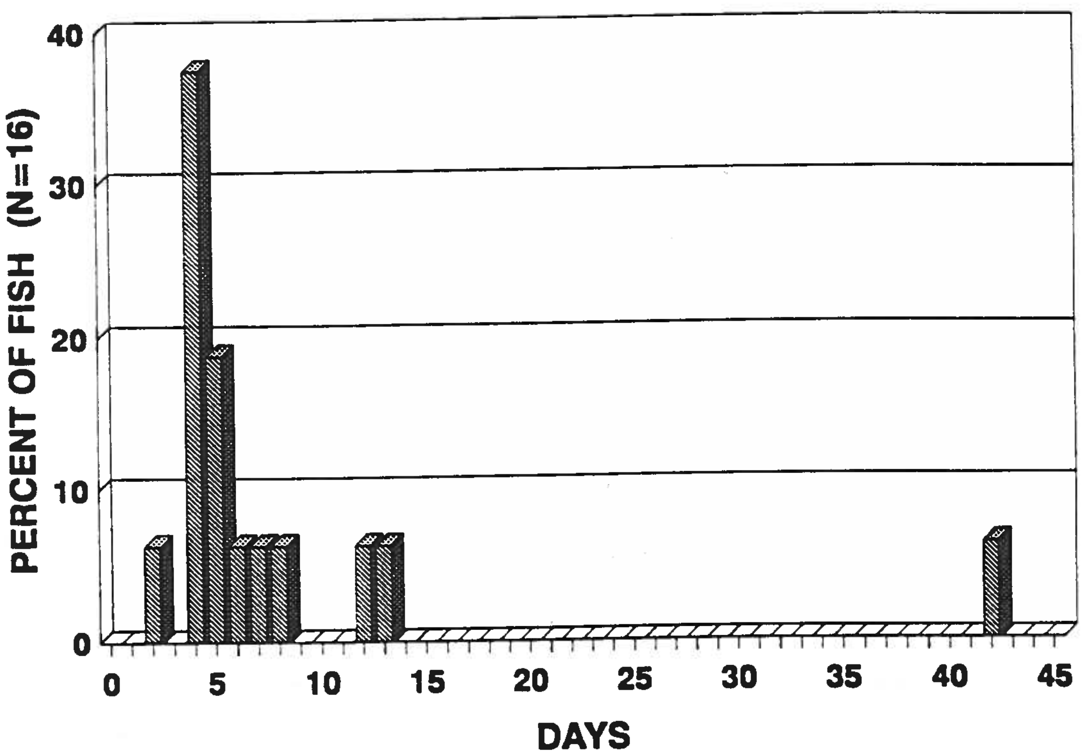

Figure 15.--Travel times of radio-tagged sockeye salmon from Okanogan River entry to Zosel Dam.

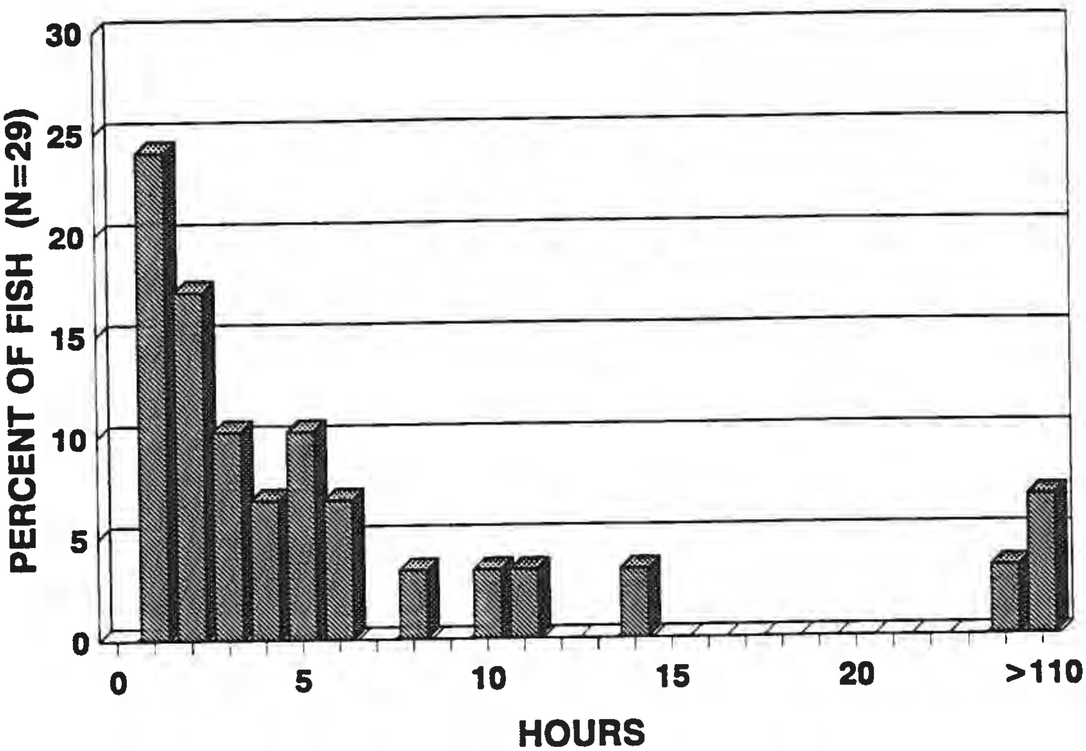

Figure 16.--Overall passage times of radio-tagged sockeye salmon at Zosel Dam.

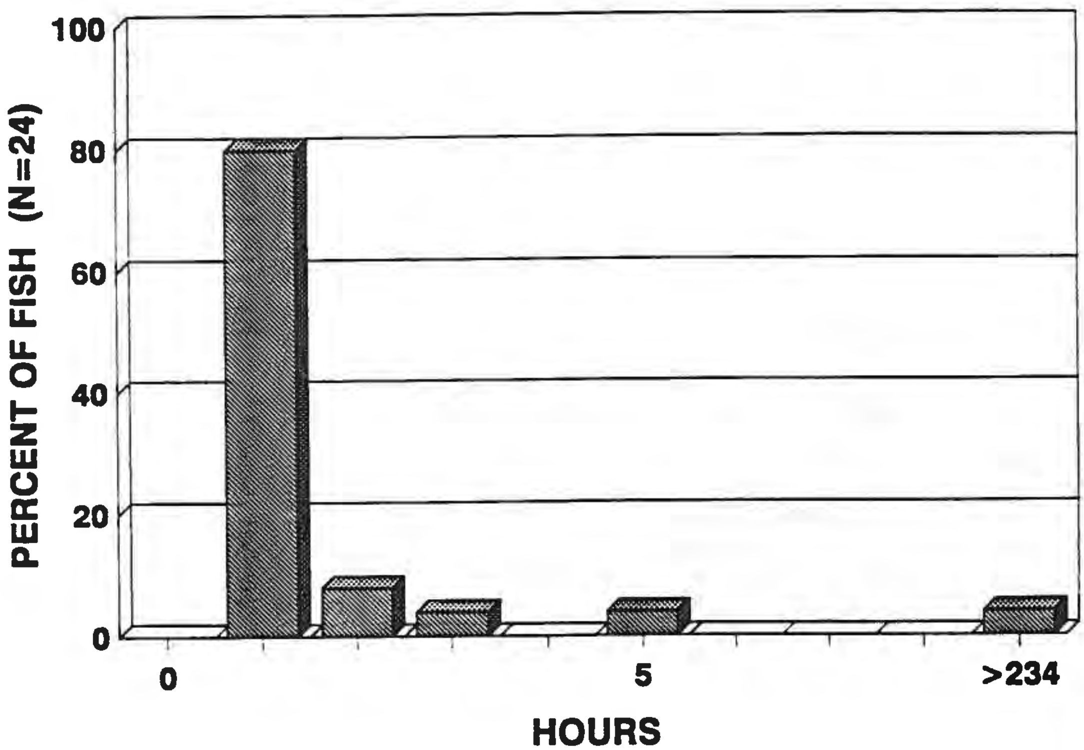

Figure 17.--Elapsed times of radio-tagged sockeye salmon in the tailrace before ladder entry at Zosel Dam.

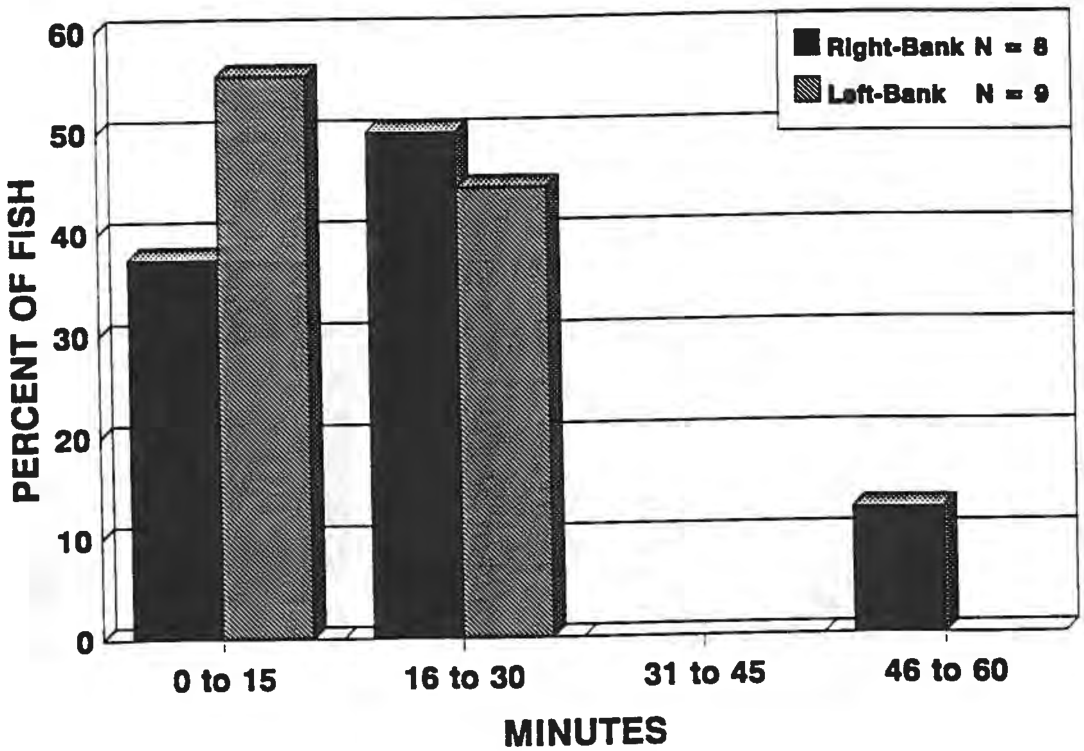

Figure 18.--Ladder-passage times of radio-tagged sockeye salmon at Zosel Dam.

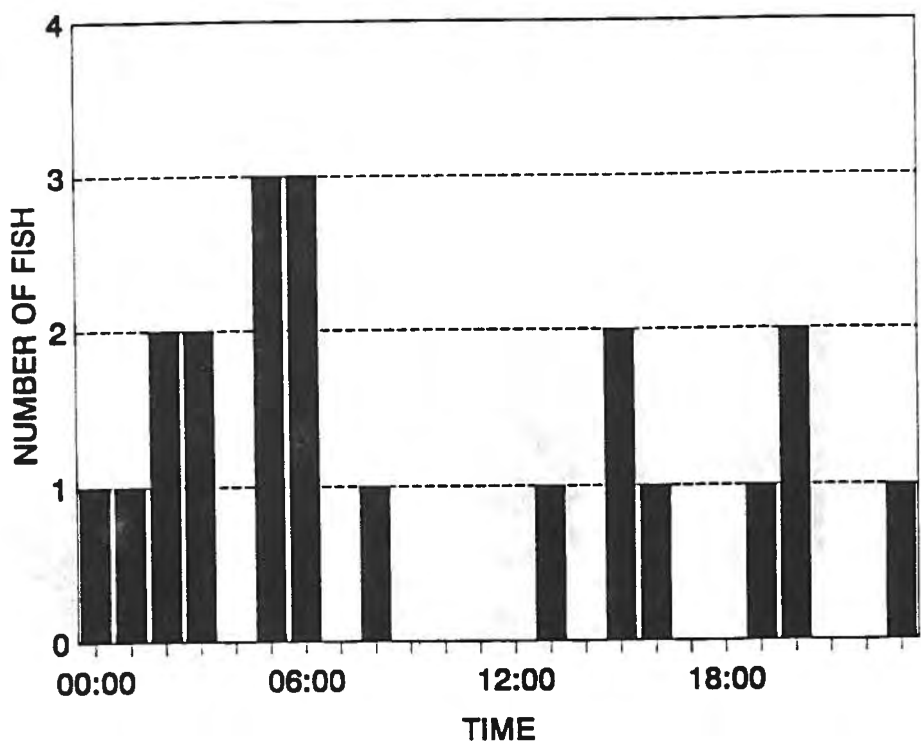

Figure 19.--Exit time from fish ladders of radio-tagged sockeye salmon passing Zosel Dam.

Task 9. Determine residence time of sockeye salmon in Osoyoos Lake before entering the spawning area.

Residence time for 22 tagged fish ranged from 16 hours to 46 days with a median of 28 days (Fig. 20). No fish were detected while they were in the lake, possibly as a result of holding in deeper waters.

Task 10. Determine river flow and temperature during the period sockeye salmon leave Osoyoos Lake for the spawning area.

Beginning in early September, marked increases in Okanogan River flow and decreases in water temperature were noted. On 5 September, water temperature dropped sharply from a long sustained level of 21.1° C to 18.3° C, remained there for about 1 week, and then gradually decreased over the next month.

Coincident with the changes in river flow and water temperature, the first of 24 radio-tagged sockeye salmon left Osoyoos Lake on 5 September and migrated upstream past Monitor 13 to the spawning area (Fig. 21 and Table 8). The last radio-tagged fish was detected at Monitor 13 on 17 October when the average daily water temperature was 12.7° C. Hansen (1993) also observed similar relationships among water temperature, river flow, and spawning activity. He noted slightly warmer temperatures in water when it passed from Vaseau Lake through Mcintyre Dam and that the water cooled as it proceeded south to Lake Osoyoos. However, when the weather cooled (or possibly when flows increased from releases) the water actually warmed by the time it reached the mouth at Lake Osoyoos. Hansen concluded that water temperature appeared to influence sockeye salmon movement and spawning activity.

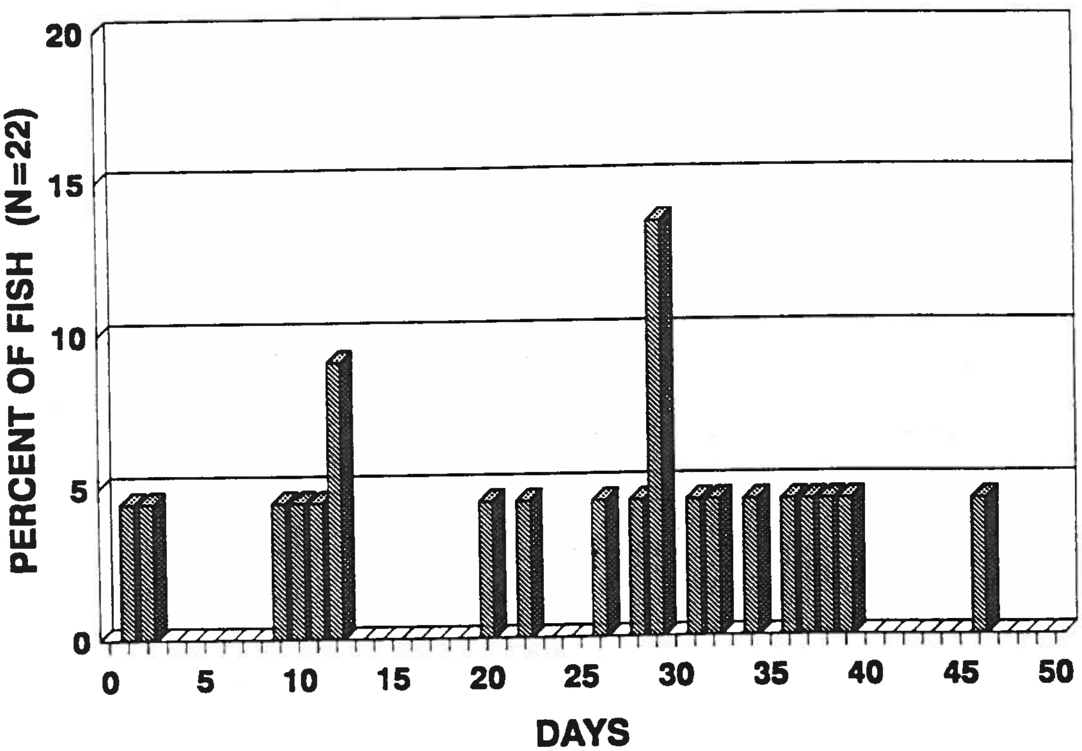

Figure 20.--Residence time for radio-tagged sockeye salmon in Osoyoos Lake before exiting to the spawning grounds.

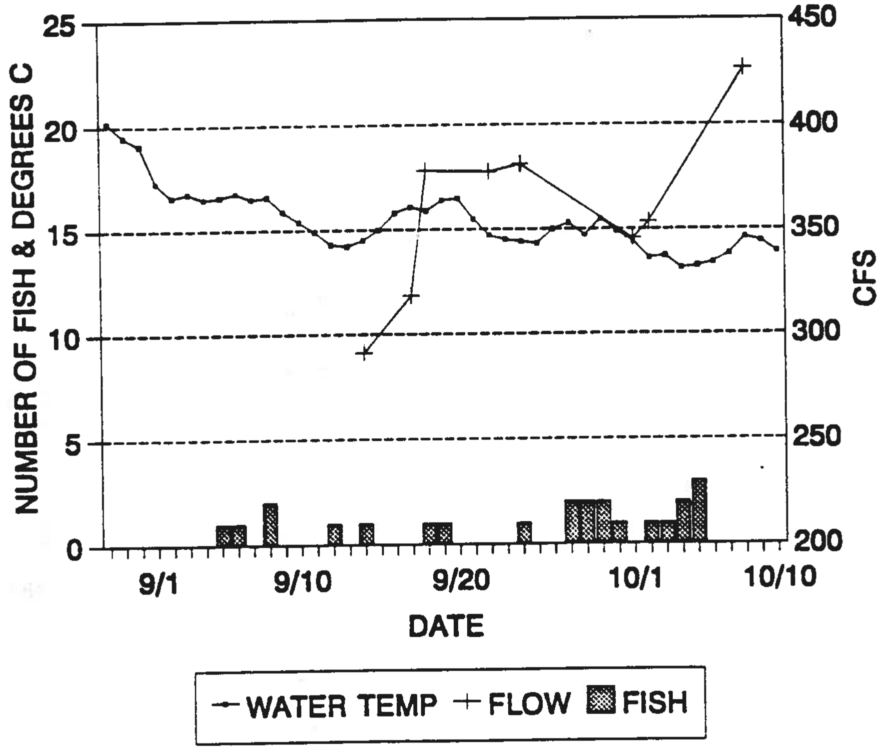

Figure 21.--Flow and water temperature during exit from Osoyoos Lake by radio-tagged sockeye salmon.

Table 8.--River flow and water temperature associated with radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning area.

Date	Number of fish	Water temperature (°C)	River flow (cfs)
29 Aug		20.2	
30 Aug		19.5	
31 Aug		19.1	
01 Sep		17.3	
02 Sep		16.6	
03 Sep		16.6	
04 Sep		15.7	
05 Sep	1	16.6	
06 Sep	1	16.8	
07 Sep		16.5	
08 Sep	2	16.6	
09 Sep		15.9	
10 Sep		15.4	
11 Sep		14.9	
12 Sep	1	14.3	
13 Sep		14.2	
14 Sep	1	14.5	291.1
15 Sep		15.0	
16 Sep		15.8	
17 Sep		16.1	318.3
18 Sep	1	15.9	378.2
19 Sep	1	16.4	
20 Sep		16.5	
21 Sep		15.5	
22 Sep		14.7	377.7
23 Sep		14.5	
24 Sep	1	14.4	381.2
25 Sep		14.3	
26 Sep		15.0	
27 Sep	2	15.3	
28 Sep	2	14.7	
29 Sep	2	15.5	
30 Sep	1	14.9	
01 Oct		14.4	345.4
02 Oct	1	13.6	353.6
03 Oct	1	13.7	
04 Oct	2	13.1	
05 Oct	3	13.2	
06 Oct		13.4	
07 Oct		13.8	
08 Oct		14.6	426.7
09 Oct		14.4	
10 Oct		13.9	
11 Oct		13.2	
12 Oct		12.9	
13 Oct		12.7	
14 Oct		13.0	
15 Oct		13.3	
16 Oct		13.3	
17 Oct	1	12.7	
	24		

Seventy-one percent of the fish migrated from the lake between 2000 and 0200 h (Fig. 22 and Table 9). The inlet to the lake flows over a wide shallow delta which may influence preference of the fish for nocturnal passage.

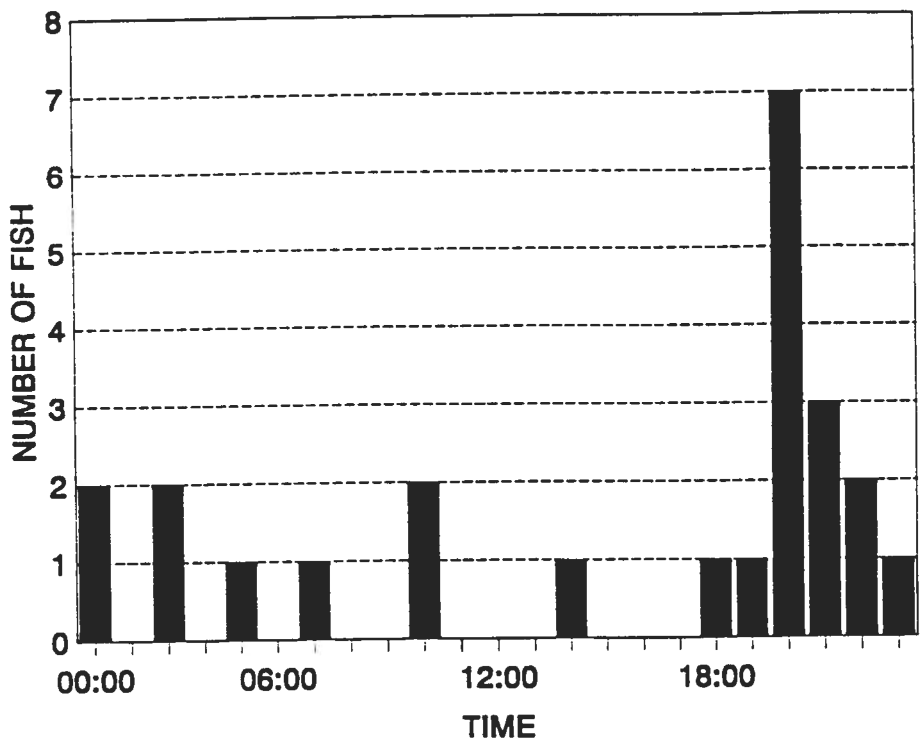

Figure 22.--Diel timing for radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning grounds.

Table 9.--Dates and diel timing of radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning area.

Exit date	Number of fish	Tag	Time recorded at Monitor 13
05 Sep	1	2250	0513
06 Sep	1	2342	2222
08 Sep	2	2336	2008
08 Sep		2430	2133
12 Sep	1	2535	2357
14 Sep	1	2344	1018
18 Sep	1	2348	1128
19 Sep	1	2148	0053
24 Sep	1	2143	0151
27 Sep	2	2439	2003
27 Sep		2442	2150
28 Sep	2	2544	1944
28 Sep		2542	1959
29 Sep	2	2335	0702
29 Sep		2339	2007
30 Sep	1	2337	2156
02 Oct	1	2349	2028
03 Oct	1	2145	2020
04 Oct	2	2243	0430
04 Oct		2546	2125
05 Oct	3	2536	0400
05 Oct		2350	1802
05 Oct		2346	2255
17 Oct	1	2445	2359
	24		

SUMMARY

Radio-tagged sockeye salmon migrated upstream from Rocky Reach Dam to Wells Dam (67.4 km) in about 37 hours. Upon arriving at Wells Dam, median passage time was about 30 hours.

Summaries by task were:

Task 1.1. The median time between at-dam arrival (entering dam tailrace) and initial record at a fish-ladder entrance at Wells Dam was 2 hours. However, the median time from first record at the dam (by either Monitor 1 or one of the four fish-ladder entrance monitors) until last record at a fish-ladder entrance was 1 day.

Task 1.2. The median fish-ladder entrance to exit time for both fish ladders combined was 5 hours. Median passage time through the right-bank fish ladder was 4 hours. Median passage time in the left-bank fish ladder was 6 hours.

Fifty-six percent of the fish exited between 1100 and 1700 h, 24% exited between 0000 and 1030 h, and 20% exited between 1700 and 2329 h.

Task 2.1. The left-bank fish ladder had a higher entrance activity and a much higher entrance efficiency than the right-bank fish ladder. Operation of the adult trapping facility significantly increased left-bank entrance activity. During trapping periods, 63.9% of entrance activity was at the left-bank fish ladder. For the total run, radio-tagged fish activity at the left-bank entrance area was 61.6%.

Task 2.2. Fish preferred the left-bank fish ladder at Wells Dam. The end entrances provided better passage than the side entrances in both the right- and left-bank fish ladders.

Task 3. Fallback of adult sockeye salmon occurred during periods of spill at Wells Dam. Fallback and its relationship to varying spill conditions at Wells Dam may be related to operational scenarios as well as to spill volumes.

Task 4. Fifteen percent of the radio-tagged fish were potentially exposed to the fishery at Chief Joseph Dam tailrace.

Task 5.1. The major migration of sockeye salmon into the Okanogan River coincided with a marked reduction in river flow (from about 950 to 510 cfs) beginning about 19 August and a decrease in water temperature (20.3 to 15.9°C) beginning on 22-24 August.

Task 5.2. Radio-tagged sockeye salmon entered the Okanogan River from 9 to 28 August, with approximately 80% of the migration occurring between 23 and 28 August. Forty-six percent entered the Okanogan River between 0400 and 0830 h, and 25% between 1600 and 2230 h. Most movement, therefore, was during the early morning hours.

Task 5.3. About half of the radio-tagged sockeye salmon that approached Chief Joseph Dam were subsequently recorded at or slightly upstream from the mouth of the Okanogan River or on the spawning grounds in Canada.

Task 6. Radio-tagged sockeye salmon that exited Wells Dam fish ladders between 13 July and 8 August arrived at Zosel Dam between 21 August and 4 October. Median migration time from Wells Dam to Zosel Dam was 36.4 days at a rate of 4.2 km per day.

Task 7. Radio-tagged sockeye salmon required a median of 4.6 days to travel the 117 km distance between Okanogan River entry and Zosel Dam.

Task 8. After arriving at Zosel Dam, the overall median passage time past the dam was 3 hours. Median time before fish-ladder entry was less than 1 hour. About 52% of the fish exited between 0100 and 0700 h, and 38% exited between 1401 and 0100 h. Passage time differed between the two fish ladders. Median passage time for radio-tagged-fish entering the left-bank fish ladder was 14 minutes, while median passage time for the right-bank fish ladder was 18.5 minutes.

Some fish apparently passed Zosel Dam by swimming under the spill gates or managed to pass through one of the fish ladders without being recorded on either the entrance or exit monitors.

Task 9. Residence time for radio-tagged sockeye salmon in Osoyoos Lake before entering the spawning grounds ranged from 16 hours to 46 days with a median of 28 days.

Task 10. A marked change in daily Okanogan River flow and temperature was noted during the period sockeye salmon began to leave Osoyoos Lake for the spawning area. Flow increased about 40 cfs, and water temperature decreased from a long sustained level of near 21.1° C to about 18.3° C, remained there for about 1 week, and then gradually decreased to 10° C over the next month. The last radio-tagged fish was detected at Monitor 13 on 17 October when the average daily water temperature was 12.7° C. Seventy-one percent of the radio-tagged sockeye salmon passed from the lake between 2000 and 0200 h.

RECOMMENDATIONS

1. We recommend, in the event of water shortage or restrictions in normal fish-ladder operations at Wells Dam, that the end entrances be selected for use over the side entrances; in more severe circumstances, we recommend that the left-bank fish ladder be operated in lieu of the right-bank fish ladder.

2. Fallback appears to directly contribute to inflated passage counts at Wells Dam. A correction factor of 0.853 should be applied to total numbers of sockeye salmon counted over Wells Dam in 1992 for a more accurate escapement estimate. Further radio-tracking studies focusing on fallback and its effects during varying spill conditions at all mid-Columbia River dams should be conducted.

3. We determined that 15% of the radio-tagged sockeye salmon were exposed to the "snag" fishery in the Chief Joseph Dam tailrace. Accurate harvest records for that fishery should be implemented.

4. Results from radio-tagged sockeye salmon indicated that delay was minimal at Zosel Dam and that most fish passed during night-time periods when their movement could not be observed. No structural changes to fish-passage facilities at Zosel Dam appear to be warranted. However, a concerted effort to determine extent of spawning, carcass counts, and harvest should be conducted for the area downstream of Zosel Dam and in the Similkameen River to account for missing fish and determine extent of spawning.

5. Increased flow, decreasing water temperature, and darkness coincided with the period most radio-tagged sockeye salmon left Osoyoos Lake for the spawning area. Manipulation of flow and water together by water management agencies may enhance sockeye salmon spawning and prevent de-watering of redds.

6. A thermal block generally occurs each summer at the mouth of the Okanogan River delaying the sockeye salmon migration until water temperature decreases to less than 21.1°C. Proportionate flows from the Similkameen River (cooler) and surface water passing over Zosel Dam from Lake Osoyoos (warmer) appear to directly affect water temperatures in the lower Okanogan River. Water regulation operations and their effect on water temperatures and flows in the Okanogan River system should be reviewed.

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We thank the residents of Oliver, British Columbia, for river flow and temperature information and for allowing access to the spawning ground area.

We thank the many other people whose assistance contributed greatly to the successful completion of this study: Jim Habermehl, U.S. Army Corps of Engineers, for providing a monitor site at Chief Joseph Dam; Dan Gebbers, Gebbers Farms, Inc., for allowing use of his pump-house near Monse, Washington as a monitor site; Jon Hansen, Rod Stensgar, and Kay Marcellay of the Colville Confederated Tribes Fish and Wildlife Department for providing temperature and flow data and for assisting in radio-tracking and tag recovery efforts; Jeffrey K. Fryer of the Columbia River Inter-Tribal Fish Commission for ageing scales from radio-tagged fish; Dennis Burton and Tom Scott of the Oroville-Tonasket Irrigation District for their help with monitor installations and information on river conditions and sockeye salmon migration behavior at Zosel Dam; Suzanne Kelly and Chad Hilmes of Kennewick Aircraft Services for their extra efforts arranging aerial tracking flights into Canada; fisheries technicians Thomas Morrison and Paul Wahpat, of the Yakima Indian Nation, for their assistance in training personnel in radio-tagging procedures; and members of the Osoyoos Indian Tribe for their efforts in recovering radio-tags on the spawning grounds near Oliver, British Columbia.

Last, but of equal importance, we acknowledge the help of the following NMFS seasonal staff members: Cleo Moser, retired WDF Hatchery Manager, for the benefit of his experience and knowledge of fish trapping and handling procedures, and Jeff Moser and Shane Bickford, for their field services during this study. Paul

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REFERENCES

Fryer, J. K., and M. Schwartzberg. 1991. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1990. Columbia River Inter-Tribal Fish Commission Tech. Rep. 91-2, 40 p. (Available from Columbia River Inter-Tribal Fish Commission, 975 S. E. Sandy, Suite #202, Portland, OR, 97214).

Hansen, J. 1993. Upper Okanogan River sockeye salmon spawning ground survey - 1992. Colville Confederated Tribes, Fish and Wildlife Department, Nespelem, Washington. Report for the Douglas County Public Utility District, 79 p. (Available from Colville Confederated Tribes, Fish and Wildlife Dept., Box 150, Nespelem, WA 99155).

Liscom, K. L., G. E. Monan, L. C. Stuehrenberg, and P. J. Wilder. 1985. Radio-tracking studies on adult chinook salmon and steelhead trout at lower Columbia River hydroelectric dams, 1971-77. NOAA Tech. Memo. NMFS F/NWC-81, 225 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097.)

Major, R. L., and J. L. Mighell. 1966. Influence of Rocky Reach Dam and the temperature of the Okanogan River on the upstream migration of sockeye salmon. Fish. Bull. 66(1): 131-147.

Pratt, K. L., D. W. Chapman, and M. Hill. 1991. Potential to enhance sockeye salmon upstream from Wells Dam. Report to Douglas County Public Utility District, 87 p. (Available from Don Chapman Consultants, 3180 Airport Way, Boise, ID 83705.)

U. S. Army Corps of Engineers. 1992. Monthly fish passage summary reports. (Available from U.S. Army Corps of Engineers, Portland District, Portland, OR 97014.)

APPENDIX

Appendix Table 1.--Characteristics and fate of radio-tagged sockeye salmon.

Tag	Length (cm)	Weight (g)	Age	Last record River	RKm	Fate
2128	52.1	1362.0	1.2	Columbia	832.4	Recorded
2130	48.5	998.8	1.2	Okanogan	3.2	Recorded
2131	55.5	1589.0	1.3	Columbia	763.1	Recorded
2134	50.8	1135.0	1.2	Okanogan	165.0	Recovered
2135	54.0	1362.0	1.2	Okanogan	0.0	Recorded
2137	50.8	1135.0	1.2	Okanogan	167.4	Recorded
2138	43.5	635.6	1.2	Okanogan	69.2	Recorded
2139	48.3	908.0	1.2	Columbia	858.1	Recorded
2141	50.8	1180.4	1.2	Columbia	832.4	Recorded
2142	50.5	1135.0	1.2	Columbia	872.6	Harvest
2143	51.9	1362.0	1.2	Okanogan	161.0	Recovered
2144	54.0	1498.2	1.2	Columbia	832.4	Recorded
2145	51.5	1271.2	1.2	Okanogan	164.2	Recovered
2146	46.0	771.8	1.2	Columbia	832.4	Recorded
2147	52.2	1225.8	1.2	Columbia	763.1	Recorded
2148	50.8	1362.0	1.2	Okanogan	161.0	Recovered
2149	54.0	1362.0	1.3	Columbia	872.6	Recorded
2150	53.3	1135.0	1.2	Columbia	832.4	Recorded
2229	49.5	1135.0	1.2	Okanogan	124.6	Recorded
2231	53.8	1180.4	1.2	Okanogan	4.8	Recorded
2234	52.2	1316.6	1.2	Okanogan	0.0	Recorded
2235	54.6	1816.0	1.2	Columbia	832.4	Recorded
2236	48.0	998.8	1.2	Okanogan	124.6	Recorded
2237	50.0	998.8	1.2	Okanogan	124.6	Recorded
2238	50.8	1135.0	1.2	Columbia	872.6	Recorded
2240	51.0	862.6	1.2	Methow	51.5	Hatchery
2241	47.2	953.4	1.2	Columbia	832.4	Recorded
2242	50.8	1135.0	1.2	Okanogan	162.6	Recovered
2243	45.7	908.0	1.2	Okanogan	161.0	Recorded
2244	56.2	1725.2	1.3	Columbia	829.2	Recorded
2245	52.0	1271.2	1.2	Okanogan	162.6	Recovered
2246	60.0	1997.6	1.3	Columbia	872.6	Recorded
2247	50.5	1044.2	1.2	Okanogan	159.4	Recovered
2249[1]	51.5	1135.0	1.2	Columbia	832.4	Recorded
2250	51.4	1135.0	1.2	Okanogan	161.0	Recovered
2328	50.5	1135.0	1.2	Okanogan	162.6	Recovered
2329	53.0	1271.2	1.2	Columbia	858.1	Recorded
2330	50.7	1180.4	1.2	Okanogan	165.8	Recovered
2331	48.2	1135.0	1.2	Columbia	832.4	Recorded
2334	60.0	1997.6	1.3	Columbia	829.2	Recorded
2335	52.3	1362.0	1.2	Okanogan	162.6	Recovered
2336	58.0	1725.2	1.3	Okanogan	165.8	Recorded
2337	49.2	953.4	1.2	Okanogan	146.2	Recorded

Appendix Table 1.--continued.

Tag	Length (cm)	Weight (g)	Age	Last record River	RKm	Fate
2338	50.5	1089.6	1.2	Okanogan	124.6	Recovered
2339	50.5	1044.2	1.2	Okanogan	163.4	Recovered
2340	50.5	1089.6	1.2	Okanogan	124.6	Recorded
2341	52.1	1362.0	1.2	Okanogan	2.4	Recorded
2342	53.0	1225.8	1.2	Okanogan	165.8	Recorded
2343	47.0	908.0	1.2	Okanogan	0.0	Recorded
2344	51.4	1225.8	1.2	Okanogan	146.2	Recorded
2345	52.4	1271.2	1.2	Okanogan	0.0	Recorded
2346	48.3	908.0	1.2	Okanogan	163.9	Recovered
2348	53.3	1589.0	1.2	Okanogan	162.6	Recovered
2349	48.3	998.8	1.2	Okanogan	164.2	Recorded
2350	53.0	1452.8	1.2	Okanogan	162.6	Recorded
2423[1]	54.1	1543.6	1.2	Columbia	829.2	Recorded
2429	49.7	1044.2	1.2	Okanogan	9.7	Recorded
2430	47.1	998.8	1.2	Okanogan	161.0	Recovered
2431	47.5	908.0	1.2	Okanogan	124.6	Recorded
2434	48.2	908.0	2.2	Columbia	875.8	Recorded
2435	49.5	1135.0	1.2	Okanogan	9.7	Recorded
2436	49.0	1044.2	1.2	Okanogan	162.6	Recovered
2437	49.5	1135.0	1.2	Okanogan	162.6	Recovered
2438	49.5	1135.0	1.2	Columbia	832.4	Recorded
2439	52.4	1271.2	1.2	Okanogan	162.6	Recovered
2441	48.3	1135.0	1.2	Columbia	859.7	Recorded
2442	48.9	998.8	1.2	Okanogan	167.4	Recovered
2443	48.0	998.8	1.2	Okanogan	2.3	Recorded
2444	51.5	1089.6	1.2	Smilkameen	4.8	Recovered
2445	48.7	908.0	1.2	Okanogan	146.2	Recorded
2446	52.0	1271.2	1.2	Okanogan	124.6	Recorded
2447	48.2	1135.0	1.2	Okanogan	162.6	Recovered
2448	45.0	771.8	1.2	Okanogan	124.6	Recorded
2449	42.4	726.4	2.1	Okanogan	3.2	Recorded
2450	49.5	953.4	1.2	Okanogan	3.2	Recorded
2528	50.0	953.4	1.2	Columbia	83.2	Recorded
2529	50.8	908.0	1.2	Okanogan	90.2	Recovered
2530	50.8	1044.2	1.2	Columbia	829.2	Recorded
2531	49.0	998.8	1.2	Okanogan	75.7	Recovered
2534[2]	47.0	908.0	nd	Okanogan	164.2	Recovered
2535	49.3	908.0	1.2	Okanogan	164.2	Recovered
2536	48.5	908.0	1.2	Okanogan	162.6	Recovered
2537	46.0	817.2	1.2	Okanogan	3.2	Recorded
2538	50.8	1362.0	1.2	Columbia	829.2	Recorded
2539	48.2	1135.0	1.2	Columbia	763.1	Recorded
2540	48.8	953.4	1.2	Methow	51.5	Hatchery
2541[3]	52.0	1225.8	1.2	Columbia	763.1	Regurg.
2541	46.8	862.6	2.2	Okanogan	123.3	Recovered
2542	46.4	908.0	1.2	Okanogan	162.6	Recorded

Appendix Table 1.--continued.

Tag	Length (cm)	Weight (g)	Age	Last record River	RKm	Fate
2543	53.4	1225.8	1.2	Columbia	829.2	Recorded
2544	50.2	1135.0	1.2	Okanogan	162.6	Recorded
2545	50.8	1135.0	1.2	Okanogan	124.6	Recorded
2546	52.5	1407.4	1.2	Okanogan	164.2	Recovered
2547	46.4	817.2	1.2	Okanogan	159.4	Recovered
2548	49.0	998.8	1.2	Columbia	872.6	Recorded
2549	51.0	1089.6	1.2	Columbia	872.6	Recorded
2550	52.0	1225.8	1.2	Okanogan	162.6	Recovered

[1] Possible age 2.2 Wenatchee River sockeye salmon.
[2] Age not determined.
[3] Tag regurgitated in holding tank prior to release, therefore reused.

Appendix Table 2.--Histories of individual radio tags, mid-Columbia River radio-telemetry study, 1992.

Tag	Release		Arrive Wells Dam		Exit Wells Dam		Monitor	M 8		M 9	Arrive Zosel Dam		Exit Zosel Dam		Ladder	Arrive M 13		Exit M 13	
	Date	Time	Date	Time	Date	Time		First	Last	Date	Date	Time	Date	Time		Date	Time	Date	Time
2148	09 Jul	1025	10 Jul	0947	14 Jul	1135	7				28 Aug	0043	28 Aug	0611	11	19 Sep	0053	19 Sep	1932
2235	09 Jul	1025	11 Jul	1237															
2343	09 Jul	1025	11 Jul	1146	30 Jul	0056	4												
2438	09 Jul	1025	12 Jul	0416	15 Jul	1632	7												
2128	10 Jul	0850	11 Jul	1537	12 Jul	1451	7												
2137	10 Jul	0850	11 Jul	0712	14 Jul	1443	7				30 Aug	0035	30 Aug	0522	12				
2238	10 Jul	0850	11 Jul	0419	12 Jul	1627	4	27 Aug	27 Aug										
2346	10 Jul	0850	11 Jul	1045	13 Jul	0343	4			23 Aug	04 Oct	0112	04 Oct	1536	10	05 Oct	2254	05 Oct	2340
2441	10 Jul	0850	12 Jul	0454	18 Jul	1406	4												
2534	10 Jul	0850	11 Jul	0653	13 Jul	1552	7			25 Aug									
2139	11 Jul	0755	12 Jul	1914	15 Jul	2022	7												
2242	11 Jul	0755	11 Jul	1531	13 Jul	1714	7												
2348	11 Jul	0755	12 Jul	0805	13 Jul	1115	7				30 Aug	0114	30 Aug	0541	11	18 Sep	1127	18 Sep	2000
2435	11 Jul	0755	14 Jul	0357	18 Jul	1114	7			28 Aug									
2529	11 Jul	0755	12 Jul	0725	13 Jul	1000	7												
2229	13 Jul	1515	15 Jul	0823	16 Jul	1349	7			23 Aug	26 Aug	1508	26 Aug	1649	11				
2341	13 Jul	1515	14 Jul	2238	17 Jul	1252	7												
2437	13 Jul	1515	15 Jul	1653	17 Jul	0431	4			28 Aug									
2545	13 Jul	1515	15 Jul	0229	15 Jul	1641	4				29 Aug	0327	29 Aug	0608	10				
2134	14 Jul	1010	15 Jul	1925	17 Jul	1227	7												
2150	14 Jul	1010	15 Jul	0738	16 Jul	0949	4												
2243	14 Jul	1010	16 Jul	0848	17 Jul	1517	7			23 Aug	26 Aug	1732	26 Aug	1913	11	04 Oct	0429	04 Oct	1024
2331	14 Jul	1010	15 Jul	2126	16 Jul	2129	4												
2447	14 Jul	1010																	
2539	14 Jul	1010																	
2135	15 Jul	1535	17 Jul	1539	18 Jul	1206	7												
2249	15 Jul	1535	04 Aug	1311															
2342	15 Jul	1535	16 Jul	1830	18 Jul	1033	7			23 Aug	26 Aug	1616	26 Aug	2045	11	06 Sep	2222	06 Sep	2234
2443	15 Jul	1535	25 Jul	0519	26 Jul	1624	4												
2444	15 Jul	1535	17 Jul	0236	17 Jul	1441	7			10 Aug									
2528	15 Jul	1535	17 Jul	0700	18 Jul	0404	7												
2146	16 Jul	1335	18 Jul	0722	19 Jul	1109	7												
2240	16 Jul	1335	17 Jul	1824															
2350	16 Jul	1335	17 Jul	1430	19 Jul	1733	7	06 Aug	06 Aug							05 Oct	1801	05 Oct	1824
2431	16 Jul	1335	18 Jul	0430	18 Jul	1608	7												
2537	16 Jul	1335	18 Jul	0415	19 Jul	2326	7												
2130	16 Jul	1545	17 Jul	2338	18 Jul	2309	7												
2234	16 Jul	1545	17 Jul	1639	18 Jul	1307	7												
2328	16 Jul	1545						10 Aug	05 Sep										
2442	16 Jul	1545	18 Jul	0336	18 Jul	1740	7			24 Aug	01 Sep	2246	02 Sep	0039	12	27 Sep	2150	27 Sep	0700
2548	16 Jul	1545	18 Jul	0203	03 Aug	2009	4	05 Aug	11 Aug										
2142	17 Jul	1140	18 Jul	2356	24 Jul	1616	7												
2245	17 Jul	1140	18 Jul	1548	19 Jul	1119	4												
2329	17 Jul	1140																	
2436	17 Jul	1140	19 Jul	0704	21 Jul	1439	4												
2550	17 Jul	1140	18 Jul	1942	19 Jul	1341	7												
2144	17 Jul	1530	19 Jul	0142	19 Jul	1209	7												
2236	17 Jul	1530	19 Jul	0630	19 Jul	2000	4			23 Aug	04 Sep	0210	04 Sep	0518	12				
2339	17 Jul	1530	20 Jul	0415	22 Jul	0220	4			25 Aug	27 Aug	1444	01 Sep	0519	12	29 Sep	2006	29 Sep	2017
2446	17 Jul	1530	18 Jul	1927	19 Jul	1356	7												
2131	20 Jul	1530																	
2247	20 Jul	1530	22 Jul	0228															
2334	20 Jul	1530	22 Jul	0828															
2450	20 Jul	1530	23 Jul	0813	25 Jul	0434	7												

Appendix Table 2.--Continued.

Tag	Release Date	Release Time	Arrive Wells Dam Date	Arrive Wells Dam Time	Exit Wells Dam Date	Exit Wells Dam Time	Monitor	M 8 First	M 8 Last	M 9 Date	Arrive Zosel Dam Date	Arrive Zosel Dam Time	Exit Zosel Dam Date	Exit Zosel Dam Time	Monitor	Arrive M 13 Date	Arrive M 13 Time	Exit M 13 Date	Exit M 13 Time
2540	20 Jul	1530	22 Jul	0203															
2143	21 Jul	1520	22 Jul	2104	25 Jul	1903	7			23 Aug	26 Aug	1742	26 Aug	2019	11	24 Sep	0151	24 Sep	0154
2231	21 Jul	1520	23 Jul	0553	23 Jul	1221	4												
2338	21 Jul	1520	23 Jul	0145	25 Jul	0430	7				23 Aug	1026	10 Sep	1334	12				
2434	21 Jul	1520	23 Jul	1654				29 Jul	04 Aug										
2541	21 Jul	1520	23 Jul	0856	24 Jul	0853	7			09 Aug									
2547	21 Jul	1520	23 Jul	0837	24 Jul	1232	7				28 Aug	0159	28 Aug	0326	11				
2141	22 Jul	1515	23 Jul	2204															
2250	22 Jul	1515	24 Jul	0646	26 Jul	1200	4			23 Aug	04 Sep	0207	04 Sep	1346	10	05 Sep	0513	27 Oct	1945
2344	22 Jul	1515														14 Sep	1018	14 Sep	1018
2429	22 Jul	1515	26 Jul	1051						28 Aug									
2536	22 Jul	1515	25 Jul	0453	29 Jul	1434	4			24 Aug	06 Sep	0334	07 Sep	0239	11	05 Oct	0400	05 Oct	0437
2241	23 Jul	1515	25 Jul	0228	25 Jul	1324	7												
2330	23 Jul	1515	25 Jul	1320	26 Jul	2044	4												
2538	23 Jul	1515	25 Jul	0501	25 Jul	1640	7												
2546	23 Jul	1515	25 Jul	0016						22 Aug	28 Aug	0431	28 Aug	0534	10	04 Oct	2124	04 Oct	2143
2244	24 Jul	1520	26 Jul	0523															
2335	24 Jul	1520	25 Jul	2049						23 Aug	26 Aug	1654	26 Aug	1757	10	29 Sep	0702	29 Sep	1355
2430	24 Jul	1520	26 Jul	0306	27 Jul	1647	4	29 Jul	29 Jul	25 Aug	30 Aug	0506	30 Aug	1337	10	08 Sep	2133	09 Sep	2036
2542	24 Jul	1520	26 Jul	0524	26 Jul	1426	7				31 Aug	2252	31 Aug	2350	10	28 Sep	1958	28 Sep	2119
2544	24 Jul	1520	26 Jul	0434							20 Sep	0052	20 Sep	0534	10	28 Sep	1944	28 Sep	1947
2345	27 Jul	1520	28 Jul	2206	30 Jul	0100	7												
2349	27 Jul	1520	29 Jul	0128	29 Jul	1333	4	01 Aug	01 Aug	23 Aug	27 Aug	1354	27 Aug	1456	11	02 Oct	2028	02 Oct	2036
2439	27 Jul	1520	28 Jul	2202						23 Aug	26 Aug	2346	27 Aug	0037	11	27 Sep	2003	29 Sep	2131
2531	27 Jul	1520	29 Jul	0046	29 Jul	1832	4			25 Aug									
2535	27 Jul	1520	29 Jul	0542	01 Aug	0301	4	15 Aug	15 Aug		02 Sep	0053	02 Sep	0426	12	12 Sep	2357	13 Sep	0206
2336	28 Jul	1520	30 Jul	0300	30 Jul	2329	7				28 Aug	0257	28 Aug	0814	10	08 Sep	2008	08 Sep	2015
2340	28 Jul	1520	30 Jul	0136	30 Jul	1101	7	01 Aug	01 Aug		26 Aug	1625	26 Aug	1733	12				
2543	28 Jul	1520	30 Jul	1742															
2530	28 Jul	1520	31 Jul	1625															
2138	31 Jul	1530	03 Aug	0434	17 Aug	1420	4			25 Aug									
2145	31 Jul	1230	02 Aug	0246	02 Aug	1424	4			24 Aug	29 Aug	0217	29 Aug	0424	11	03 Oct	2019	03 Oct	2030
2147	31 Jul	1230																	
2149	31 Jul	1530	02 Aug	1759	05 Aug	0309	7	06 Aug	19 Aug										
2337	31 Jul	1230	01 Aug	2131	02 Aug	1846	7				21 Aug	0338	31 Aug	0318	10	30 Sep	2155	04 Oct	1926
2423	31 Jul	1230	08 Aug	0906															
2445	31 Jul	1530	02 Aug	0639	03 Aug	1521	7				02 Sep	0050	02 Sep	0158	12	17 Oct	2358	18 Oct	0011
2448	31 Jul	1530	02 Aug	1118															
2449	31 Jul	1230	02 Aug	1729	06 Aug	0100	7												
2237	04 Aug	1415	06 Aug	0653	08 Aug	0708	4	18 Aug	18 Aug		30 Aug	0318	30 Aug	1344	11				
2246	04 Aug	1415	05 Aug	1734	09 Aug	0729	4	10 Aug	05 Sep										
2549	04 Aug	1415	06 Aug	0328	08 Aug	1221	7	11 Aug	12 Aug										

Monitor Numbers: (M = monitor, see Figure 1.)
Monitor 4 Right-bank fish ladder at Wells Dam
Monitor 7 Left-bank fish ladder at Wells Dam
Monitor 8 Colville Tribal Fish Hatchery
Monitor 9 Monse pumping station (Okanogan River entry)
Monitor 10 Right-bank fish ladder at Zosel Dam
Monitor 11 Left-bank fish ladder at Zosel Dam
Monitor 12 Air antenna at Zosel Dam
Monitor 13 Okanogan River above Lake Osoyoos

MIGRATIONAL CHARACTERISTICS OF ADULT SPRING, SUMMER, AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER
FINAL REPORT BY
L. C. STUEHRENBERG, et. al.

APPENDIX - H

Migrational Characteristics of Adult Spring, Summer, and Fall Chinook Salmon Passing through Reservoirs and Dams of the Mid-Columbia River

Final Report

by
Lowell C. Stuehrenberg, George A. Swan,
Leslie K. Timme, Paul A. Ocker,
M. Brad Eppard, Robert N. Iwamoto,
Byron L. Iverson, and Benjamin P. Sandford

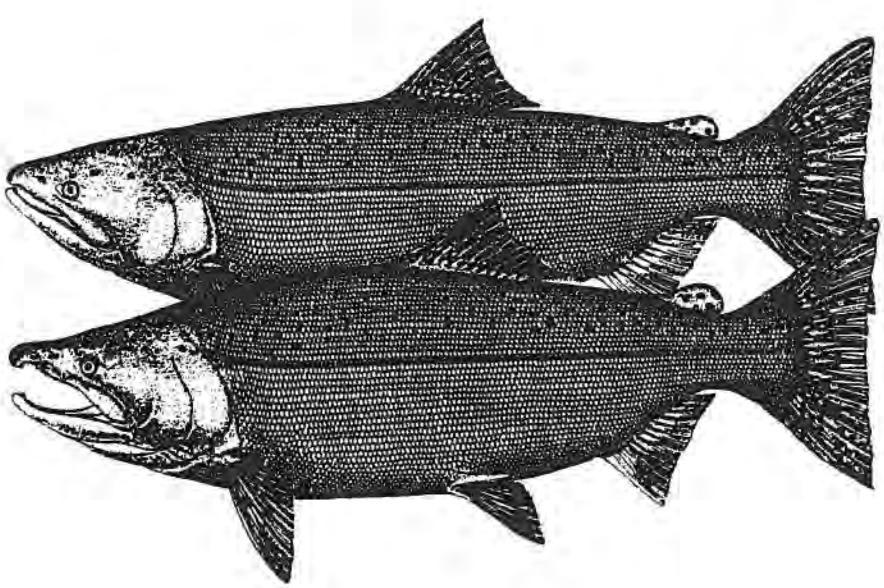
Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

March 1995



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2725 Montlake Boulevard East
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March 1995

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Contents--continued.

INTRODUCTION

No detailed radio-telemetry research to evaluate adult salmonid passage was conducted after the construction of the Public Utility District (PUD) dams on the mid-Columbia River. Consequently, adult fishways at the dams were operated using criteria based on research conducted at lower Columbia River and Snake River dams. However, discrepancies between expected fish counts at upstream dams compared to counts at downstream dams indicated that passage problems might exist at the mid-Columbia River dams.

In 1993, the National Marine Fisheries Service (NMFS), funded by Chelan County, Douglas County, and Grant County PUDs and the NMFS conducted radio-telemetry research to document adult fish passage and passage problems. Studies were designed to determine migration rates, passage success, dam-passage behavior, and final destinations of adult spring, summer, and fall chinook salmon *(Oncorhynchus tshawytscha)* in the main stem and tributaries of the mid-Columbia River (Fig. 1).

The University of Idaho conducted a separate but concurrent study to radio-track spring and summer chinook salmon in the Snake River; NMFS shared data and tagging efforts with them.

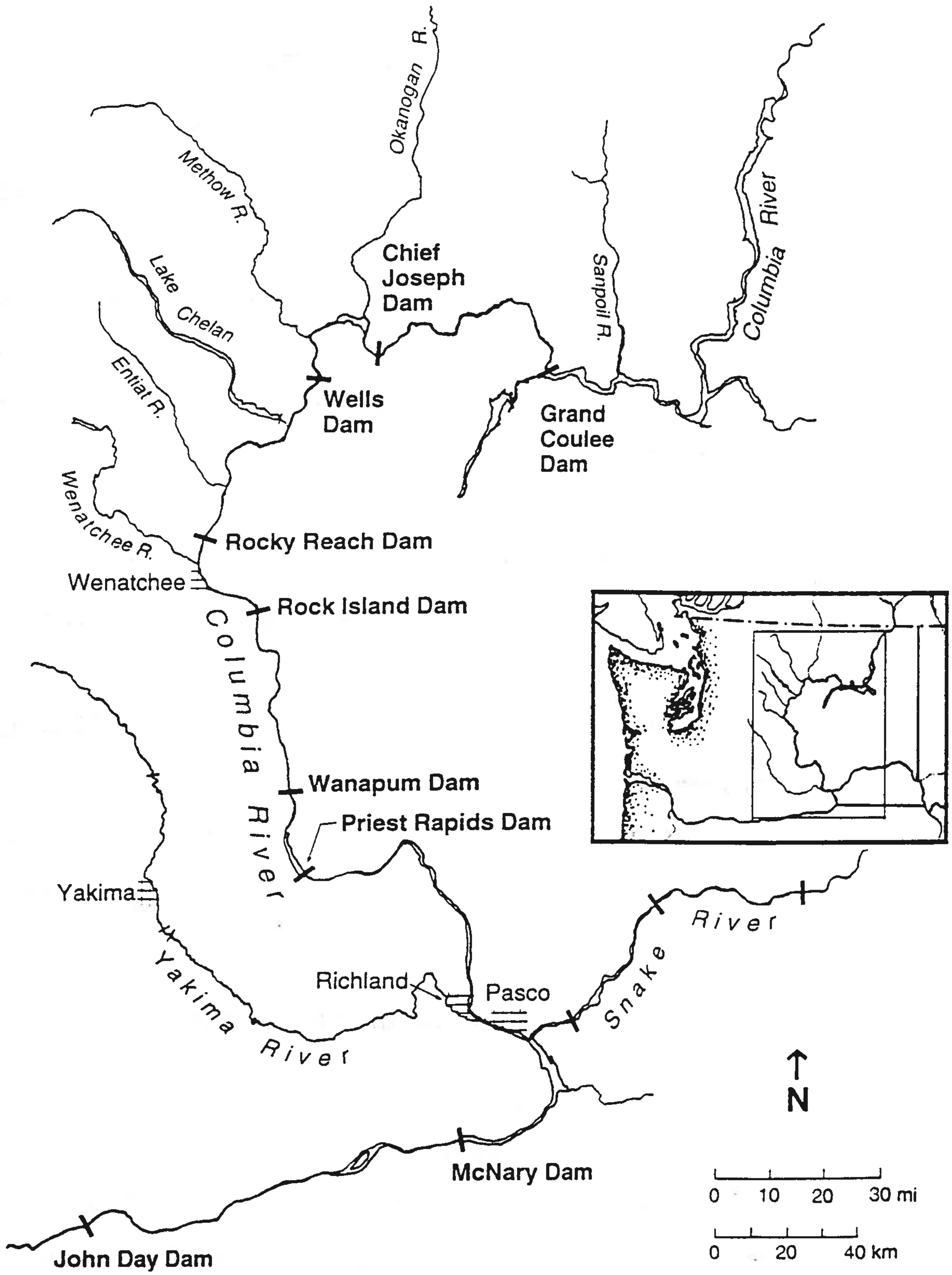


Figure 1.--Study area for the 1993 mid-Columbia River radio-telemetry study.

OBJECTIVES

The study had five objectives, as follow:

Objective 1: Determine the date and time of arrival for radio-tagged fish at tailraces, fishway openings (collection channels and fish ladders), intermediate points in the fishway, and fishway exits at Priest Rapids (River Kilometer [RKm] 638.9, River Mile [RM] 397.1); Wanapum (RKm 669.0, RM 415.8); Rock Island (RKm 729.5, RM 453.4); Rocky Reach (RKm 762.2, RM 473.7); and Wells Dams (RKm 829.6, RM 515.6).

Objective 2: Determine fate of radio-tagged fish.

Objective 3: Determine the proportion of fish using each fishway opening at each dam.

Objective 4: Determine the efficiency of fishway openings.

Objective 5: Determine incidence of fallbacks (fish detected downstream from a dam after having been detected exiting one of the fish ladders at the same dam) at each dam.

MATERIALS AND METHODS

Field work began in February with setup of trapping and tagging facilities at John Day Dam (RKm 346.9, RM 215.6) and ended in late November with adult spawning. The terms "spring," "summer," and "fall," as applied to runs of chinook salmon in this study, are based on established dates for fish counting at Columbia River Basin dams (U.S. Army Corps of Engineers 1993).

Study Area

The study area included the Columbia River from McNary Dam (RKm 469.8, RM 292.0) to Chief Joseph Dam (RKm 877.1, RM 545.1), and the major Columbia River tributaries upstream from the confluence of the Snake and Columbia Rivers. Chief Joseph Dam has no fish ladders, and therefore is the upstream limit for migrating adult salmon on the mainstem Columbia River.

Radio-Telemetry Tags

Radio-telemetry tags for the study were purchased from Lotek Engineering Inc.[1], of Newmarket, Ontario, Canada. Each tag was powered by two 7.2-V lithium batteries, with life spans of about 8 months, to ensure detection throughout the migration and spawning periods. The transmitter and battery were sealed with Scotch Cast in a cylindrical plastic capsule 8.25-cm long x 1.5-cm diameter, which allowed tagging of fish as small as 60-cm fork length. Tags weighed about 30 g in air and had a 43-cm, 22-gauge, flexible-whip antenna attached to one end. Each tag transmitted a unique identification code within the range of 149.320 to 149.800 MHz.

Radio Tagging

Radio tagging of adult salmon involved three major procedures: trapping, tagging, and releasing.

---

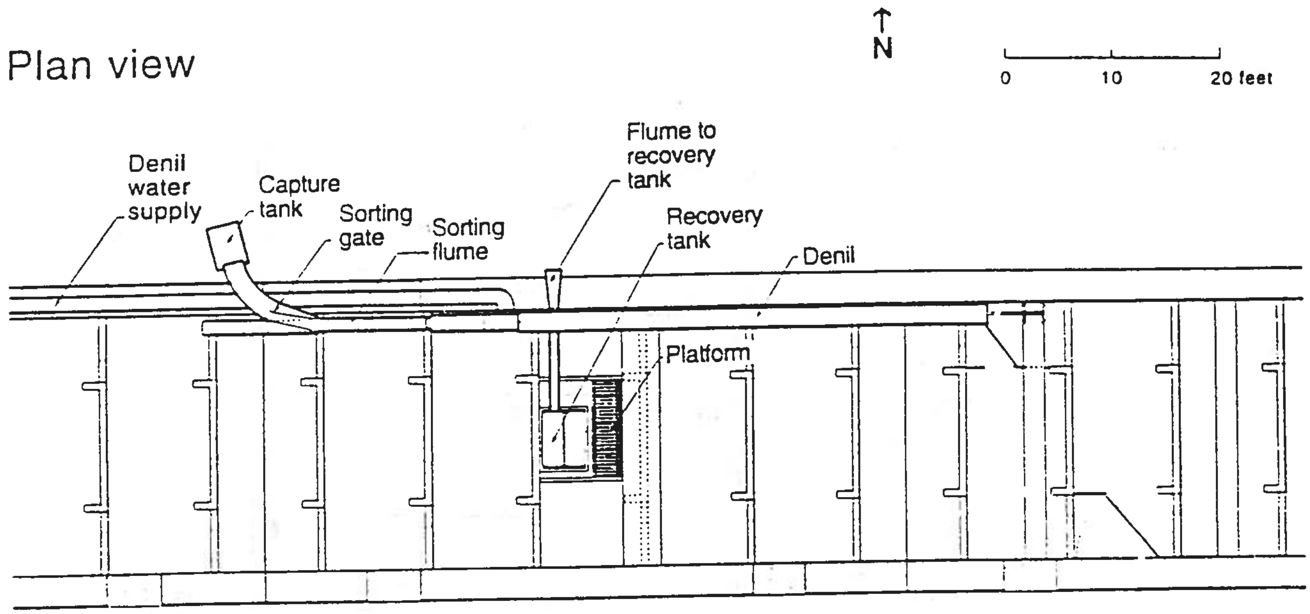
[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

We collected, tagged, and released spring and summer chinook salmon at John Day Dam from 19 April to 4 June and from 7 June to 29 July, respectively. At Priest Rapids Dam, spring chinook salmon were radio tagged from 24 to 25 May, and fall chinook salmon tagged from 7 September to 27 October. No summer chinook salmon were tagged at Priest Rapids Dam. At Rocky Reach Dam, spring, summer, and fall chinook salmon were radio tagged from 7 June to 11 June, 27 July to 29 July, and 8 September to 27 October, respectively.

Trapping

Temporary adult trapping facilities were installed in the left-bank (river banks are designated left and right based on the direction of movement of the water, i.e. looking downstream) fish ladder at John Day Dam (Fig. 2). Fish that passed over a denil fishway were selected for tagging by an observer controlled pneumatic flipper gate that routed the fish into an anesthetic tank.

At Priest Rapids Dam, the existing adult trap near the exit of the left-bank fish ladder was used to collect fish for radio tagging (Fig. 3). A picketed-lead gate was positioned over the left orifice to divert fish to a denil and via a flume to the trap. Non-target fish were released into the fish ladder upstream from the trapping facility by activating a hydraulic diversion gate in the flume.



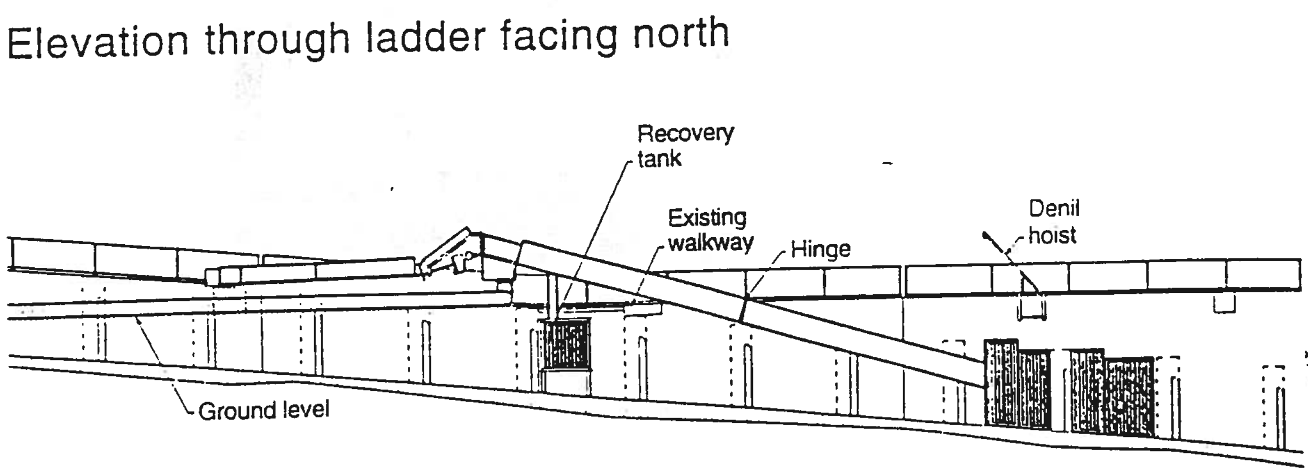


Figure 2.--Adult trap at John Day Dam south fish ladder, 1993.

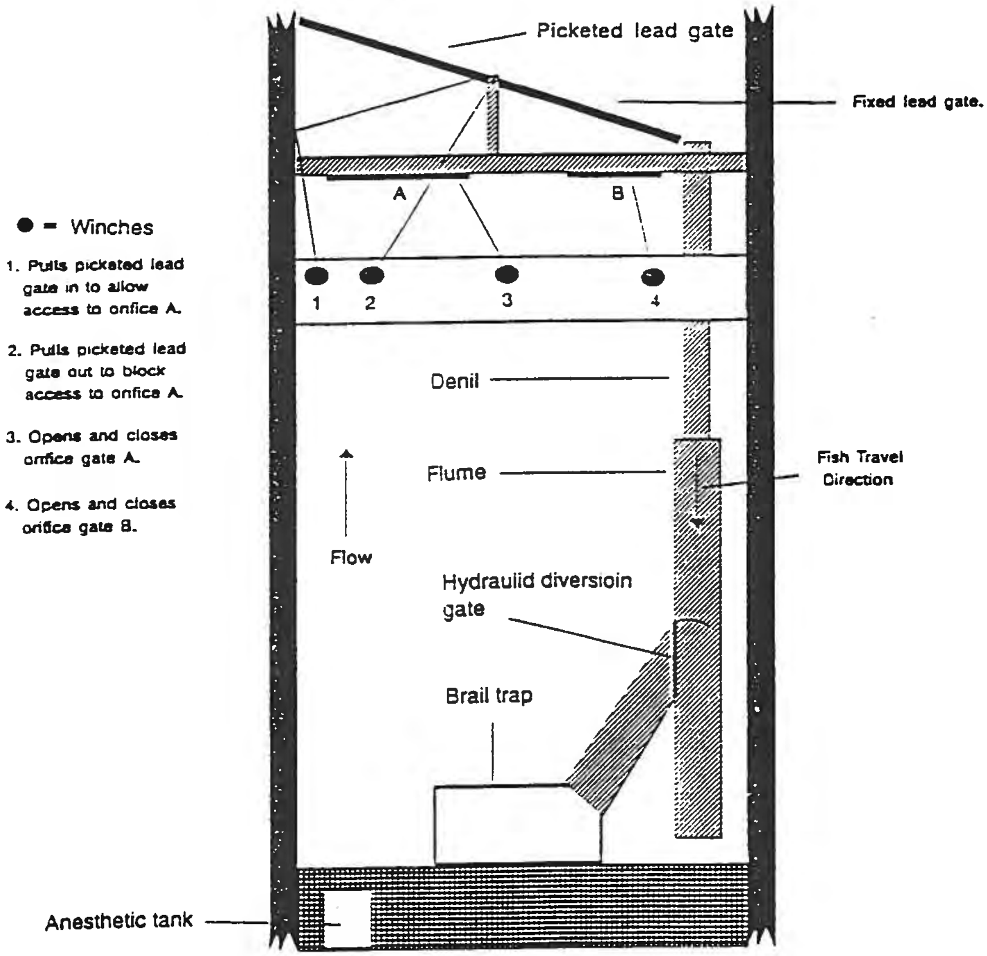


Figure 3.--Diagrammatic top view of adult trap at Priest Rapids Dam, 1993.

At Rocky Reach Dam, the existing Buckley trap in the fish ladder was used to collect fish (Fig. 4). The trap was lowered to cover two submerged weir orifices in the fish ladder. The trap floor in front of the right-side orifice was covered with a sheet of white plastic to facilitate viewing the fish from above water as they entered the trap. The left-side orifice was closed by a slide gate to prevent escape. The trap was raised when target fish were observed in the trap. Fish were transferred via a 46.1-cm diameter pipe from the trap to a tank located on a 3.0-m x 6.1-m barge in the forebay. Non-target fish were immediately released into the fish ladder upstream from the trap or removed from the collection tank and released into the forebay.

Tagging

Salmon were anesthetized with a tricaine methane sulfonate (MS-222) solution of about 40 ppm. After examination for marks, tags, or injuries, fish were measured. Chinook salmon longer than 60-cm fork length without severe head injuries were radio tagged. Fish were supported in the water, and a radio tag was inserted through the mouth and into the stomach of the fish. The entire tagging procedure lasted approximately 2 to 5 minutes per fish. Fish remained in water throughout the tagging process.

Releasing

After tagging, fish were placed into a holding tank until they recovered from the anesthetic. At John Day and Priest Rapids Dams, recovered fish were released back into fish ladders

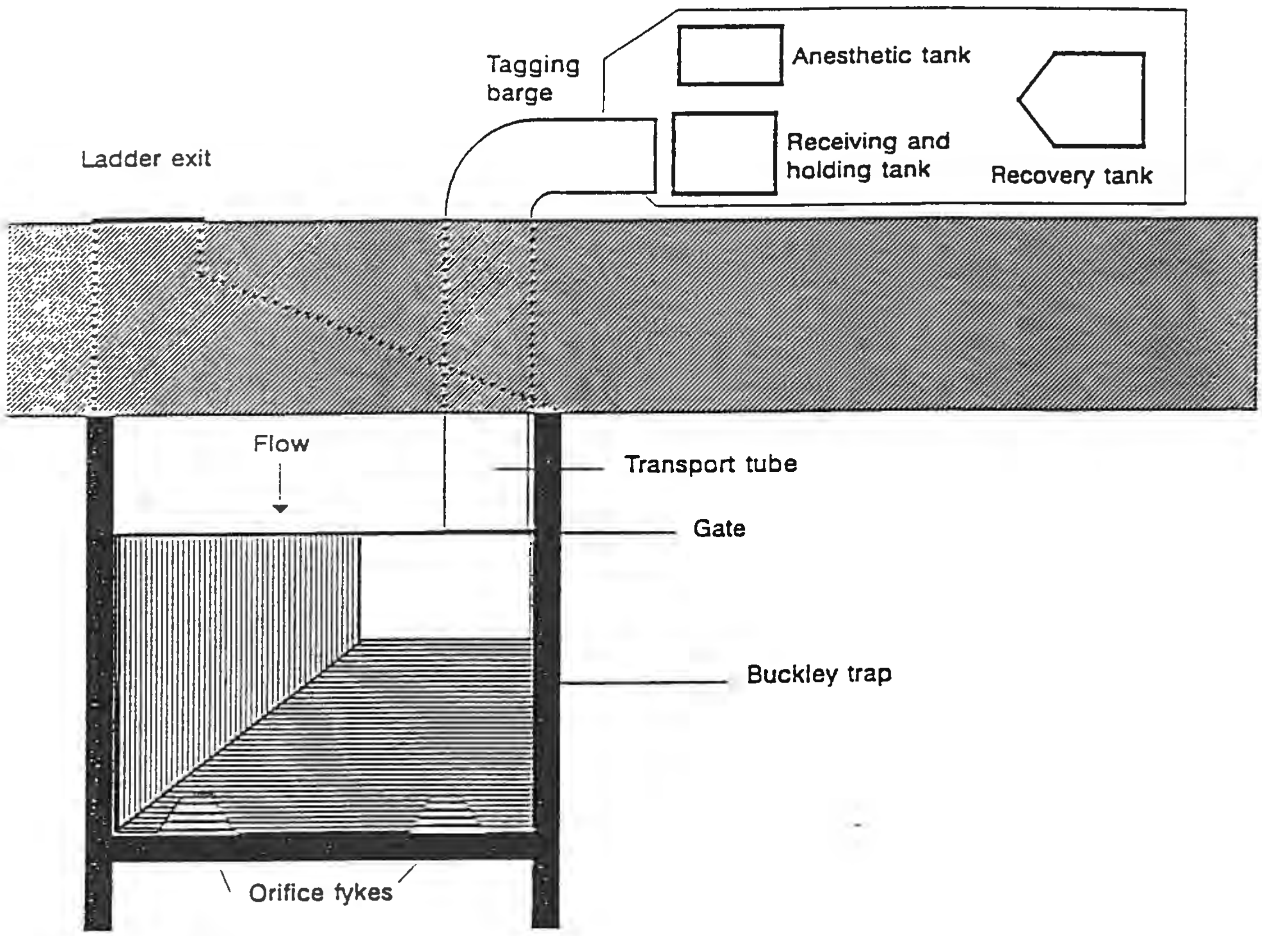


Figure 4.--Diagrammatic top view of Buckley trap at Rocky Reach Dam, 1993.

upstream from the traps. At Rocky Reach Dam, tagged spring and summer chinook salmon were transported downstream from the dam and released into the tailrace. Fall chinook salmon were released directly into the forebay from the floating work-barge on which they were tagged.

Radio Tracking

Radio tracking began when the first tagged fish was released. Fixed-site monitors were installed to continuously record the presence of radio-tagged fish in specific areas. Mobile surveillance from auto, boat, and airplane was used to monitor fish between fixed-site monitors and to locate and recover stationary tags.

The general location and numerical designation of fixed-site monitors at dams are listed in Table 1. Specific locations of fixed-site monitors and antennae at the dams are shown in Appendix Figures A1 to A5. Information for fixed-site monitors on major tributaries is presented in Table 2. Data collected from fixed-site monitors were downloaded to lap-top computers. The frequency of downloading ranged from every day to once a week, depending on fish activity within range of the monitor.

Radio-Telemetry Monitoring Equipment

All monitors used Lotek Model SRX-400 telemetry receivers for signal detection, data processing, and data storage.

Table 1.--Mainstem Columbia River, fixed-site telemetry monitors and antennae used during the 1993 spring, summer, and fall chinook salmon radio-telemetry study.

Monitor number	Monitor location (upstream progression)	River Km.	Number of antennae	Antennae type
1	John Day Dam (left-bank fish ladder)	346.9	1	Underwater coaxial cable
2	John Day Dam (right-bank fish ladder)	346.9	1	Underwater coaxial cable
4	McNary Dam (left-bank fish ladder)	469.8	1	Underwater coaxial cable
5	McNary Dam (right-bank fish ladder)	469.8	1	Underwater coaxial cable
98	Priest Rapids Dam (right-bank aerial)	639.5	2	9-element Yagi
97	Priest Rapids Dam (right-bank fish ladder)	639.6	4	Underwater coaxial cable
96	Priest Rapids Dam (right collection channel)	639.6	7	Underwater coaxial cable
95	Priest Rapids Dam (mid collection channel)	639.6	6	Underwater coaxial cable
94	Priest Rapids Dam (left collection channel)	639.6	4	Underwater coaxial cable
93	Priest Rapids Dam (left-bank fish ladder)	639.6	6	Underwater coaxial cable
92	Priest Rapids Dam exit (left-bank fish ladder)	639.6	4	Underwater coaxial cable
91	Wanapum Dam (right-bank aerial)	669.0	2	9-element Yagi
90	Wanapum Dam (right-bank ladder entrance)	669.0	2	Underwater coaxial cable
89	Wanapum Dam (right collection channel)	669.0	7	Underwater coaxial cable
88	Wanapum Dam (mid collection channel)	669.0	6	Underwater coaxial cable
87	Wanapum Dam (left collection channel)	669.0	6	Underwater coaxial cable
86	Wanapum Dam entrance (left-bank fish ladder)	669.0	6	Underwater coaxial cable
85	Wanapum Dam exit (left-bank fish ladder)	669.0	4	Underwater coaxial cable
84	Wanapum Dam exit (right-bank fish ladder)	669.0	4	Underwater coaxial cable
83	Rock Island Dam (right-bank aerial)	729.5	2	9-element Yagi
82	Rock Island Dam (right powerhouse entrance)	729.5	7	Underwater coaxial cable

Table 1.--continued.

Monitor number	Monitor location (upstream progression)	River Km	Number of antennae	Antennae type
81	Rock Island Dam (left powerhouse entrance)	729.5	2	Underwater coaxial cable
80	Rock Island Dam (center fish ladder)	729.5	4	Underwater coaxial cable
79	Rock Island Dam (left-bank ladder entrance)	729.5	2	Underwater coaxial cable
78	Rock Island Dam (left-bank ladder exit)	729.5	5	Underwater coaxial cable
77	Rock Island Dam (right-bank ladder exit)	729.5	4	Underwater coaxial cable
76	Rocky Reach Dam (right-bank aerial)	762.2	2	9-element Yagi
75	Rocky Reach Dam (right collection channel)	762.2	7	Underwater coaxial cable
74	Rocky Reach Dam (mid collection channel)	762.2	7	Underwater coaxial cable
73	Rocky Reach Dam (left powerhouse entrance)	762.2	6	Underwater coaxial cable
72	Rocky Reach Dam (spillway entrance)	762.2	2	Underwater coaxial cable
71	Rocky Reach Dam (fish ladder exit)	762.2	4	Underwater coaxial cable
68	Wells Dam (right-bank aerial)	828.6	2	9-element Yagi
67	Wells Dam (right-bank ladder entrance)	829.6	4	Underwater coaxial cable
66	Wells Dam (left-bank ladder entrance)	829.6	4	Underwater coaxial cable
65	Wells Dam (left-bank ladder exit)	829.6	5	Underwater coaxial cable
64	Wells Dam (right-bank ladder exit)	829.6	5	Underwater coaxial cable

Table 2.--Fixed-site radio-telemetry monitors located on the tributaries of the Columbia River.

Monitor number	Monitor location	River	River Km	Antennae number	Antennae type
3	John Day River	John Day	7.9	1	6-element Yagi
6-14	Ice Harbor Dam	Snake	15.6	21 2	Underwater 9-element Yagi
99	Horn Rapids Dam	Yakima	29.0	2	6-element Yagi
70	Wenatchee River County Park	Wenatchee	8.4	2	6-element Yagi
69	Private Property (Bob Whitehall)	Entiat	5.1	2	4-element Yagi
63	Private Property (Wayne Marsh)	Methow	25.7	2	4-element Yagi
62	Monse	Okanogan	9.7	2	4-element Yagi

Fixed-site monitors using underwater antennae incorporated Lotek DSP-500 receiver/co-processors for simultaneous scanning of all antennae and frequencies. The receiver/co-processor detected transmitter signals and passed frequency, code, and signal strength to the SRX-400 receiver for data verification and storage.

Four types of antennae were used for signal detection: underwater; multiple-element Yagi; hand-held, 3-element, folding Yagi; and H antennae. Underwater antennae consisted of coaxial cable with about 37.5 cm of the shielding stripped from the distal end. The cable was suspended outside and within fish-ladder openings to detect the presence of radio-tags. The detection range of underwater antennae ranged from 4.6 to 6.1 m. Yagi multiple-element antennae were used as air antennae at fixed sites to monitor fish in a general area. A nine-element Yagi antenna was used aboard a 5.8-m work boat for mobile tracking. Mobile tracking was performed with a monitor equipped with hand-held or staff-mounted, 3-element, folding Yagi antennae. Two wing-strut mounted, H-pattern antennae were used on a high-winged aircraft for aerial tracking.

Data Collection

The data collected for each radio-tagged fish included:

1) Fish length and injuries.
2) Site, date, and times of both tagging and release of tagged fish.
3) Date and time that tagged fish entered the study area.

4) Dates and times of arrival at the tailrace of each mid-Columbia River dam, including fishway entrances and exits (location, date, and time).
5) Date and time of entry and exit to the Wenatchee, Entiat, Methow, and Okanogan Rivers.
6) Weekly mobile track data (River Kilometer, notes, date, and time).

Data Analysis

Because travel-time data are seldom distributed normally, we recorded ranges and median travel times. Data were analyzed with non-parametric statistical tests.

Specific goals of this study were met by analyzing data in the following categories:

Run Timing

Fixed-site monitors determined run timing (dates and hours) and between-site migration times. These units operated continuously, except for short periods during data downloading. Run timing was calculated for a number of study area sections upstream from McNary Dam fishways to entrances of spawning tributaries.

Travel Time

Travel time in each reservoir and at each dam was obtained from monitors in the tailrace, collection channel, and fish-ladder entrances and exits. Tributary monitors were located far enough upstream so that tagged fish in the reservoir were not recorded. Dual antennae on the tailrace and tributary receivers provided sequential data for determining direction of movement.

The following terms were used to categorize travel times for tagged fish:

- **Previous dam to tailrace**--Elapsed time between exit or tagging at a dam and the first record at the nearest monitor downstream from the next upstream dam.
- **Tailrace to arrival**--Elapsed time between the first record at the nearest monitor downstream from the dam and the first record immediately outside a collection-channel opening.
- **Arrival to entry**--Elapsed time between the first record immediately outside a collection-channel opening and the first record inside the collection channel.
- **Entry to last collection channel**--Elapsed time between the first record inside the collection channel and the last record inside the collection channel.
- **Last collection channel to ladder exit (ladder time)**--Elapsed time between the last record inside the collection channel and the last record at the fish-ladder exit. These data were segregated according to fishways.
- **Total passage time at specific dam**--Elapsed time between the first record immediately outside a collection-channel opening (arrival) and the last record at a fish-ladder exit.

Travel times for all radio-tagged fish were included in the analysis unless travel times between tagging sites were significantly different (P = 0.05).

Fate of Radio-Tagged Fish

The fates of individual radio-tagged fish were assigned to categories based on last known locations determined by fixed-site monitors and mobile and aerial tracking. For example, we assumed fish last detected in a tributary would have stayed in that tributary. Assigning tags last detected between dams to a specific category was more problematic since fish could have died, spawned, regurgitated the tag, or been harvested. To help determine possible categories, we encouraged the return of recovered radio tags and information on their fate by offering a $5 reward. The fate of each tagged fish was examined for correlation with location, total passage time, fallback, and collection-channel exit rates.

Adult Collection Channel Efficiency

Collection channel efficiency was calculated with data from fixed-site monitors at each of the collection-channel openings and at the fish-ladder exits. Net collection-channel entry was estimated for each opening by Equation 1.

$$\text{Net Entry} = \sum \text{entries} - \sum \text{exits} \qquad (1)$$

where

$\sum$ entries = total entries (including multiple entries per fish) at a specific opening.

$\sum$ exits = total exits **at that opening.**

Data were also analyzed to determine the direction of fish movement within the collection channel. Net, direction of movement for the radio-tagged fish was calculated from the chronological records of individual tagged fish. Given that a tag was recorded at a collection channel opening, and was inside the collection channel, and that the next consecutive record was inside the channel, the direction of movement between the two records (toward or away) was summed. Net direction of movement from each collection channel opening was determined by subtracting the total number of records where tags were moving away from the base of the fish ladder from the total number of records where tags were moving toward the fish ladder.

The percentage of entries at a given opening that resulted in arrivals at the base of the fish ladder was calculated by Equation 2.

$$\textit{Percent Arrival at Base of Fish Ladder} = \frac{\sum ebfl}{\sum e} \qquad \textbf{(2)}$$

where

$\sum$ ebfl = number of entries at a specific opening that reached the base of the fish ladder.

$\sum$ e = total number of entries at that opening.

Total passage efficiency, indicating successful ladder passage from collection channel entry at a specific opening, was determined using Equation 3.

$$\text{Total Passage Efficiency} = \frac{\sum pe}{\sum p} \tag{3}$$

where

$\sum$ pe = ladder exits from collection channel entry at a specific opening.

$\sum$ p = total ladder exits.

Fish-Ladder Selection

A fast scanning fixed-site monitor recorded activity at individual adult collection-channel openings. Each fixed-site monitor collected data simultaneously from up to seven antennae.

Fallback

Fish detected in the tailrace of a dam subsequent to an exit record at the top of a fish ladder were classified as fallbacks. Fallbacks were determined by assessing fish activity from sequential data obtained from monitors in the collection channels, fish-ladder exits, tailraces, and by mobile tracking. We also assigned a fate to each fallback.

RESULTS AND DISCUSSION

A total of 742 spring, 426 summer, and 279 fall chinook salmon were radio tagged and released.

The average flows at Priest Rapids Dam during spring, summer, and fall chinook salmon migrations were 124.0, 105.9, and 75.7 kcfs, respectively. Water was spilled at each dam during spring and summer migrations, with the exception of the summer chinook salmon migration at Rocky Reach Dam. With one minor exception (one day at Rock Island Dam), there was no spill during the fall chinook salmon migration.

Run Timing/Separation

Run timing of spring and summer chinook salmon at the Wenatchee River, Priest Rapids Dam, Wanapum Dam, and Rock Island Dam was considerably earlier than run timing for fish that passed Rocky Reach and Wells Dams (Fig. 5). Differences were most apparent during the early stages of the migration.

There were, however, no distinct separations between the different stocks of spring chinook salmon adults destined for the Wenatchee, Entiat, Methow, and Okanogan Rivers at Priest Rapids, Rocky Reach, and Wells Dams (Fig. 6).

At Priest Rapids Dam, the run timing of radio-tagged spring chinook salmon adults was late relative to the total population counted passing the dam (Fig. 7). The difference was caused by a differential between the run and tagging schedule at John Day Dam. Three percent of the run had past John Day Dam when tagging

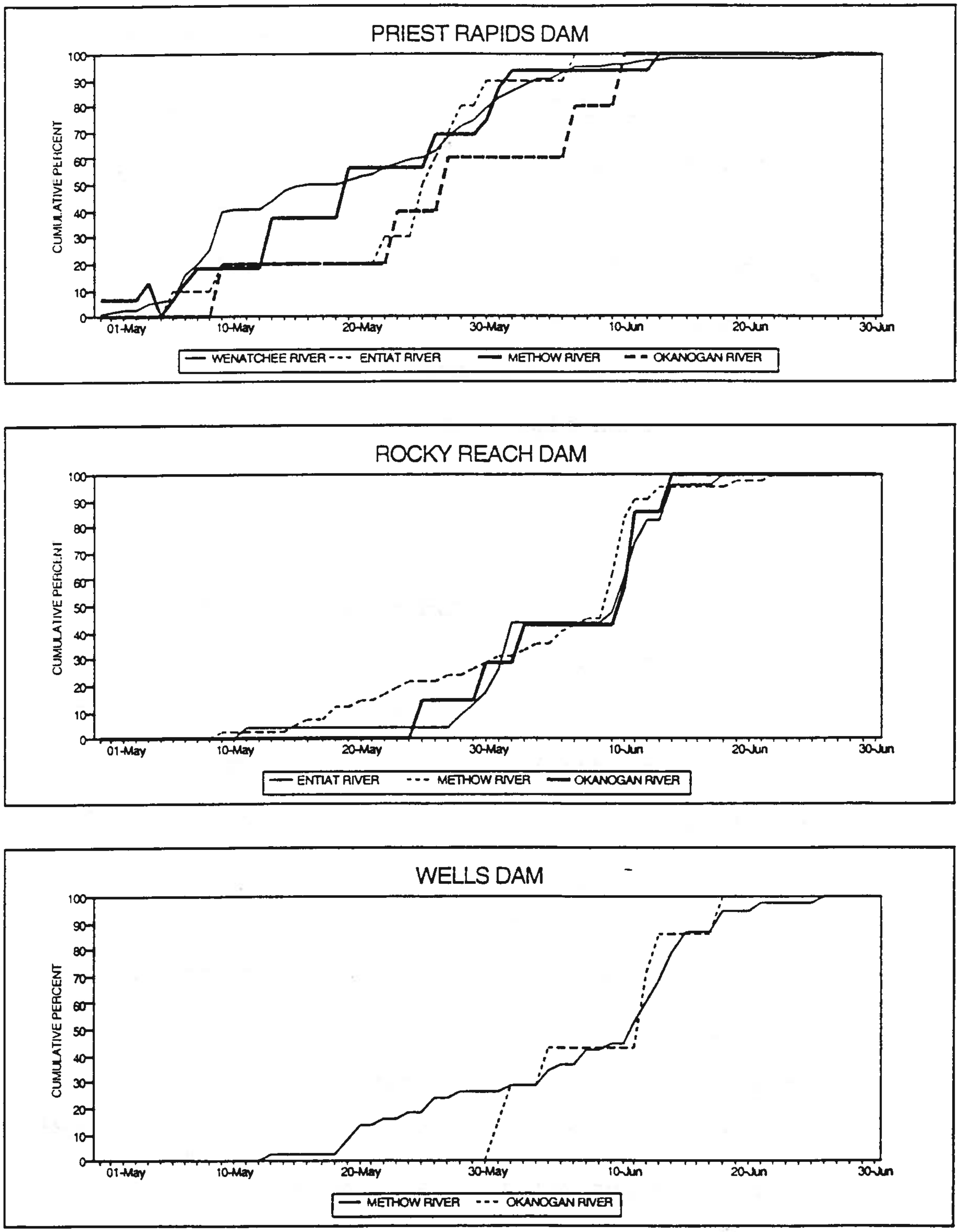
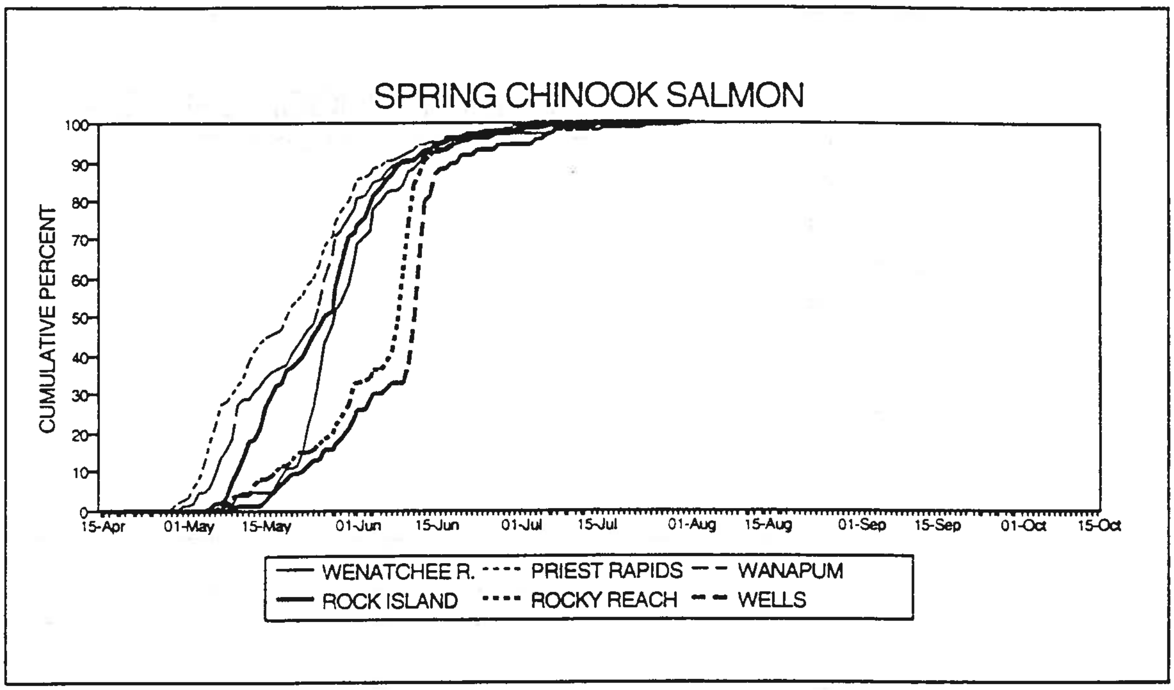


Figure 6.--Run timing at dams with adult trapping facilities for the radio-tagged spring chinook salmon that entered tributaries, 1993.



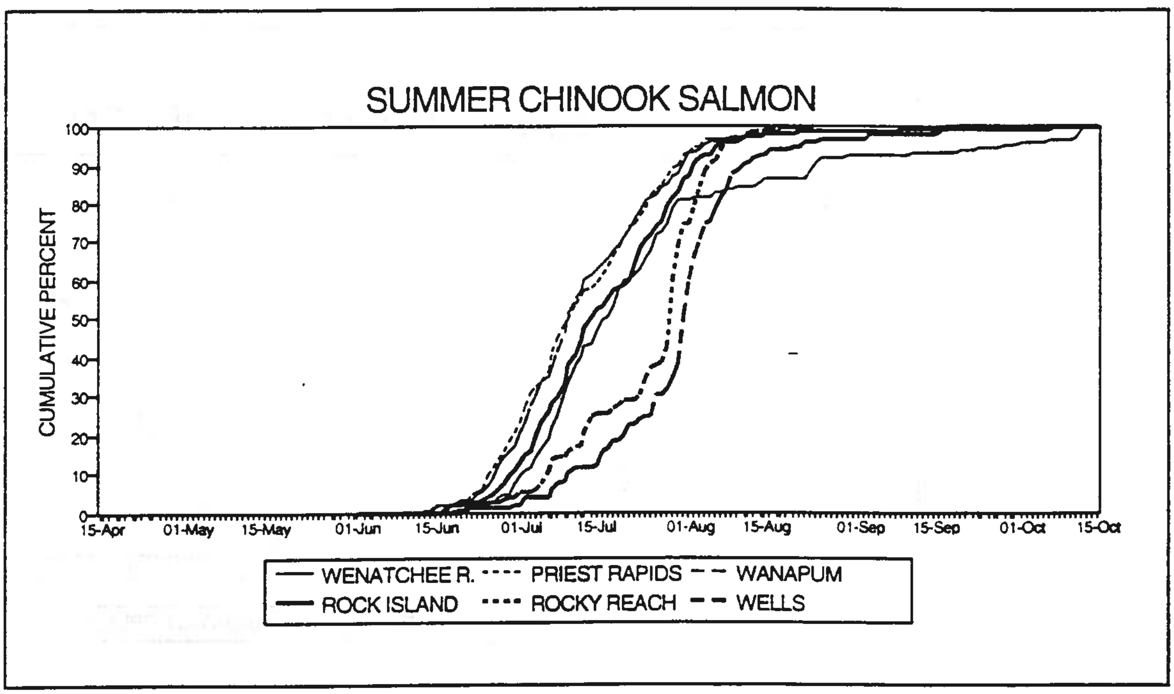
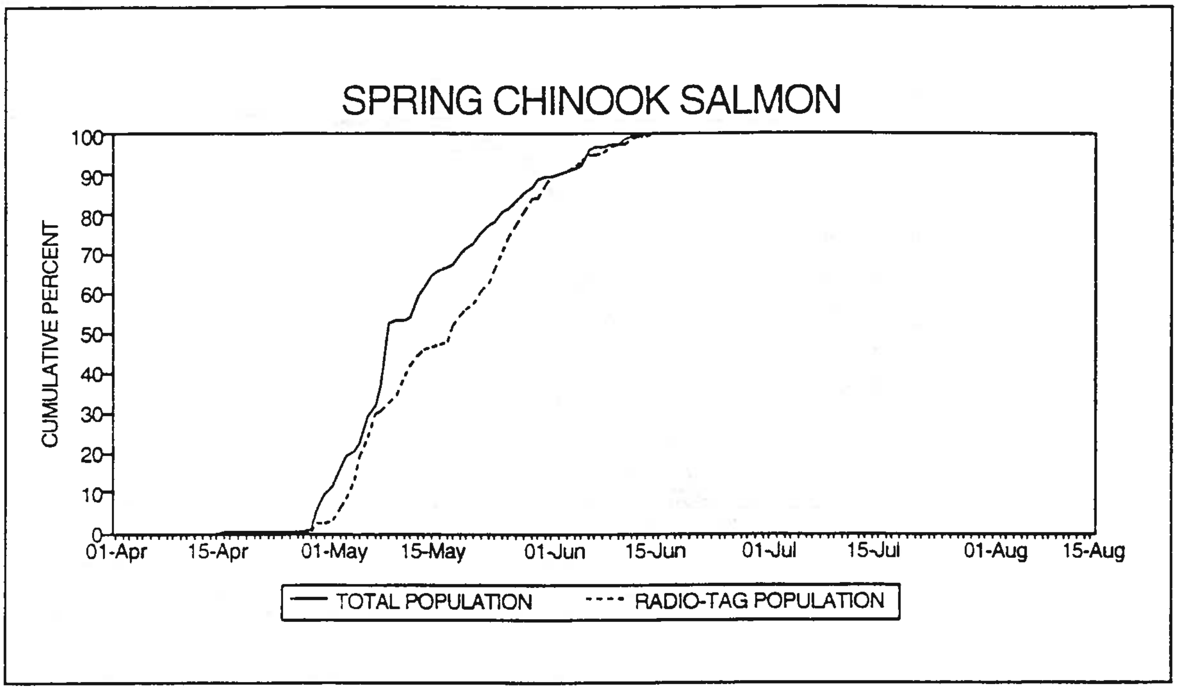


Figure 5.--Run timing of radio-tagged chinook salmon in the mid-Columbia River, 1993.



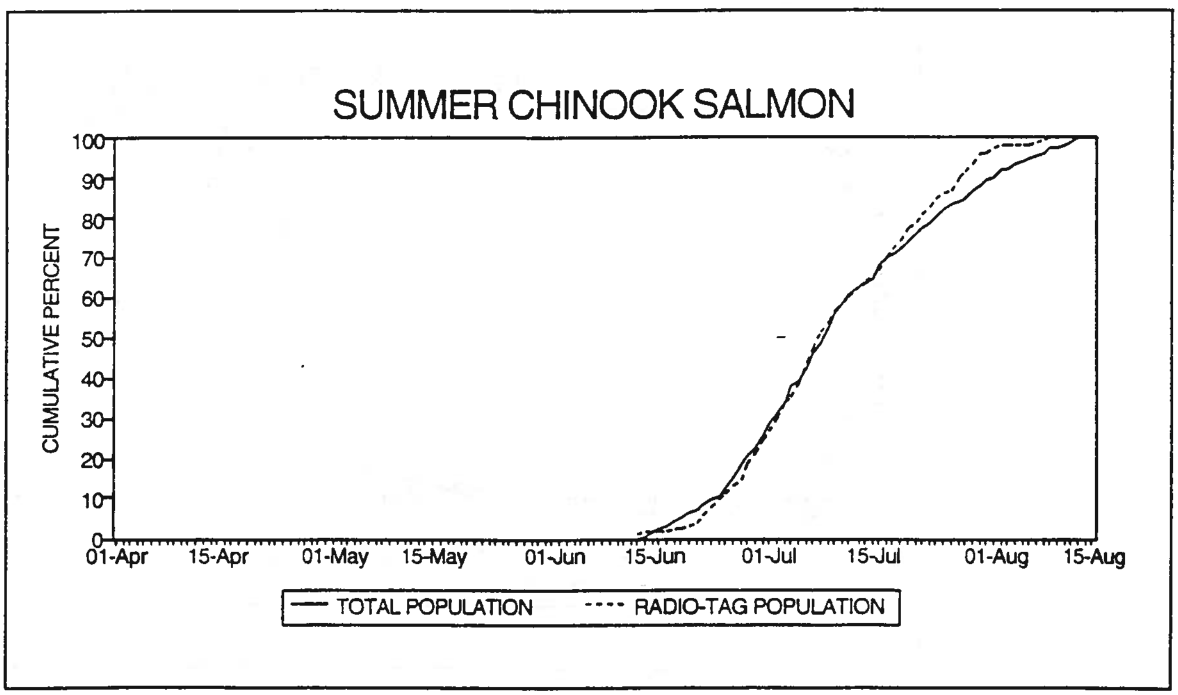


Figure 7.--Run timings of the total and radio-tagged populations at Priest Rapids Dam, 1993

started and the median run and tagging dates were 1 May and 11 May, respectively. Therefore, run timing of radio-tagged spring chinook salmon adults farther upstream may not be indicative of the population in general. Run timing of summer chinook salmon adults was similar for both tagged and observed fish (Fig. 7).

Fish arrived at the tailraces and collection channels throughout the day, with the highest numbers arriving during daylight hours (Appendix B, Figs. 1-20). Fish generally made their first collection-channel entries during daylight hours. Last collection-channel records (ladder entrances) and exits from fish ladders were almost completely limited to daylight hours, with the exception of Rocky Reach and Wells Dams.

Travel Time

The first radio-tagged spring chinook salmon passed McNary Dam on 27 April. Median migration time from McNary Dam to Priest Rapids Dam was 95.8 hours for spring chinook salmon and 87.2 hours for summer chinook salmon (Table 3).

Priest Rapids Dam

Upon arrival in the tailrace of Priest Rapids Dam, fish moved directly to the collection channel. The first collection-channel records at Priest Rapids Dam were made 1.4 and 0.7 hours (median) after the first downstream monitor records for spring and summer chinook salmon, respectively.

Table 3.--Travel time (hours) of radio-tagged spring and summer chinook salmon passing Priest Rapids Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
McNary Dam to tailrace (Priest Rapids Dam)	161	95.8	1,802	54.3
Tailrace to arrival (at Priest Rapids Dam)	154	1.4	1,076	0.1
Arrival to entry	216	14.4	415	<0.1
Fate below Priest Rapids Dam	30	3.6	330	<0.1
Fate above Priest Rapids Dam	159	16.4	415	<0.1
First entry to last channel exit	226	8.9	487	<0.1
Ladder time right	12	2.0	20	1.5
left	184	3.1	105	1.8
Total passage time at Priest Rapids Dam	197	44.9	2,084	2.6
Summer chinook salmon				
McNary Dam to tailrace (Priest Rapids Dam)	222	87.2	415	46.7
Tailrace to arrival (at Priest Rapids Dam) 233	0.7	81	0.1	
Arrival to entry	269	1.0	178	<0.1
First entry to last channel exit	269	25.5	1,416[1]	<0.1
Ladder time right	21	2.3	26	1.4
left	240	2.9 -	55	1.4
Total passage time at Priest Rapids Dam	261	29.4	682	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Arrival-to-entry timing differed for spring and summer chinook salmon. Spring chinook salmon took a median of 14.4 hours to make their first collection-channel entry, while summer chinook salmon moved into the collection channel in 1 hour (Table 3). Spring chinook salmon with final records upstream from Priest Rapids Dam had longer median arrival-to-entry times (16.4 hours) than those below the dam (3.6 hours). Analysis with the Wilcoxon Signed Rank test (Bickel and Doksum, 1977) indicated that the difference between the two groups was not statistically different (P = 0.9483).

Median duration of entry to last collection channel record was 8.9 hours for spring chinook salmon and 25.5 hours for summer chinook salmon (Table 3). Median ladder times for spring chinook salmon were 2.0 and 3.1 hours for the right and left fish ladders, respectively. Median ladder times for summer chinook salmon were 2.3 and 2.9 hours, respectively. Total passage time (median) at Priest Rapids Dam for spring and summer chinook salmon was 44.9 and 29.4 hours, respectively (Appendix Figure D1).

The median migration time from Priest Rapids Dam to Wanapum Dam was 15.8 hours for spring chinook salmon, 13.6 hours for summer chinook salmon, and 62.4 hours for fall chinook salmon (Table 4). Spring chinook salmon tagged at Priest Rapids Dam took significantly more time (32.4 hours) (P = 0.0108) to reach Wanapum Dam than fish tagged at John Day Dam (16.9 hours), suggesting a handling-associated effect.

Table 4.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Wanapum Dam, 1993.

		N	Median	Max.	Min.
Spring chinook salmon					
Priest Rapids Dam to tailrace (Wanapum Dam)		54	15.8	1,314	6.8
Priest Rapids Dam to collection channel (Wanapum)					
	Tagged at John Day Dam	174	16.9	1,314	5.7
	Tagged at Priest Rapids Dam	30	32.4	466	14.8
Tailrace to arrival (at Wanapum Dam)		65	1.5	197	<0.1
Arrival to entry		226	8.9	486	<0.1
First entry to last channel exit		226	2.0	1,104	<0.1
Ladder time	right	7	4.2	23	1.7
	left	203	2.8	67	1.4
Total passage time at Wanapum Dam		211	36.6	1,108	2.0
	Tagged at John Day Dam	185	35.7	1,108	2.6
	Tagged at Priest Rapids Dam	26	46.0	496	2.0
Summer chinook salmon					
Priest Rapids Dam to tailrace (Wanapum Dam)		38	13.6	415	46.7
Tailrace to arrival (at Wanapum Dam)		38	0.9	81	0.1
Arrival to entry		255	1.9	178	<0.1
First entry to last channel exit		255	20.2	1,416[1]	<0.1
Ladder time	right	44	2.3	26	1.4
	left	160	2.7	55	1.4
Total passage time at Wanapum Dam		209	22.9	682	2.4
Fall chinook salmon					
Priest Rapids Dam to tailrace (Wanapum Dam)		19	62.4	288	16.8
Tailrace to arrival (at Wanapum Dam)		19	2.4	29	<2.4
Arrival to entry		57	<2.4	362	<2.4
First entry to last channel exit		58	24.0	684	<2.4
Ladder time	right	7	4.8	14	2.4
	left	33	2.4	17	<2.4
Total passage time at Wanapum Dam		40	40.7	689	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Wanapum Dam

Upon arrival at the Wanapum Dam tailrace, fish moved directly into the collection channel. Median times from the tailrace to arrival were 1.5, 0.9, and 2.4 hours for spring, summer, and fall chinook salmon, respectively (Table 4). Similar to the behavior they exhibited at Priest Rapids Dam, spring chinook salmon at Wanapum Dam had longer median first collection-channel entry (8.9 hours) than summer chinook salmon (1.9 hours) or fall chinook salmon (2.4 hours), but spent less time from entry to last collection-channel records (2.0 hours for spring chinook salmon vs. 20.2 hours for summer chinook salmon and 24.0 hours for fall chinook salmon).

Spring chinook salmon median ladder times were 4.2 and 2.8 hours for the right and left fish ladders, respectively. Ladder times were 2.3 (right fish ladder) and 2.7 (left fish ladder) hours for summer chinook salmon and 4.8 (right fish ladder) and 2.4 (left fish ladder) hours for fall chinook salmon.

Median total passage times at Wanapum Dam were 36.6, 22.9, and 40.7 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D2). No Wanapum Dam total passage time differences were observed between spring chinook salmon tagged at John Day Dam and those tagged at Priest Rapids Dam after arrival at Wanapum Dam (Table 4). Median passage time for spring chinook salmon tagged at Priest Rapids Dam was longer (46.0 hours) than passage time for fish tagged at John Day Dam

(35.7 hours). The difference, however, was not significant (P = 0.3878).

The median migration time from Wanapum Dam to Rock Island Dam was 22.6 hours for spring chinook salmon, 24.3 hours for summer chinook salmon, and 36.0 hours for fall chinook salmon (Table 5).

Rock Island Dam

Fish moved directly from the tailrace to the collection channel at Rock Island Dam. Median tailrace to arrival times were 0.9, 0.8, and less than 2.4 hours for spring, summer, and fall chinook salmon, respectively.

Median tailrace-to-arrival and arrival-to-entry times were consistent throughout the migration. First entries occurred quickly (spring chinook salmon, 0.9 hours; summer chinook salmon, 0.5 hours; and fall chinook salmon, <2.4 hours). Durations between entry into the collection channel and last record in the collection channel were 10.7, 8.0, and 14.4 hours for spring, summer, and fall chinook salmon, respectively.

Median ladder times for spring chinook salmon were 0.5, 2.6, and 3.1 hours for the right, center, and left fish ladders, respectively. Ladder times were 1.8 (right fish ladder), 2.5 (center fish ladder), and 1.4 (left fish ladder) hours for summer chinook salmon, and 4.8 (right fish ladder), 2.4 (center fish ladder), and 2.4 hours (left fish ladder) for fall chinook salmon. Median total passage times at Rock Island Dam were 20.3,

Table 5.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Rock Island Dam, 1993.

		N	Median	Max.	Min.
Spring chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		138	22.6	172	16.0
Tailrace to arrival (at Rock Island Dam)		145	0.9	588	0.1
Arrival to entry		206	0.9	105	<0.1
First entry to last channel exit		205	10.7	770	<0.1
Ladder time	right	145	0.5	17	0.1
	center	44	2.6	46	0.4
	left	5	3.1	26	1.1
Total passage time at Rock Island Dam		195	20.3	779	1.2
Summer chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		189	24.3	115	14.2
Tailrace to arrival (at Rock Island Dam)		236	0.8	42	0.1
Arrival to entry		255	0.5	283	<0.1
First entry to last channel exit		255	8.0	1,891[1]	0.1
Ladder time	right	214	1.8	1,760	0.6
	center	17	2.5	800	9.8
	left	17	1.4	12	0.5
Total passage time at Rock Island Dam		250	14.6	1,768	1.2
Fall chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		23	36.0	598	12.0
Tailrace to arrival (at Rock Island Dam)		34	<2.4	10	<2.4
First entry to collection channel		53	<2.4	10	<2.4
First entry to last channel exit		53	14.4	775	<2.4
Ladder time	right	30	4.8	1,334	<2.4
	center	2	2.4	2	<2.4
	left	6	2.4	2	<2.4
Total passage time at Rock Island Dam		38	19.2	1,366	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

14.6, and 19.2 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D3).

Wenatchee River

The median travel time from the exit of Rock Island Dam to entry of the Wenatchee River was 36.0 hours for spring chinook salmon and 53.2 hours for summer chinook salmon (Table 6). The median Wenatchee River entry dates for spring and summer chinook salmon were 2 June and 17 July, respectively (Appendix C, Fig. 1).

Rocky Reach Dam

The first spring chinook salmon arrived at Rocky Reach Dam on 7 May. Median migration time from Rock Island Dam to Rocky Reach Dam was 13.5 hours for spring chinook salmon, 14.3 hours for summer chinook salmon, and 14.4 hours for fall chinook salmon (Table 6). Median tailrace to arrival times were 0.7, 0.9, and 2.4 hours for spring, summer, and fall chinook salmon, respectively. Fall chinook salmon took over three times longer than spring and summer chinook salmon between arrival and entry (4.8 vs. 1.4 hours for spring and summer chinook salmon). The median time between entry into the collection channel and the last record (spring chinook salmon, 25.6 hours; summer chinook salmon, 10.4 hours; and fall chinook salmon, 38.4 hours) made up the longest portion of the total dam-passage time. The median ladder times were 3.3, 2.8, and 4.8 hours for spring, summer, and fall chinook salmon, respectively. Median total passage times at

Table 6.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Rocky Reach Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
Rock Island Dam to Wenatchee River entry	148	36.0	343.6	14.1
Rock Island Dam to tailrace (Rocky Reach Dam)	28	13.5	400	8.6
Tailrace to arrival (Rocky Reach Dam)	58	0.7	96	0.1
Arrival to entry	100	1.4	159	<0.1
First entry to last channel exit	100	25.6	835	<0.1
Ladder time	89	3.3	85	1.8
Total passage time at Rocky Reach Dam	211	36.6	1,108	2.0
Summer chinook salmon				
Rock Island Dam to Wenatchee River entry	156	53.2	2,174	13.3
Rock Island Dam to tailrace (Rocky Reach Dam)	107	14.3	1,605	9.5
Tailrace to arrival (Rocky Reach Dam)	142	0.9	743	0.1
Arrival to entry	158	1.4	262	<0.1
First entry to last channel exit	158	10.4	1,321[1]	<0.1
Ladder time	127	2.8	26	1.4
Total passage time at Rocky Reach Dam	209	22.9	682	2.4
Fall chinook salmon				
Rock Island Dam to tailrace (Rocky Reach Dam)	22	14.4	118	9.6
Tailrace to arrival (Rocky Reach Dam)	27	2.4	112	<2.4
Arrival to entry	37	4.8	105	<2.4
First entry to last channel exit	37	38.4	571	<2.4
Ladder time	34	4.8	247	2.4
Total passage time at Rocky Reach Dam	38	60.0	609	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Rocky Reach Dam were 36.6, 22.9, and 60.0 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D4).

Entiat River

The median migration time between exiting Rocky Reach Dam and entering the Entiat River was 37.8 hours for spring and 150 hours for summer chinook salmon (Table 7). The median Entiat River entry dates were 12 June and 31 July for spring and summer chinook salmon, respectively (Appendix C, Fig. 2).

Wells Dam

The median migration time from Rocky Reach Dam to Wells Dam was 22.7 hours for spring chinook salmon, 25.8 hours for summer chinook salmon, and 40.8 hours for fall chinook salmon (Table 7). The fish moved directly from the tailrace to the collection channel as determined by short median tailrace to arrival times of 1.4, 1.8, and 2.4 hours for spring, summer, and fall chinook salmon, respectively. Median time from arrival to entry of the collection channel ranged from 0.4 hours for summer chinook salmon to less than 2.4 hours for fall chinook salmon. Median time between entry into the collection channel and the last record in the collection channel made up the longest portion of the total dam passage time (26.8, 33.3, and 31.2 hours for spring, summer, and fall chinook salmon, respectively).

Median ladder times were 2.2 (right fish ladder) and 2.1 (left fish ladder) hours for spring chinook salmon, 2.6 (right

Table 7.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Wells Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
Rocky Reach Dam to Entiat River entry	20	37.8	560	11.8
Rocky Reach Dam to tailrace (Wells Dam)	63	22.7	97	17.9
Tailrace to arrival (Wells Dam)	66	1.4	96	0.6
Arrival to entry	72	0.9	29	<0.1
First entry to last channel exit	73	26.8	1,383	<0.1
Ladder time				
right	27	2.2	52	1.2
left	28	2.1	22	0.6
Total passage time at Wells Dam	56	28.5	1,396	2.9
Wells Dam to Methow River entry	41	30.9	1,178	17.8
Wells Dam to Okanogan River entry	7	270.4	531	103.2
Summer chinook salmon				
Rocky Reach Dam to Entiat River entry	10	150.0	1,803	15.3
Rocky Reach Dam to tailrace (Wells Dam)	111	25.8	50	15.4
Tailrace to arrival (Wells Dam)	112	1.8	1,610	0.5
Arrival to entry	123	0.4	646	<0.1
First entry to last channel exit	123	33.3	1,698[1]	<0.1
Ladder time				
right	10	2.6	32	1.5
left	87	2.7	28	1.3
Total passage time at Wells Dam	97	46.9	1,108	2.0
Wells Dam to Methow River entry	16	434.2	2,025	73.3
Wells Dam to Okanogan River entry	50	24.6	1,631	13.4
Fall chinook salmon				
Rocky Reach Dam to tailrace (Wells Dam)	33	40.8	180	7.2
Tailrace to arrival (Wells Dam)	36	2.4	36	<2.4
Arrival to entry	52	<2.4	823	<2.4
First entry to last channel exit	51	31.2	749	<2.4
Ladder time				
right	20	2.4	100	<2.4
left	32	2.4	19	2.4
Total passage time at Wells Dam	52	45.6	828	4.8

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

fish ladder) and 2.7 (left fish ladder) hours for summer chinook salmon, and 2.4 hours for both right and left fish ladders for fall chinook salmon. Median total passage times at Wells Dam were 28.5, 46.9, and 45.6 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D5).

Methow and Okanogan Rivers

Migration times for spring chinook salmon from Wells Dam to the Methow River and from Wells Dam to the Okanogan River were 30.9 and 270.4 hours, respectively (Table 7). The median Methow River entry date for spring chinook salmon was 13 June, and the median Okanogan River entry date was 16 June. Median migration times for summer chinook salmon from Wells Dam to the Methow River (Appendix C, Fig. 3) and from Wells Dam to the Okanogan River (Appendix C, Fig. 4) were 434.2 and 24.7 hours, respectively. For summer chinook salmon, the median date of entry to the Methow River was 31 August and the median date of entry to the Okanogan River was 2 August.

Fate of Radio-Tagged Fish

Spring Chinook Salmon

Most radio-tagged spring chinook salmon migrating above Priest Rapids Dam terminated their migration in tributaries (Fig. 8). The Wenatchee River was the final destination of the largest proportion of radio-tagged fish (57.4%), with lesser

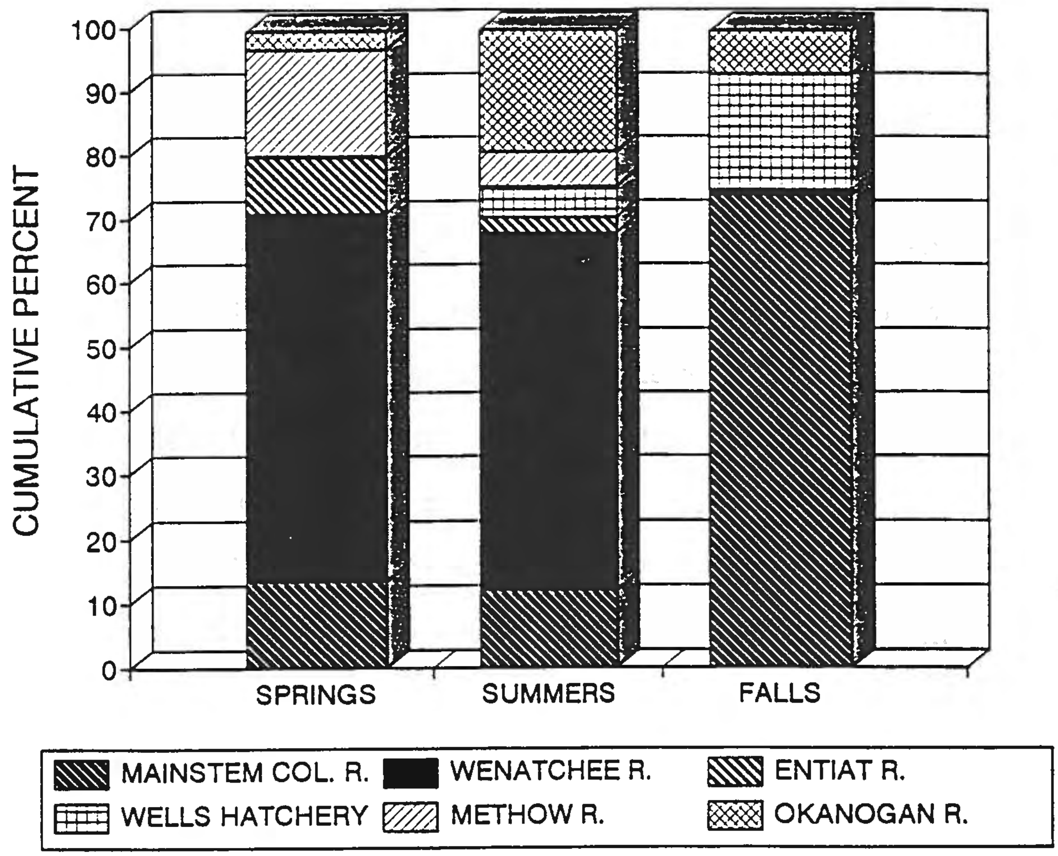


Figure 8.--Distribution of radio-tagged spring, summer, and fall chinook salmon upstream from Priest Rapids Dam, 1993.

numbers in the Entiat (9.0%), Methow (16.8%), and Okanogan (3.0%) Rivers (Table 8). Tags detected in the mainstem Columbia River above Priest Rapids Dam that remained stationary for long periods were assigned to pre-spawning mortality or tag regurgitations. We assumed tags that disappeared during the spring chinook migration period were related to harvest or tag failures. Below Priest Rapids Dam, the mainstem population consisted of fallbacks from above Priest Rapids Dam, and in some instances, Wanapum Dam. Some fallbacks eventually moved into the Ringold Spring Chinook Salmon Facility (RM 353). Other radio-tagged spring chinook salmon never passed Priest Rapids Dam but milled below the dam until after they should have spawned. We suspect most of these fish were adult returns that were a product of juvenile releases from the Ringold Facility.

Some mortalities below Priest Rapids may have been fallbacks that should have migrated to areas upstream from Priest Rapids Dam. It is also very likely that some of the mainstem mortalities above Priest Rapids Dam were fish from the Ringold Facility that were trying to move downstream. We estimated that the maximum mortality of spring chinook salmon in the study area (excludes all fish entering spawning areas) was 22.2%. If all of the fish with unknown fates below Priest Rapids Dam (N = 38) were fish from the Ringold Facility, the mortality estimate would have decreased to 11.1%.

Table 8.--Summary of last locations of radio-tagged spring and summer chinook salmon in the mid-Columbia River study area.

Last recorded location	Spring chinook salmon			Summer chinook salmon	
	PR[1]	RR[2]	TOTAL	RR[2]	TOTAL
Columbia River near Walla Walla River			2		0
Yakima River			3		2
Ringold Facility	4	2	25		2
Unknown, downstream Priest Rapids Dam	5		38		7
Priest Rapids trap	1		6		1
Below Priest Rapids Dam			1		2
Priest Rapids Dam fishery			0		1
Unknown, upstream Priest Rapids Dam	2		2		0
Wanapum Dam fishery			1		0
Columbia River near Wanapum Dam	1		1		0
Unknown, Downstream Wanapum Dam			7		0
Unknown, Wanapum Dam			2		0
Unknown, upstream Wanapum Dam	1		1		1
Unknown, downstream Rock Island Dam			3	4	7
Stationary, Rock Island Dam			1		0
Unknown, upstream Rock Island Dam			0		3
Wenatchee River	18		154		171
Unknown, downstream Rocky Reach Dam		1	3		2
Entiat River	2	11	24	2	8
Chelan River	1		1		0
Unknown, downstream Wells Dam		3	8	1	2
Wells Hatchery		1	1	7	15
Wells Dam fishery			0		1
Unknown, upstream Wells Dam	1	4	6		2
Methow River	2	23	45	6	17
Okanogan River		3	8	21	59
Chief Joseph Dam fishery			0		12
Unknown, below Chief Joseph Dam			0		3
TOTAL	38	48	343	49	318

PR[1] Fish tagged at Priest Rapids Dam
RR[2] Fish tagged at Rocky Reach Dam

Summer Chinook Salmon

The majority of radio-tagged summer chinook salmon passing above Priest Rapids Dam also terminated their migrations in tributaries. The largest number of fish was last recorded in the Wenatchee River (56.4%), and smaller numbers were last recorded in the Entiat (2.6%), Methow (5.6%), and Okanogan (19.5%) Rivers. An additional 5.0% of radio-tagged fish entered the Wells Hatchery.

Mainstem fish above Priest Rapids Dam were fish that did not move for long periods (pre-spawning mortality or tag regurgitations), and fish that disappeared during the summer chinook salmon migration period (harvest or tag failures). The fishery in the tailrace of Chief Joseph Dam removed at least 12, and possibly up to 15, radio-tagged summer chinook salmon. We estimated that the maximum mortality (which includes all fish not entering spawning areas) of summer chinook salmon in the study area was 13.5%. It is highly likely that some of the radio-tagged fish with last locations downstream from Wanapum, Rock Island, Rocky Reach and Wells Dams were also spawners.

Fall Chinook Salmon

Final detections of fall chinook salmon above Priest Rapids Dam were recorded predominantly in the main stem (72.9%) and in Wells Hatchery (17.9%) (Table 9). The largest number of mainstem fish were detected in the Wells Dam tailrace (61), with smaller

Table 9.--Summary of last locations of radio-tagged fall chinook salmon in the mid-Columbia River study area.

Last recorded location	PR[1]	RR[2]
Below Vernita Bridge	6	0
Columbia River sport fish harvest	1	0
Priest Rapids Salmon Hatchery	8	0
Priest Rapids Dam tailrace	2	0
Priest Rapids Reservoir (PR vicinity)	3	0
Priest Rapids Reservoir (wildlife area)	3	0
Priest Rapids Reservoir (mouth of Crab Creek)	7	0
Columbia River sport fish harvest	1	0
Wanapum Dam tailrace	36	0
Wanapum Dam Reservoir (Crescent Bar area)	1	1
Rock Island Dam tailrace	3	3
Rock Island Reservoir (RI vicinity)	0	1
Rock Island Reservoir (Wenatchee River mouth)	0	1
Wenatchee River (lower)	1	1
Wenatchee River sportfish harvest	0	1
Rocky Reach Dam tailrace	17	9
Rocky Reach Reservoir (RR vicinity)	0	4
Rocky Reach Reservoir (Entiat River mouth)	0	4
Entiat River	0	0
Rocky Reach Reservoir (Chelan River mouth)	0	7
Chelan River	0	2
Wells Salmon Hatchery	13	34
Wells Dam tailrace	13	48
Wells Dam Reservoir (Wells Dam vicinity)	3	4
Methow River	0	0
Wells Dam Reservoir (Okanogan River mouth)	1	0
Okanogan River	2	15
Similkameen River	1	3
Wells Dam Reservoir (Bridgeport Bar area)	0	7
Chief Joseph Dam tailrace	0	2
Chief Joseph Dam snag fishery	0	2
Priest Rapids Dam area	1	0
Rocky Reach Dam area	0	5
Wells Dam area	0	2
TOTAL	123	156

[1] Fish tagged at Priest Rapids Dam

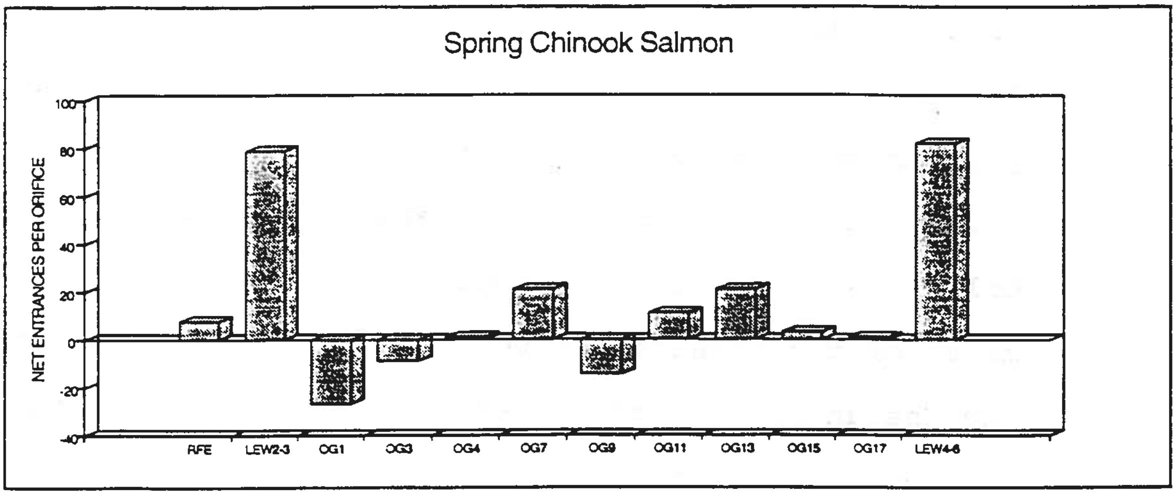
[2] Fish tagged at Rocky Reach Dam

groups observed below Priest Rapids (16), Wanapum (36), Rock Island (6), and Rocky Reach Dams (26). A major exception to this pattern was observed in 21 fish that migrated into the Okanogan River. A few fish were last detected at the confluences of the Columbia River and its tributaries: two were detected at the mouth of the Wenatchee River; four at the Entiat River; nine at the Chelan River; and one at the mouth of the Okanogan River. We could not estimate maximum mortality for fall chinook salmon, because pre-spawning mortalities could not be separated from spawners. However, a fraction of the fish that fell back but did not reascend the fishways were probably pre-spawning mortalities.

Adult Collection Channel Efficiency

Priest Rapids Dam

Spring chinook salmon at Priest Rapids Dam had net positive entries (number of entries higher than number of exits) at 8 of the 11 powerhouse collection-channel openings (Fig. 9). Locations of their last powerhouse collection-channel entry were spread across the collection channel (Fig. 10). Fish moved both directions in the channel but tended to move toward the fish ladder (Fig. 11). Fish entering at 6 of the 11 openings had a greater than 50% probability of reaching the base of the fish ladder before exiting the channel either downstream or via the fish ladder (Fig. 12). All of the openings where fish had less than a 50% chance of being at the base of the ladder before exiting were orifice gate openings.



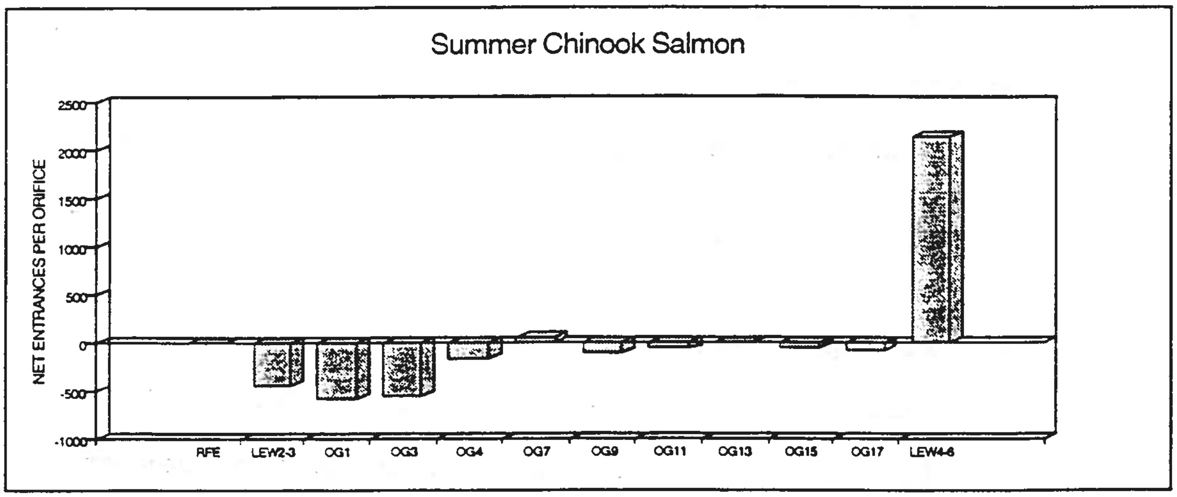


Figure 9.--Net passage per collection-channel opening at Priest Rapids Dam, 1993; RFE (Right Fishway Entrance), LEW (Left Entrance Weir), and OG (Orifice Gates).

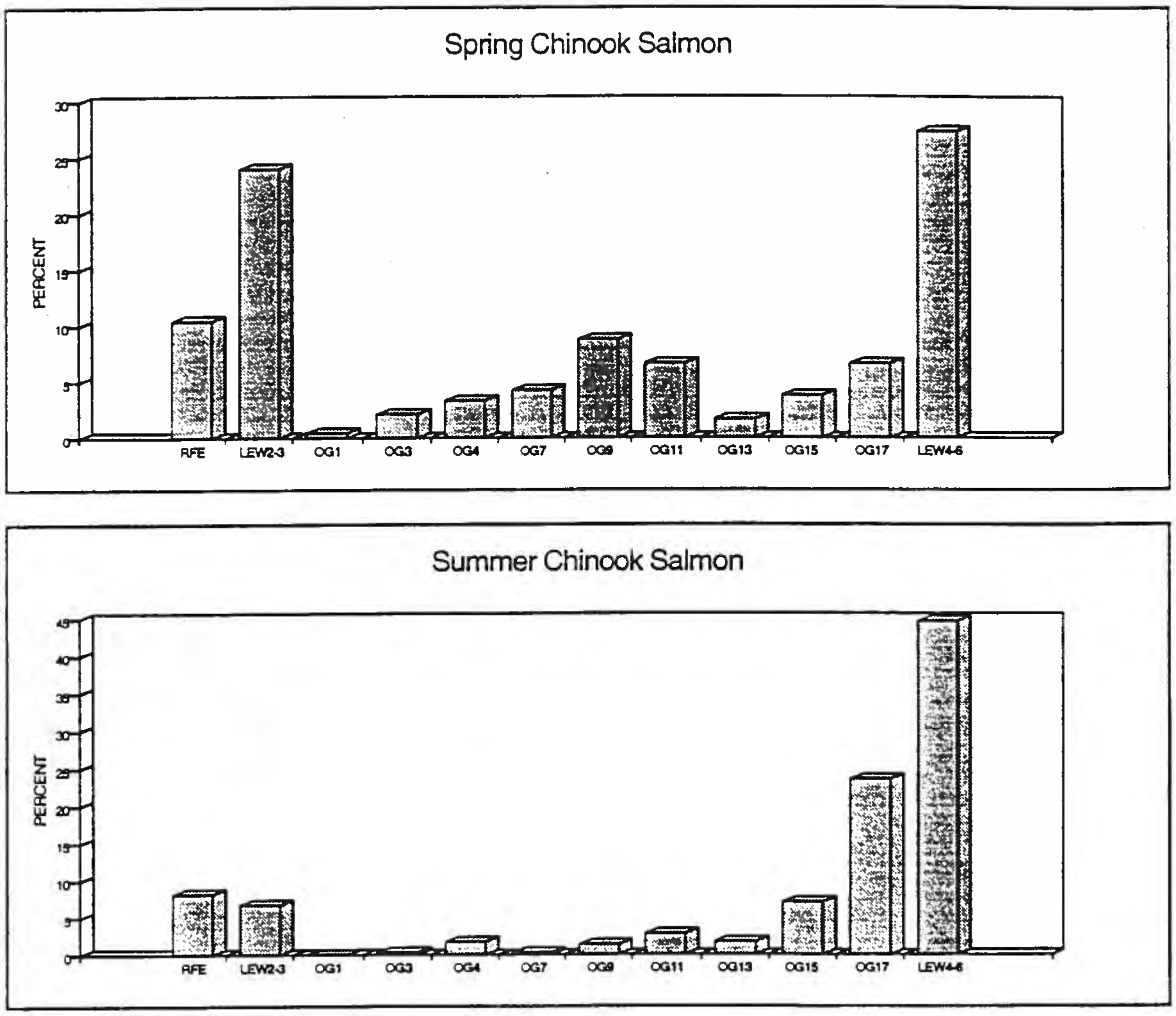


Figure 10.--Percent of last entrances per collection-channel opening at Priest Rapids Dam, 1993; RFE (Right Fishway Entrance), LEW (Left Entrance Weir), and OG (Orifice Gates).

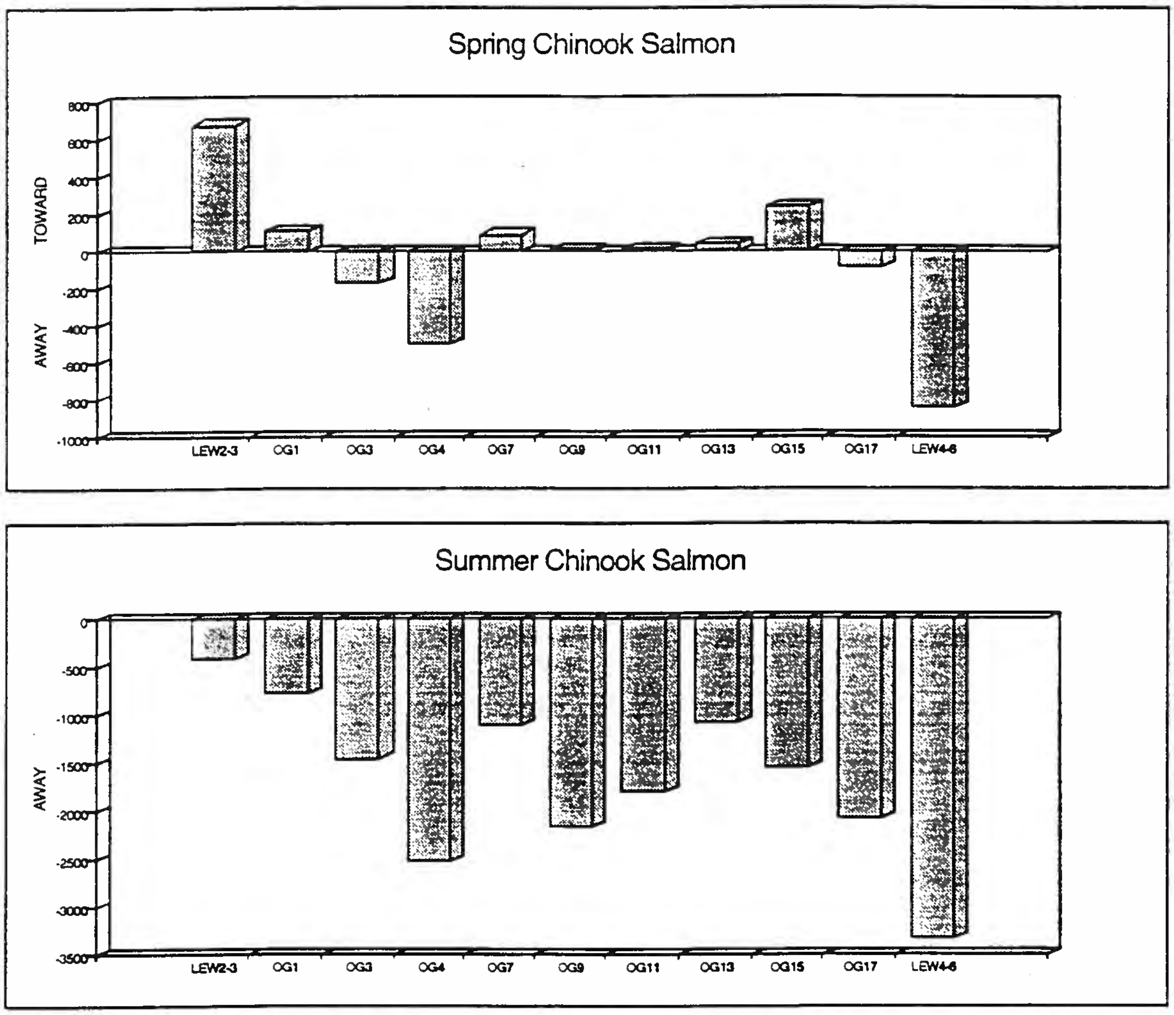
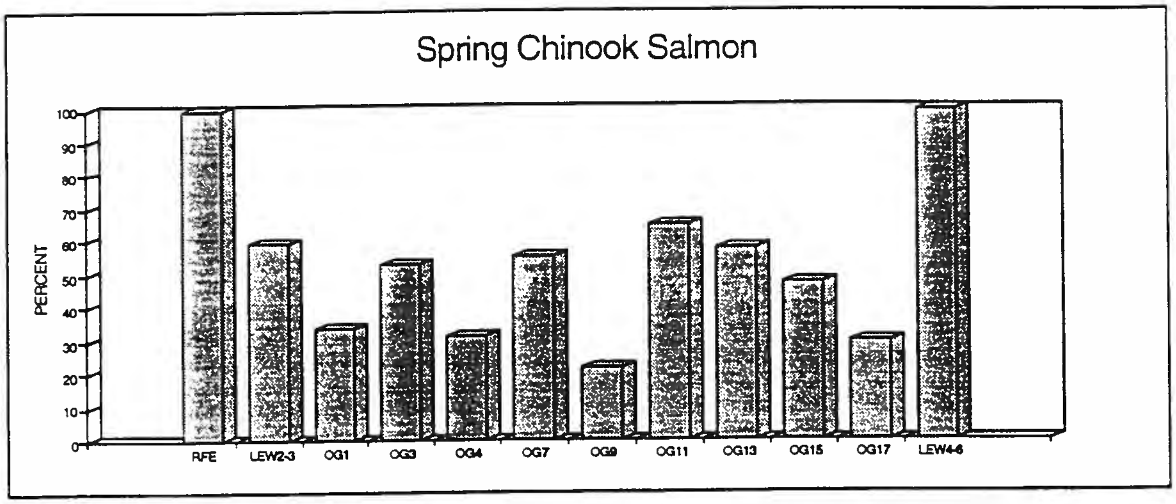


Figure 11.--Net movement toward the fish ladder per collection-channel opening in the Priest Rapids Dam collection channel, 1993; RFE (Right Fishway Entrance), **LEW** (Left Entrance Weir), and OG (Orifice Gates).



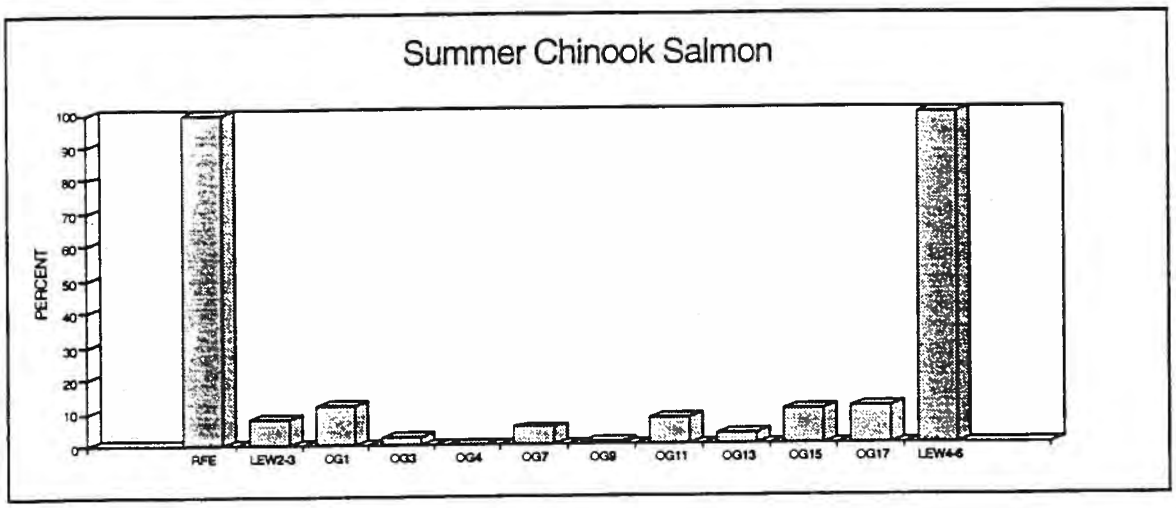


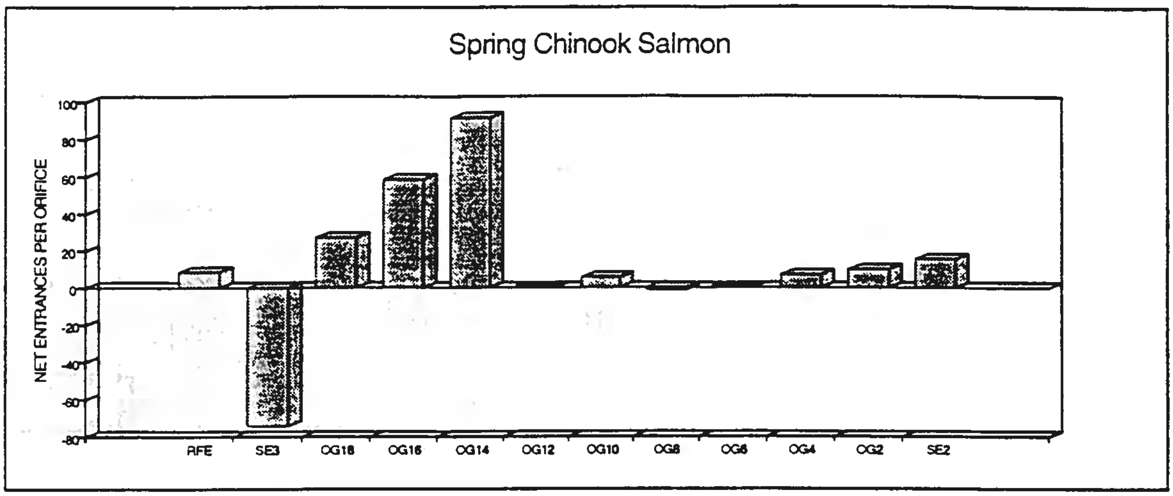
Figure 12.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Priest Rapids Dam, 1993.

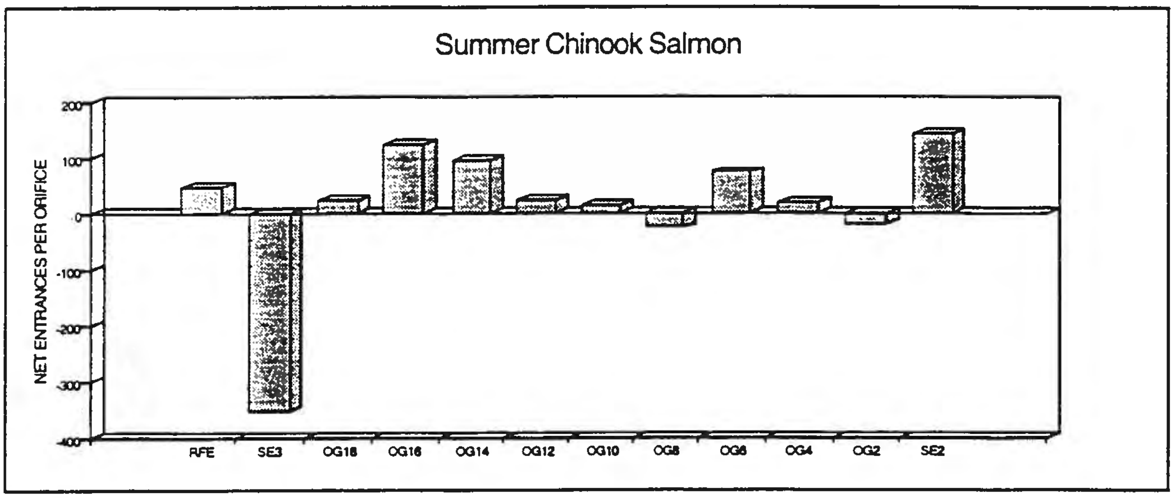
Summer chinook salmon behavior was different at the powerhouse collection channel openings and within the channel compared to spring chinook salmon. Net entries at most of the openings were negative (Fig. 9), and last entry locations were concentrated at the base of the fish ladder (Fig. 10). Also, summer chinook salmon movement in the channel was away from the fish ladder (Fig. 11), and less than 10% of the entries at most openings produced a record on the antenna at the base of the fish ladder before the fish fell out of the collection channel (Fig. 12).

Wanapum Dam

At Wanapum Dam, spring and summer chinook salmon detections yielded net positive entries at most of the powerhouse collection channel openings with the exception of the highly negative net entrance rate of fish at Slotted Entrance 3 (SE3) (results for SE3 are the sum of observations for SE3 and Orifice Gate 20 (OG20)) (Fig. 13). However, nearly half of the spring chinook salmon that entered the channel at SE3 traversed to the base of the fish ladder (Fig. 14). Nearly 25% of spring chinook salmon passing the fish ladder and 13% of summer chinook salmon passing the fish ladder (Fig. 15) made their last powerhouse collection-channel entry at SE3.

In contrast, fall chinook salmon had a positive net entry at SE3 (Fig. 13), where 20% of their last channel entrances were recorded (Fig. 15).





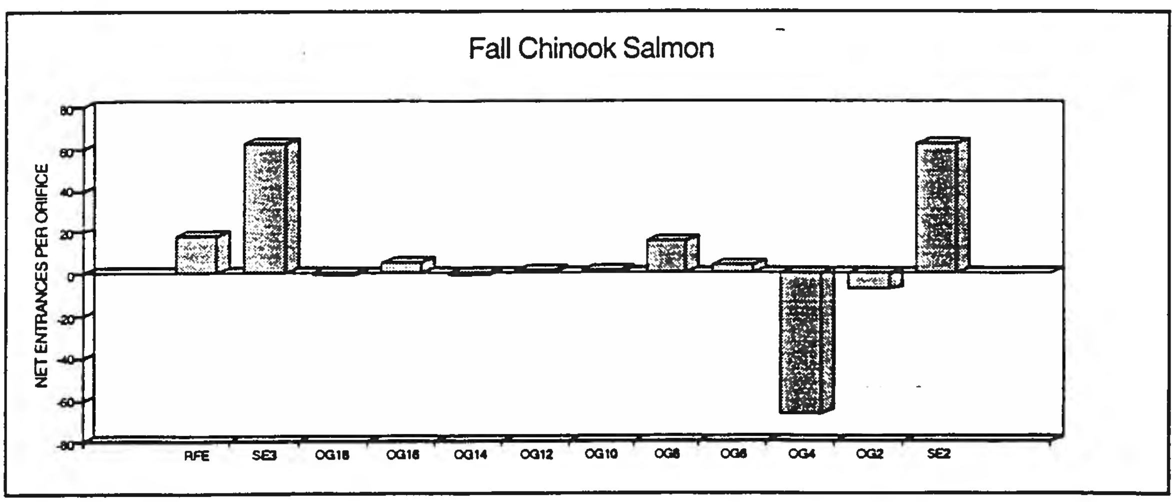


Figure 13.--Net passage per collection-channel opening at Wanapum Dam, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).

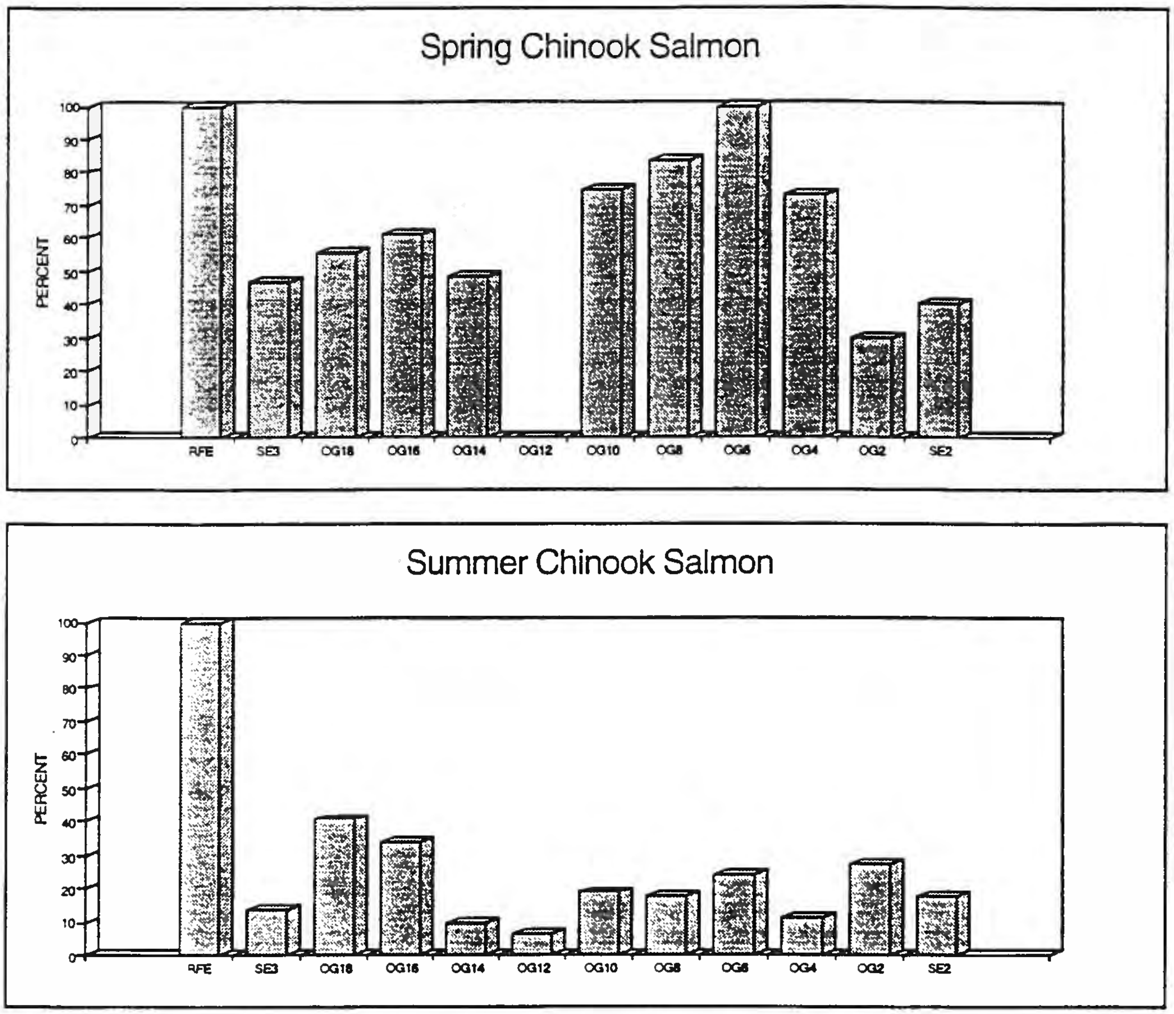


Figure 14.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Wanapum Dam, 1993.

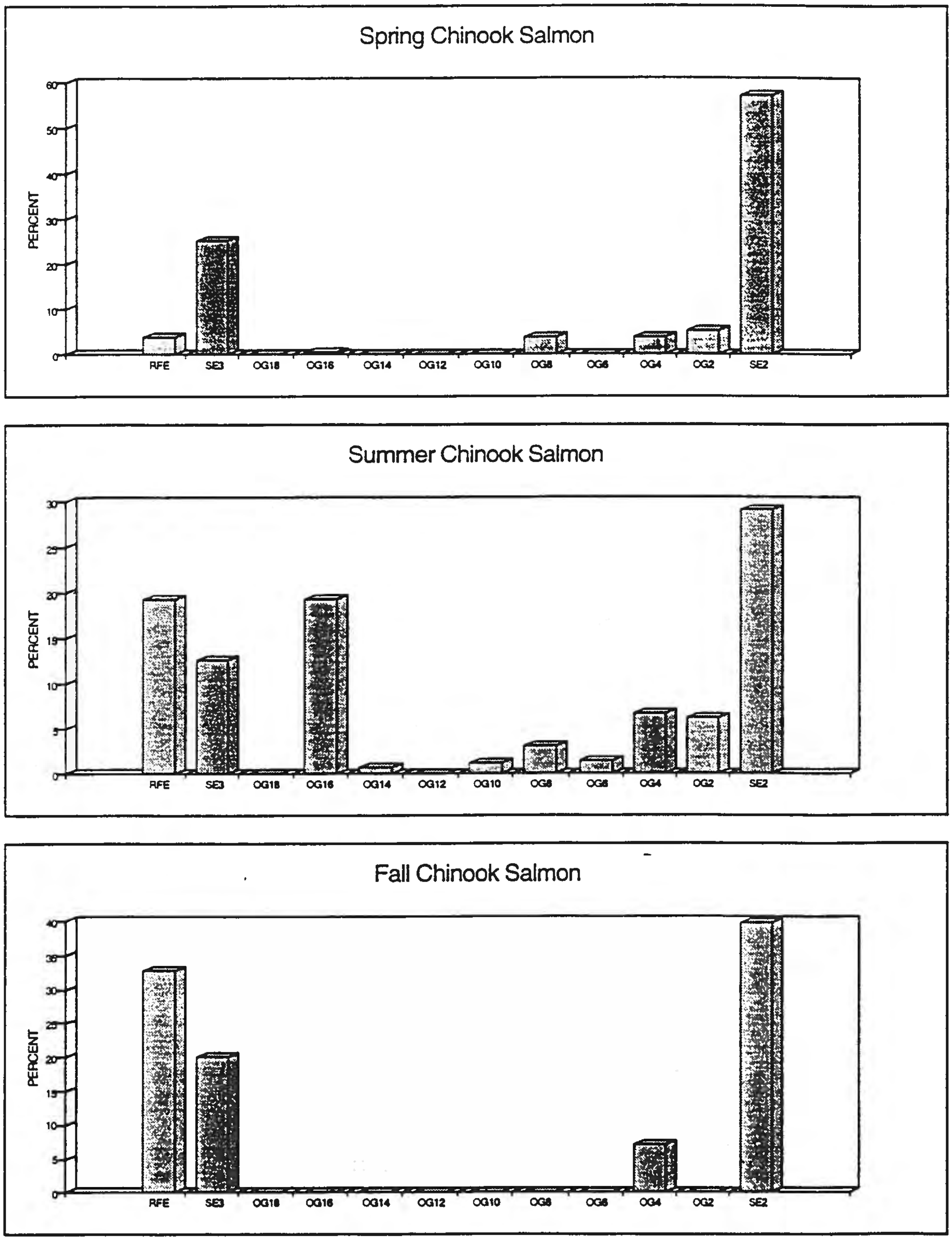


Figure 15.--Percent of last entrances per collection-channel opening at Wanapum Dam, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).

Fish moved mostly in the channel toward the fish ladder during the spring run and away from the fish ladder during the summer run (Fig. 16).

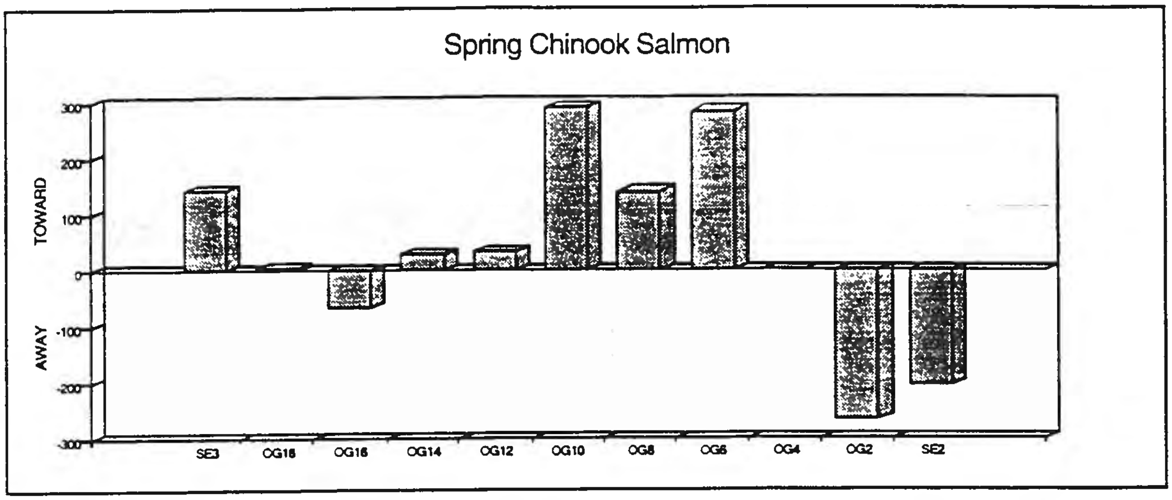
Rock Island Dam

At Rock Island Dam, spring and summer chinook salmon had positive net entries at two collection channel openings: the Right Powerhouse Right Entrance (RPRE), and the Right Powerhouse Left Entrance (RPLE) (Fig. 17). One collection channel opening, the Right Powerhouse Downstream (RPDS), had a negative net entry, and the Right Bank Left Powerhouse Entrance (RBLPE) was ineffective for fish passage. For fall chinook salmon, the RPDS opening produced the highest net entry. Entries into the fish ladder were made from all of the right powerhouse collection-channel openings (Fig. 18), with RBLPE used the least. The proportion of spring and summer chinook salmon reaching the base of the fish ladder were nearly equal (Fig. 19).

At the Center (CLAD) and Left Powerhouse Entrance (LPHE) net entrances were slightly positive yet they provide a significant percentage of the total last entrances.

Rocky Reach Dam

Net entries for spring and summer chinook salmon at the Rocky Reach Dam collection-channel openings were very similar (Fig. 20). The majority of positive entries occurred through Orifice Passage Entrance 18 (OPE18) and LPE while the collection-channel openings at RPE-OPE20 (combined) and the Spill Entrance



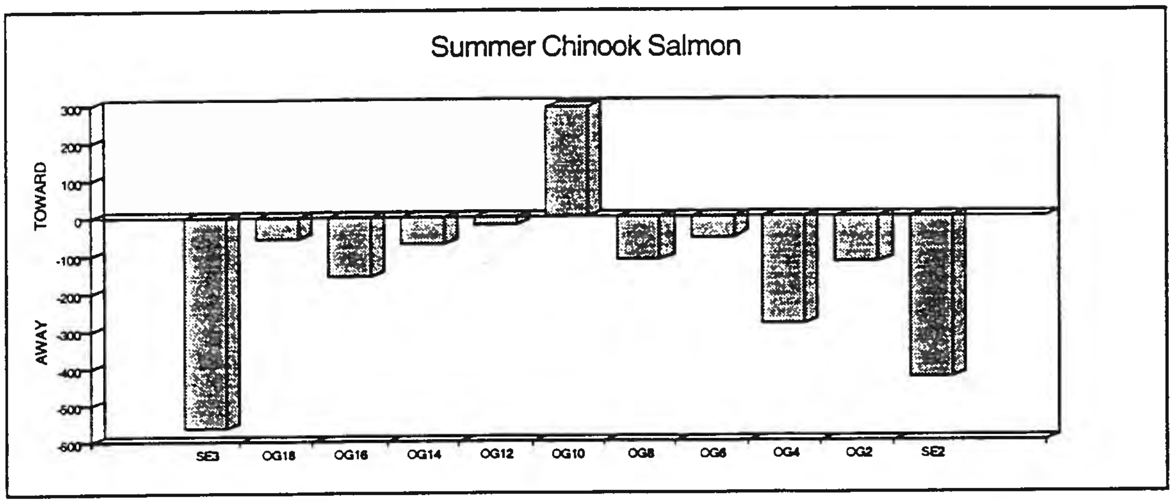


Figure 16.--Net movement toward the fish ladder per collection-channel opening in the Wanapum Dam collection channel, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).

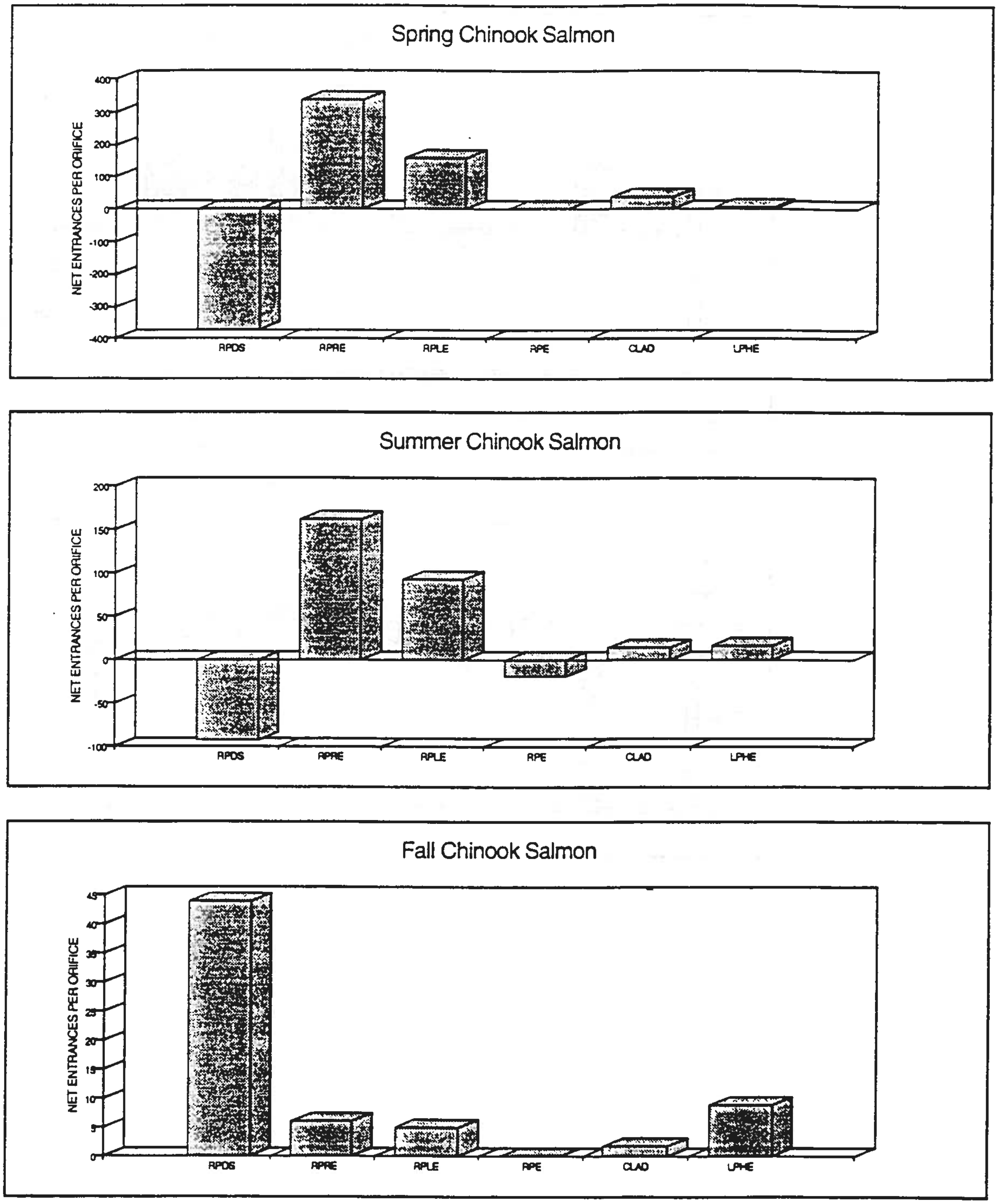


Figure 17.--Net passage per collection-channel opening Rock Island Dam, 1993; RPDS (Right Powerhouse Downstream), RPRE (Right Powerhouse Right Entrance), RPLE (Right Powerhouse Left Entrance), RBLPE (Right Bank Left Powerhouse Entrance), CLAD (Center Ladder Entrance), and LPHE (Left Powerhouse Entrance).

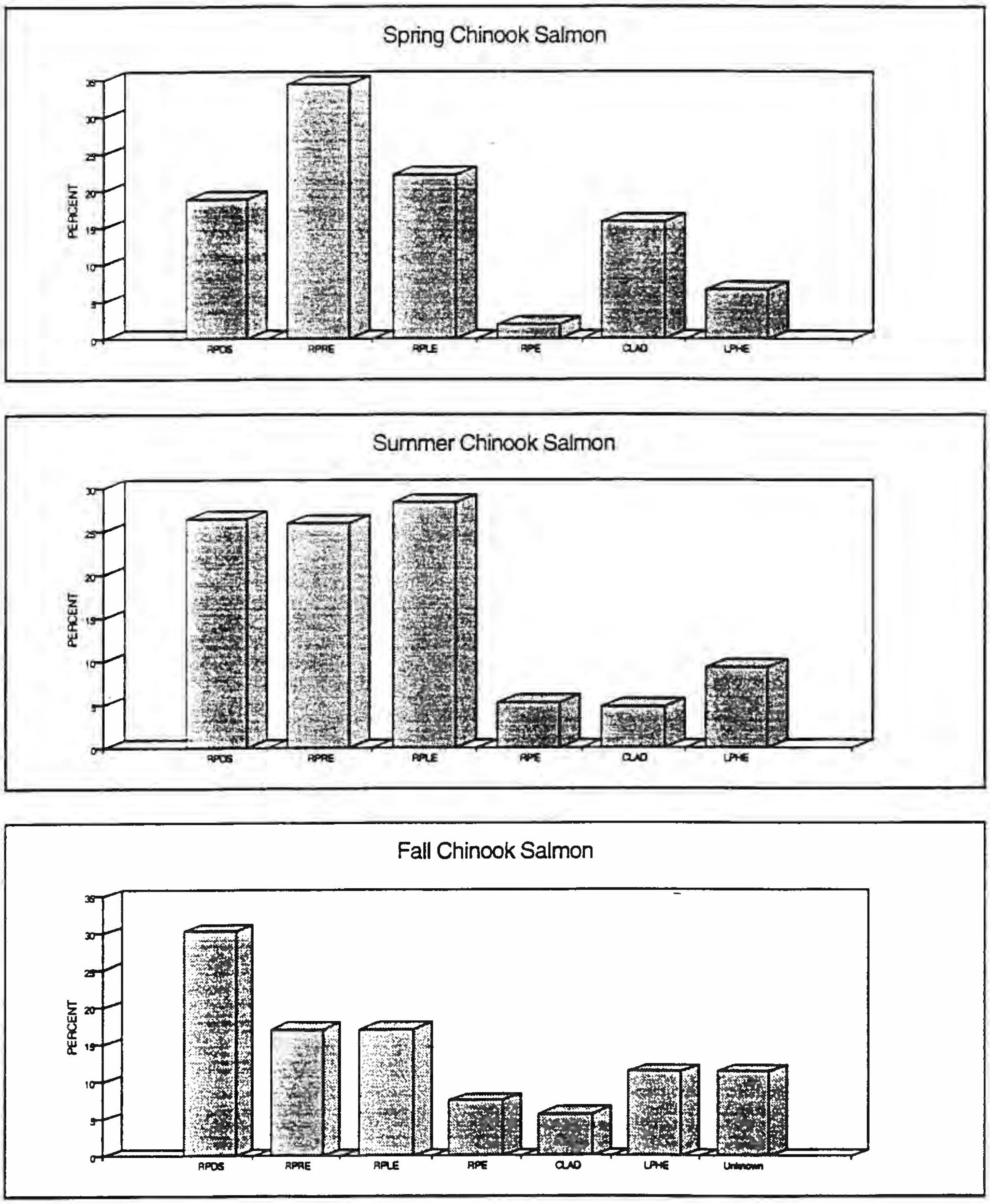


Figure 18.--Percent of last collection-channel opening per entrance at Rock Island Dam, 1993; RPDS (Right Powerhouse Downstream), RPRE (Right Powerhouse Right Entrance), RPLE (Right Powerhouse Left Entrance), RBLPE (Right Bank Left Powerhouse Entrance), CLAD (Center Ladder Entrance), and LPHE (Left Powerhouse Entrance).

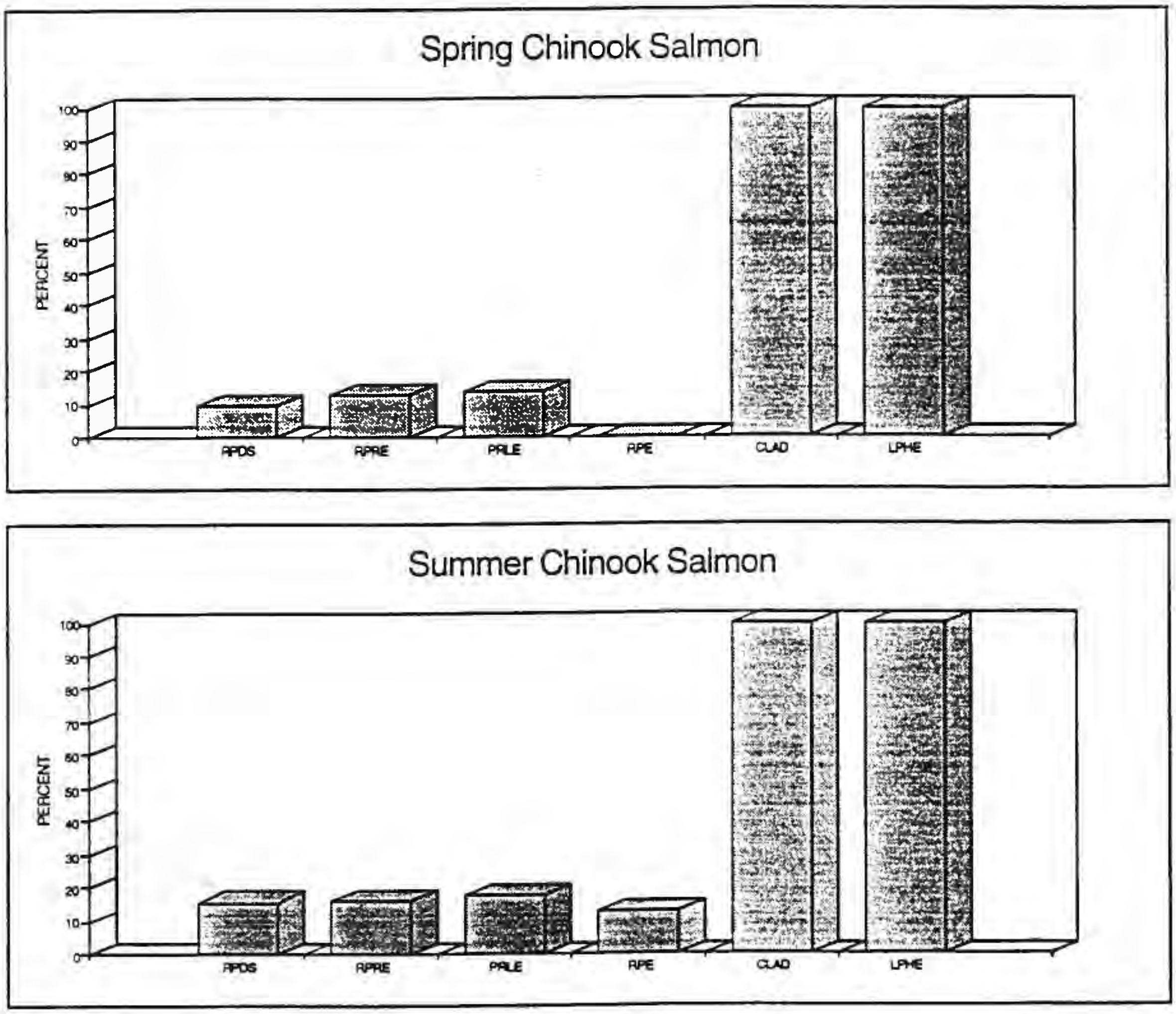


Figure 19.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Rock Island Dam, 1993.

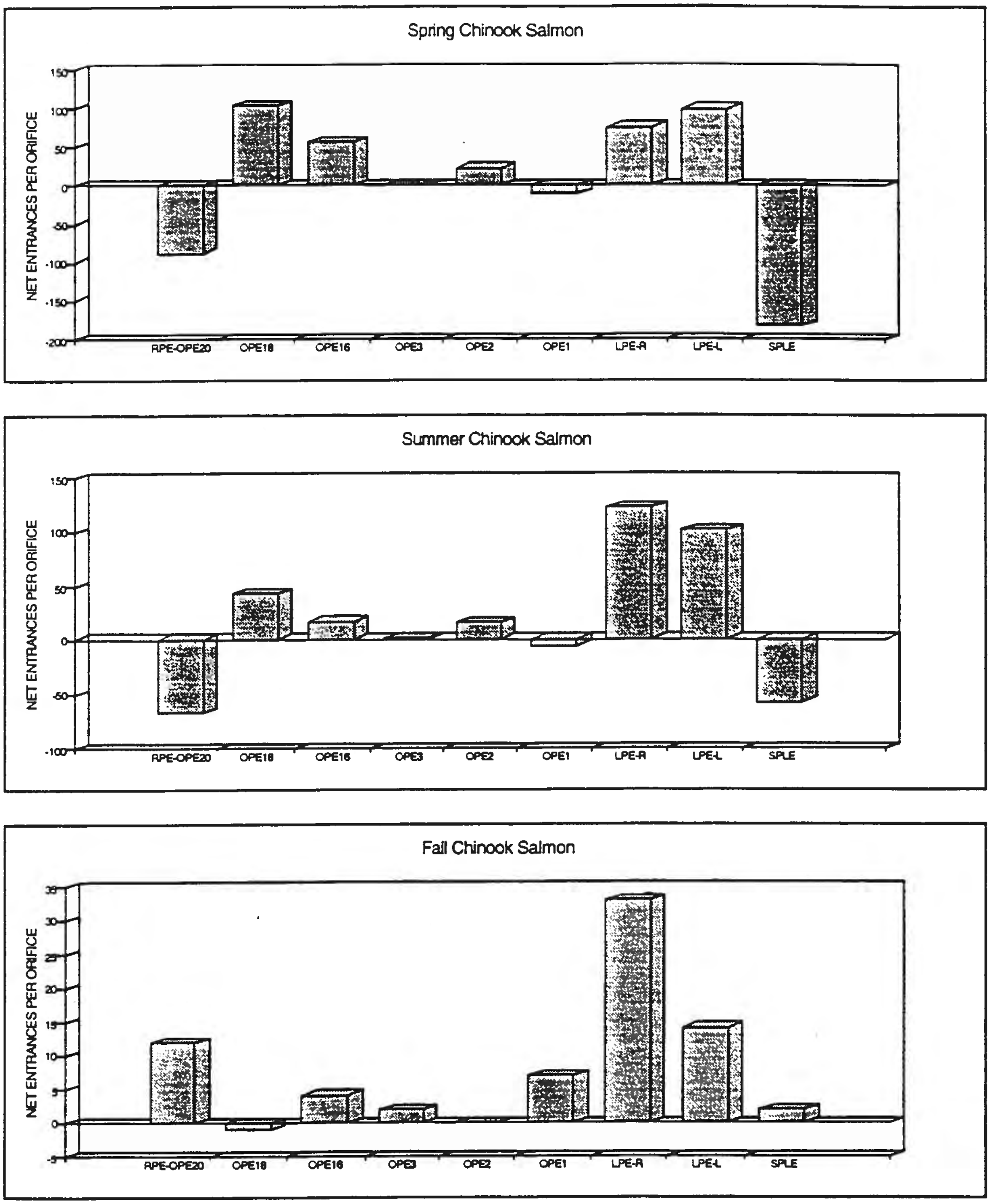


Figure 20.--Net passage per collection-channel opening at Rocky Reach Dam, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).

(SPLE) were ineffective. Fall chinook salmon had positive net entries through almost all collection-channel openings, including the combined RPE-OPE20 and the SPLE. The OPE18 opening was a minor exception.

The majority of last collection-channel entrances were made near the base of the fish ladder at OPE1 and LPE for spring, summer, and fall chinook salmon (Fig. 21). Movement in the collection channel was distinctly toward the fish ladder during the spring run and somewhat less so during the summer run (Fig. 22). The high rate of movement away from the fish ladder through LPE was caused by large numbers of fish moving to the junction pool after entry at LPE and then back down the channel to exit through the LPE. The probability of reaching the base of the fish ladder was dependent on opening location, and was higher for spring chinook salmon than summer chinook salmon, with the exception of the combined RPE-OPE20 (Fig. 23).

Wells Dam

Low net entries or low negative net entrances were recorded for spring and summer chinook salmon at the Wells Dam collection-channel openings facing the powerhouse/spill channel (RSE and LSE) (Fig. 24). For fall chinook salmon, positive net entries were recorded at three collection channel openings: the Left Side Entrance (LSE), the Left Downstream Entrance (LDSE), and the Right Side Entrance (RSE). Each of these collection channel openings was used to access the fish-ladders, with the LDSE as

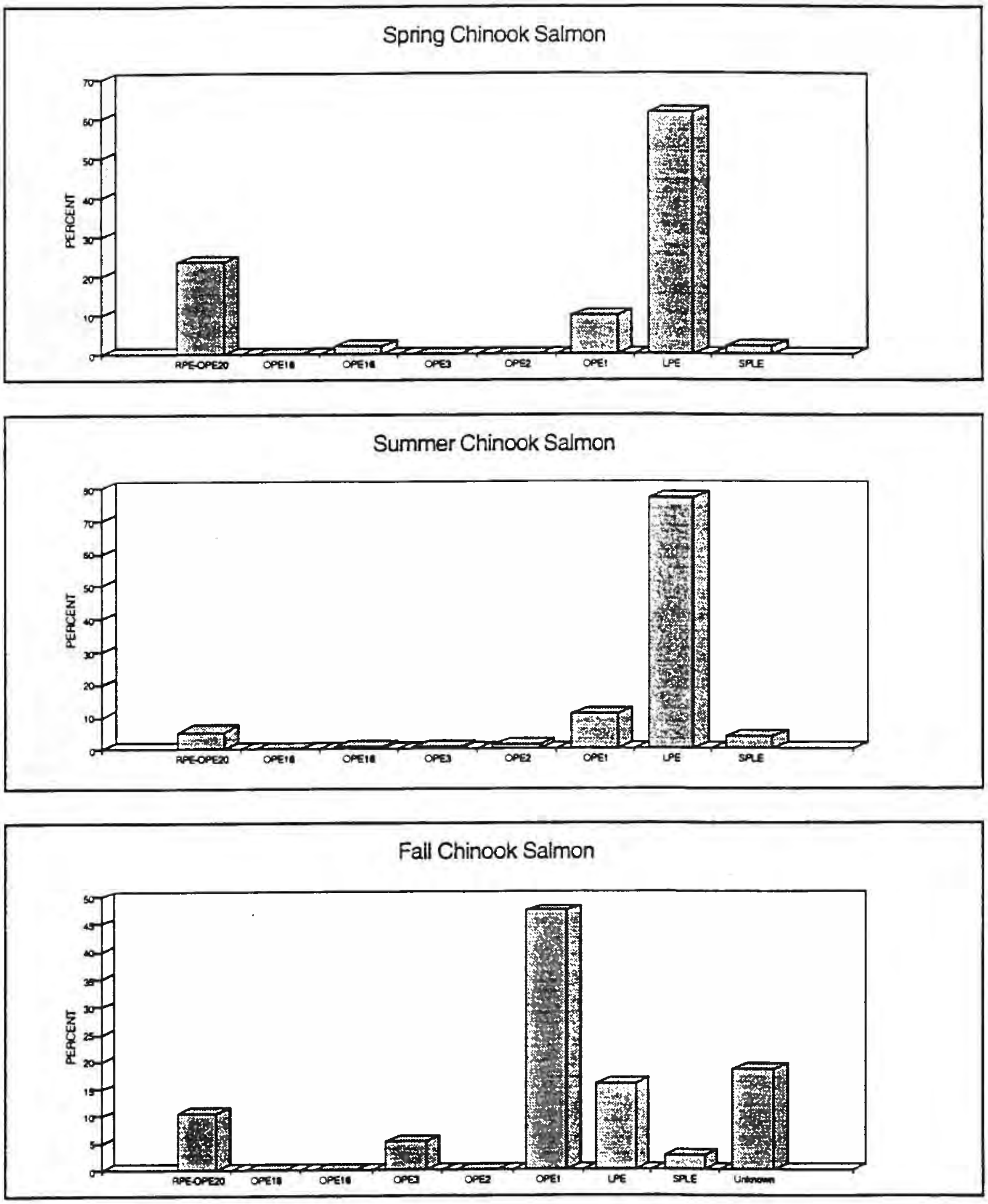
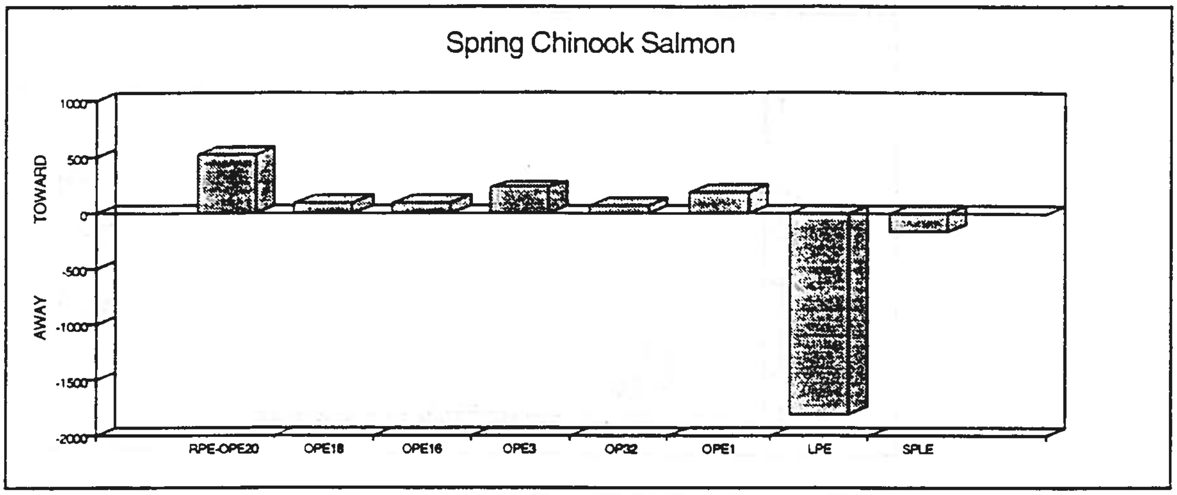


Figure 21.--Percent of last entrances per collection-channel opening at Rocky Reach Dam, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).



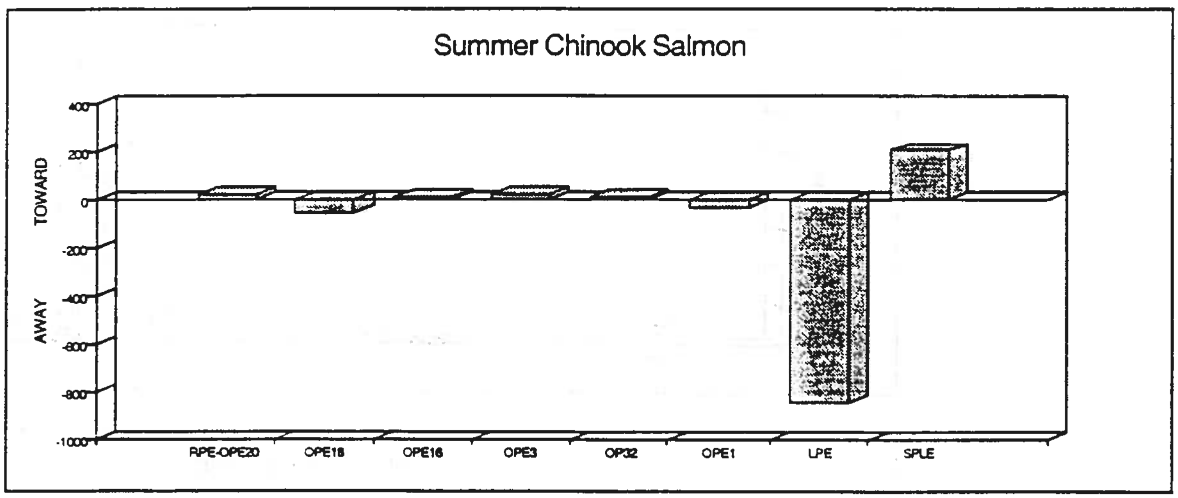


Figure 22.--Net movement toward the fish ladder per collection-channel opening in the Rocky Reach Dam collection channel, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).

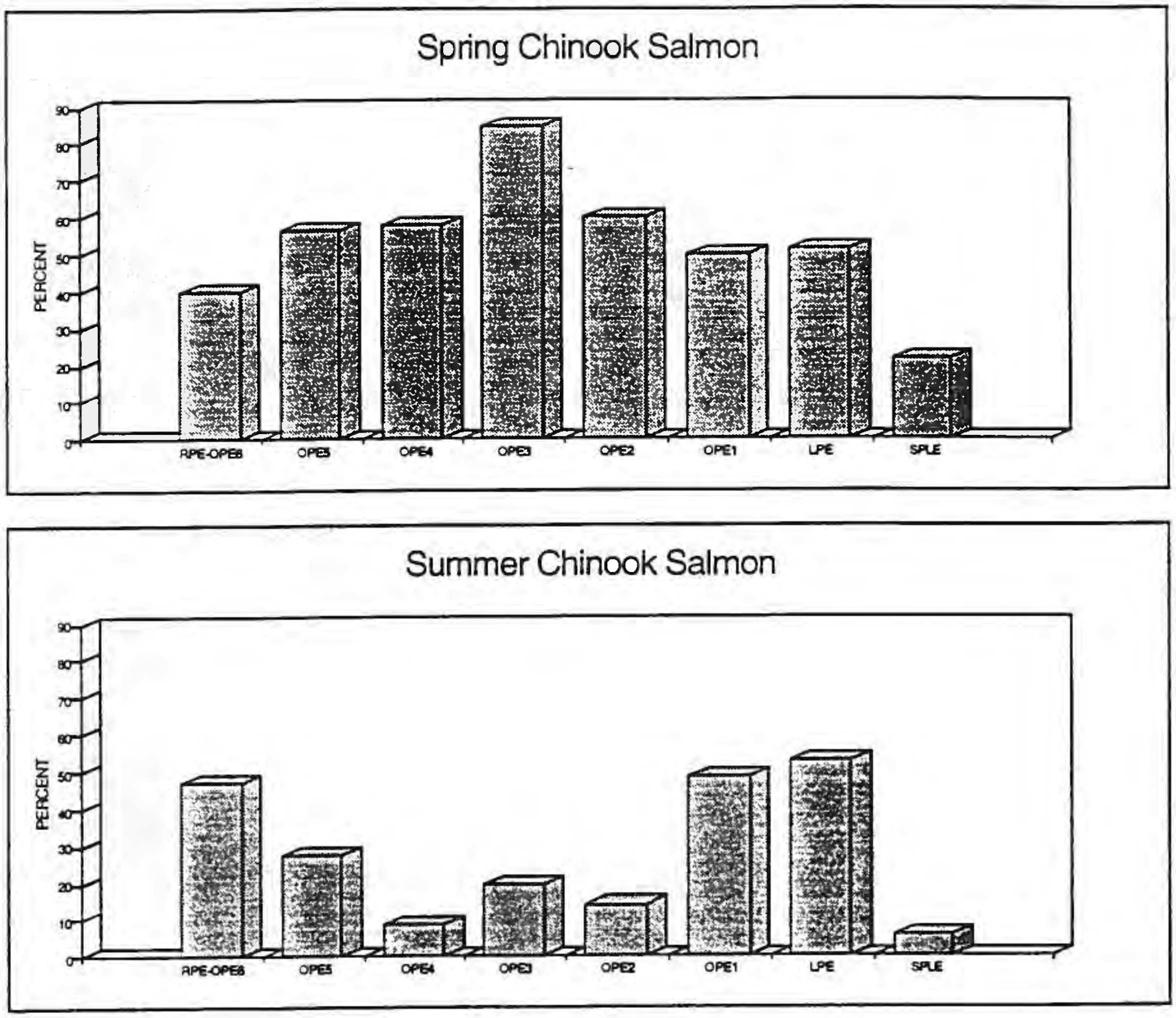


Figure 23.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Rocky Reach Dam, 1993.

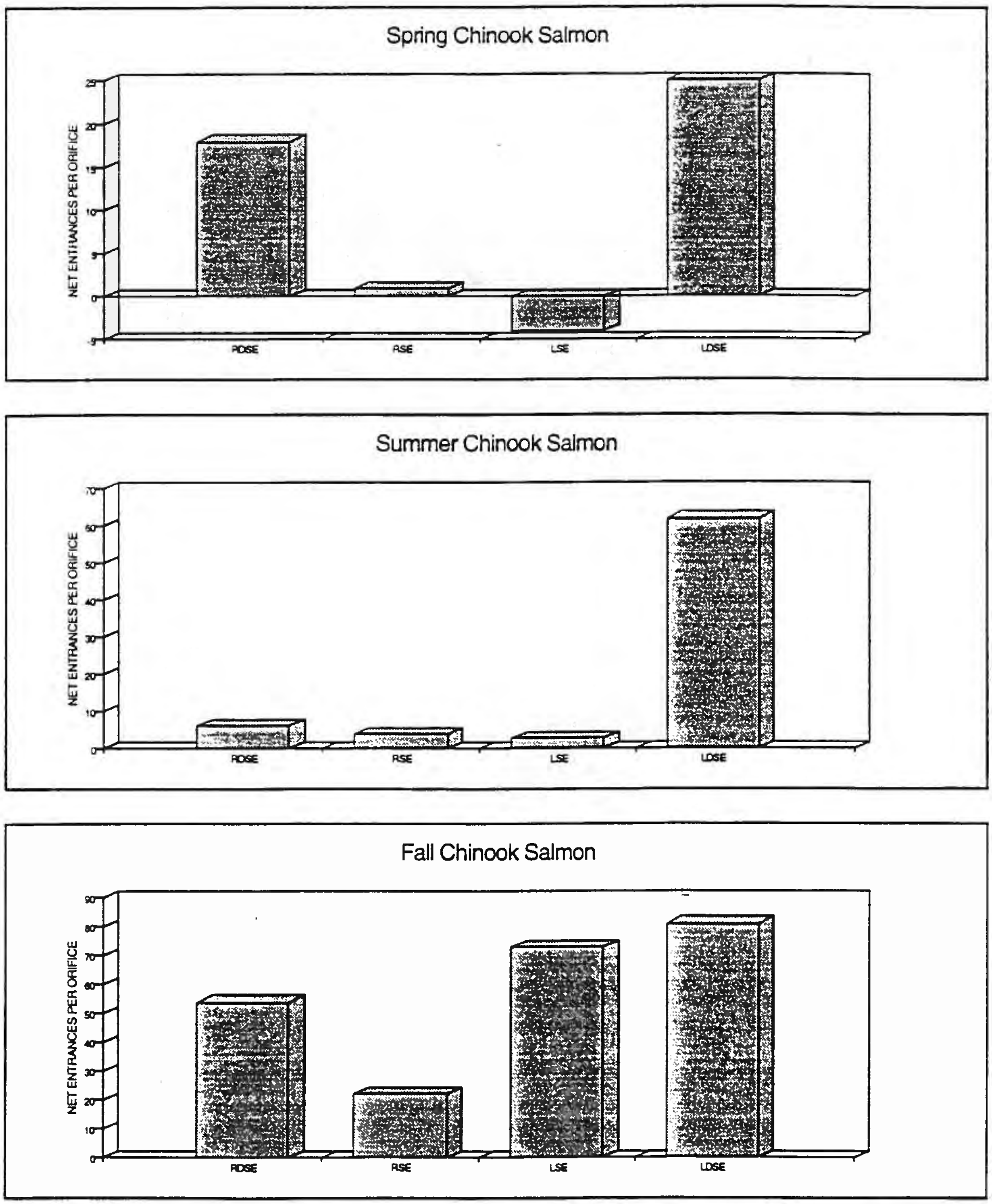


Figure 24.--Net passage per collection-channel opening at Wells Dam, 1993; RDSE (Right Downstream Entrance), RSE (Right Side Entrance), LDSE (Left Downstream Entrance), and LSE (Left Side Entrance).

the most frequently used (Fig. 25). During the summer chinook salmon migration, the highest entry rate observed at Wells Dam was at the LSE.

Fish-Ladder Selection

At Priest Rapids Dam, 93.9 and 92.0% of the spring and summer chinook salmon favored the left-bank fish ladder (Table 10). Additional fish may have passed the right-bank fish ladder without detection, as all detections were made by a single antenna at the top of the fish ladder. For example, 17 spring and 9 summer chinook salmon that were recorded upstream from Priest Rapids Dam were not recorded by the fish-ladder exit monitors at Priest Rapids Dam; neither were they transported to the forebay from the Priest Rapids Hatchery trap.

At Wanapum Dam, radio-tagged fish also preferred the left-bank fish ladder (spring chinook salmon, 96.7%; summer chinook salmon, 78.5%; and fall chinook salmon, 82.5%). However, the efficiency of the right-bank fish-ladder exit monitor may have been reduced by radio-frequency noise. Based on upstream monitors, 9 spring and 48 summer chinook salmon were not recorded and apparently passed the right-bank fish ladder.

Fish at Rock Island Dam favored the right-bank fish ladder (spring chinook salmon, 74.6%; summer chinook salmon, 87.0%; and fall chinook salmon, 78.9%). At Wells Dam, the majority of radio-tagged fish chose the left-bank fish ladder (spring chinook salmon, 51.8%; summer chinook salmon, 89.8%; fall chinook salmon, 61.5%).

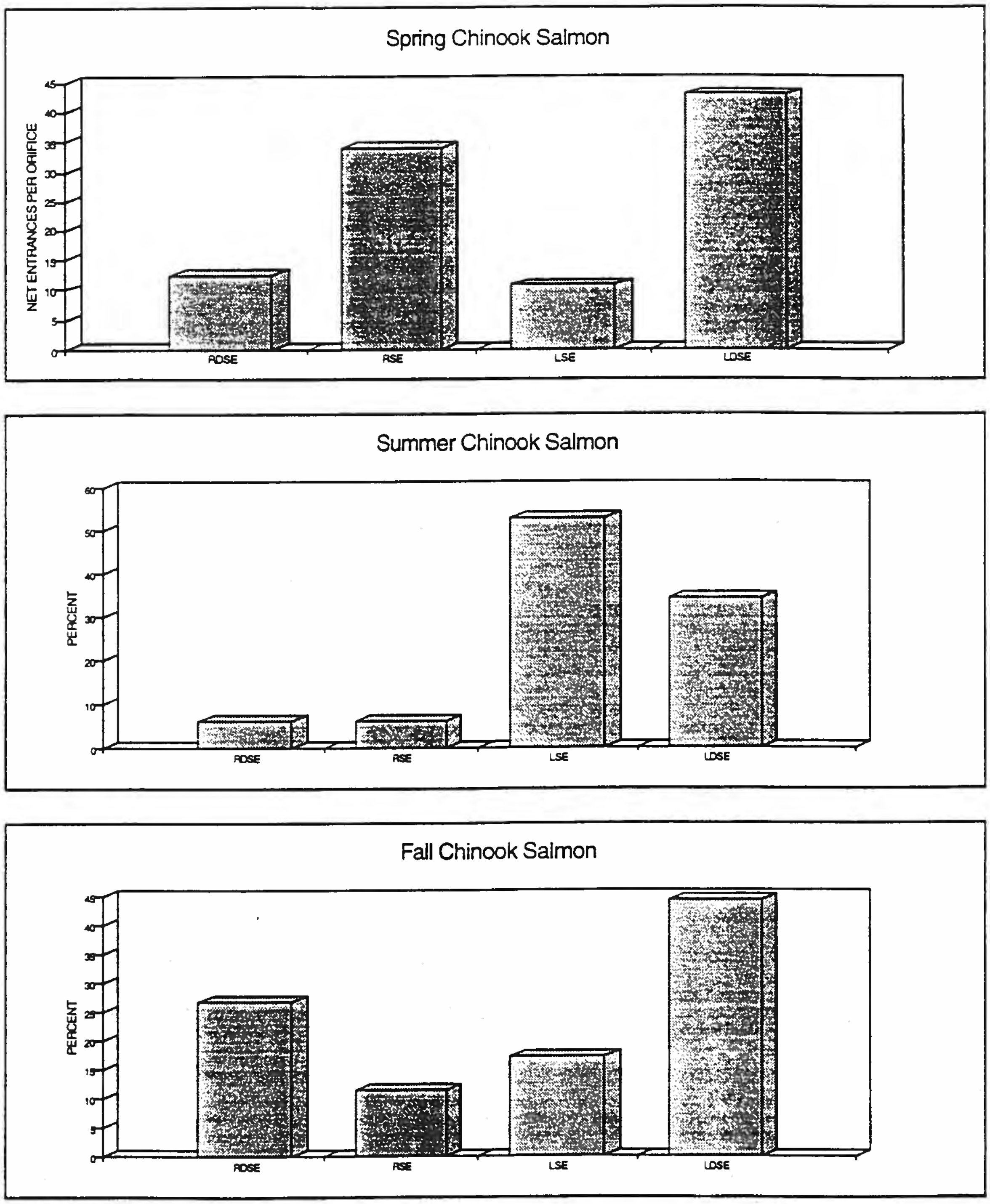


Figure 25.--Percent of last entrances per collection-channel opening per entrance at Wells Dam, 1993; RDSE (Right Downstream Entrance), RSE (Right Side Entrance), LDSE (Left Downstream Entrance), and LSE (Left Side Entrance).

Table 10.--Fish-ladder selection by radio-tagged spring, summer, and fall chinook salmon at the mid-Columbia River dams, 1993.

	Left	Center	Right
Spring Chinook Salmon			
Priest Rapids Dam	185	-	12
Wanapum Dam	204	-	7
Rock Island Dam	5	5	147
Rocky Reach Dam	-	-	89
Wells Dam	29	-	27
Summer Chinook Salmon			
Priest Rapids Dam	241	-	21
Wanapum Dam	165	-	44
Rock Island Dam	17	15	215
Rocky Reach Dam	-	-	128
Wells Dam	88	-	10
Fall Chinook Salmon			
Wanapum Dam	33	-	7
Rock Island Dam	6	2	30
Rocky Reach Dam	-	-	194
Wells Dam	32	-	20

Fallback and the Fate of Fallback Fish

Priest Rapids Dam

Of the 35 spring chinook salmon fallbacks (Table 11), 24 were last detected downstream (Table 12). Six of the 24 were recaptured at the Ringold Spring Chinook Salmon Facility, 2 strayed into the Priest Rapids Hatchery, and 16 displayed overshoot behavior or milling behavior in the McNary Reservoir similar to that of fish recovered at the Ringold Facility. Five of the 35 fallbacks entered the Wenatchee River, one entered the Okanogan River, and five were distributed in the mainstem Columbia River between Wanapum and Wells Dams. The fate of fallbacks that did not enter spawning tributaries or the Ringold Facility were potentially the same as all other fish last detected in the main stem: pre-spawning mortality, harvest, mainstem spawning, or tag failure.

Three of the four Priest Rapids Dam summer chinook salmon fallbacks were last detected upstream (two in the Wenatchee River and one at the Wells Hatchery). The fourth fallback was last detected downstream from Priest Rapids Dam in the Hanford Reach.

Eighteen fall chinook salmon tagged at Priest Rapids Dam were fallbacks (Table 11). One of these fish passed the dam twice and subsequently entered the Wells Salmon Hatchery (Table 12). The remainder stayed below the dam. One was harvested from the Hanford Reach, six were last recorded in the Hanford Reach, eight entered the Priest Rapids Salmon Hatchery, and two were last recorded in the Priest Rapids Dam tailrace.

Table 11.--Summary of fallbacks of radio-tagged spring, summer, and fall chinook salmon at mid-Columbia River dams.

Dam	Spring chinook salmon			Summer chinook salmon			Fall chinook salmon		
	Number passing	Number of fallbacks	(%)	Number passing	Number of fallbacks	(%)	Number passing	Number of fallbacks	(%)
Priest Rapids	197	35	(17.7)	261	4	(1.5)	123	18	(14.6)
Wanapum	211	17	(8.1)	209	2	(1.0)	58	3	(5.2)
Rock Island	197	5	(2.5)	247	7	(2.8)	53	7	(13.2)
Rocky Reach	89	0	(0.0)	128	5	(3.9)	194	22	(11.3)
Tagged P.R. Dam							38	5	(13.2)
Tagged R.R. Dam							156	17	(10.9)
Wells	56	2	(3.6)	98	14	(14.3)	52	11	(21.2)

Table 12.--Fate of radio-tagged chinook salmon fallbacks at the mid-Columbia River dams, 1993.

Location of fallback	Number
Priest Rapids Dam	
Spring chinook salmon	
Ringold Spring Chinook Salmon Facility	6
Priest Rapids Hatchery	2
McNary Reservoir	16
Mainstem Columbia River upstream	5
Wenatchee River	5
Okanogan River	1
Summer chinook salmon	
Hanford Reach	1
Wenatchee River	2
Wells Hatchery	1
Fall chinook salmon	
Hanford Reach harvest	1
Hanford Reach	6
Priest Rapids Hatchery	8
Priest Rapids tailrace	2
Wells Hatchery	1
Wanapum Dam	
Spring chinook salmon	
Ringold Spring Chinook Salmon Facility	2
McNary Reservoir	4
Downstream from Wanapum Dam	2
Wenatchee River	8
Okanogan River	1
Summer chinook salmon	
Wenatchee River	1
Okanogan River	1
Fall chinook salmon	
Wanapum Dam tailrace	3
Rock Island Dam	
Spring chinook salmon	
Wenatchee River	4
Entiat River	1
Summer chinook salmon	
Rock Island Dam tailrace	5
Wenatchee River	1
Wells Hatchery	1
Fall chinook salmon	
Crescent Bar area	1
Rock Island Dam tailrace	6

Table 12.--Continued.

Location of fallback	Number
Rocky Reach Dam	
Spring chinook salmon	
Summer chinook salmon	
Rock Island Dam tailrace	1
Wenatchee River	4
Fall chinook salmon	
Rock Island Dam tailrace	3
Rock Island Reservoir harvest	1
Rock Island Reservoir	4
Rocky Reach Dam tailrace	13
Wells Dam tailrace	1
Wells Dam	
Spring chinook salmon	
Entiat River	2
Summer chinook salmon	
Wenatchee River	1
Entiat River	1
Wells Dam tailrace	4
Wells Hatchery	2
Methow River	3
Okanogan River	2
Chief Joseph Dam harvest	1
Fall chinook salmon	
Rocky Reach Reservoir harvest	1
Wells Dam tailrace	6
Wells Hatchery	3
Okanogan River	1

Wanapum Dam

At Wanapum Dam, 6 of the 17 spring chinook salmon fallbacks (Table 11) returned to below Priest Rapids Dam. Two of these six fish were recaptured at the Ringold Spring Chinook Salmon Facility (Table 12). Eight of the 17 fallbacks terminated in the Wenatchee River, and one returned to the Okanogan River. The remaining two fish were last detected downstream from Wanapum Dam.

Two summer chinook salmon fallbacks were last detected upstream from Wanapum Dam: one in the Wenatchee River and one in the Okanogan River.

Only three fall chinook salmon fallbacks were observed at Wanapum Dam and they remained in the Wanapum Dam tailrace.

Rock Island Dam

All five spring chinook salmon fallbacks (Table 11) survived to enter spawning tributaries: four entered the Wenatchee River and one entered the Entiat River (Table 12).

Five of the seven summer chinook salmon fallbacks were last detected in the tailrace near the dam. The remaining two fish entered either the Wenatchee River or the Wells Hatchery. Of the five fallbacks last detected below the dam, four were detected above the Wenatchee River confluence before returning to below Rock Island Dam.

The fall chinook salmon fallbacks at Rock Island Dam (Table 13) were last recorded in the Rock Island Dam tailrace or in the Crescent Bar area (Table 12).

Rocky Reach Dam

No spring chinook salmon and five summer chinook salmon were fallbacks at Rocky Reach Dam (Table 11). Four of the five summer chinook salmon fallbacks were apparent overshoots from the Wenatchee River (Table 12), and the fifth was last detected just upstream from Rock Island Dam.

Twenty-two fall chinook salmon fallbacks were observed (Table 11). Thirteen of these remained in the tailrace (Table 12), three continued downstream to the Rock Island Dam tailrace, four were last recorded in the Rock Island Dam reservoir, one was harvested from the Rock Island Dam reservoir, and one passed a second time and was last detected in the Wells Dam tailrace.

Wells Dam

Two spring chinook salmon fallbacks were observed at Wells Dam (Table 11), and both subsequently entered the Entiat River (Table 12).

Fourteen summer chinook salmon fallbacks were observed at Wells Dam (Table 11): six were last detected upstream and eight were last detected downstream from Wells Dam (Table 12). Three of the upstream fish were last monitored in the Methow River, two in the Okanogan River, and one was captured below Chief Joseph Dam. The eight downstream fish were last detected in the Wenatchee River, the Entiat River, Wells Hatchery (2), and Wells Dam tailrace (4).

Eleven (21.2%) fall chinook salmon fallbacks were observed at Wells Dam (Table 12). Six remained in the tailrace, three entered the Wells Salmon Hatchery, one was harvested downstream from the dam, and one passed a second time and entered the Okanogan River.

SUMMARY

A total of 742 spring, 426 summer, and 279 fall chinook salmon were trapped, radio tagged, and released from John Day, Priest Rapids, and Rocky Reach Dams to determine migration characteristics. These characteristics included run timing and travel time, passage success, and dam-passage behavior. Final destinations in the main stem and tributaries of the Columbia River were also recorded.

Run Timing

Run timing for fish destined for lower-river locations (Wenatchee River, Priest Rapids Dam, Wanapum Dam, and Rock Island Dam) was advanced relative to run timing for fish that passed Rocky Reach and Wells Dams.

Individual spring chinook salmon stocks, destined for the tributaries, could not be separated on the basis of arrival time at Priest Rapids, Rocky Reach, or Wells Dams.

Most fish arrived at the dams during daylight hours. Similarly, most activity into and out of the fish ladders occurred during daylight hours.

Travel Time

In general, median passage-time estimates at individual mid-Columbia River dams ranged from 14.6 to 60 hours. The longest travel times were associated with fall chinook salmon. Total passage times at dams, depending on the stock of fish, were similar to estimates made with radio-telemetry techniques at dams

in the lower Columbia and Snake Rivers (Bjornn and Peery 1992).

After arriving at the tailraces of dams, most radio-tagged fish moved rapidly to the vicinity of the collection channel and, with the exception of spring chinook salmon at Priest Rapids and Wanapum Dams, quickly made a first entry into the collection channel. Most radio-tagged fish also spent only a few hours passing through the fish ladders, and fish-ladder passage times were comparable to those recorded at lower Columbia and Snake River dams (Bjornn and Peery 1992).

Fate of Radio-Tagged Fish

The majority of radio-tagged spring and summer chinook salmon terminated their migration in tributaries. The Wenatchee River was the final destination for 44.9% of spring and 53.9% of summer chinook salmon.

Fall chinook salmon, in contrast, terminated their migration in the main stem (likely spawners) of the Columbia River either downstream from Priest Rapids Dam, in the tailraces of dams, or in Priest Rapids or Wells Hatcheries. Approximately 22, 13, and 9% of all radio-tagged adults were last detected in the Wells Dam, Wanapum Dam, and Rocky Reach Dam tailraces, respectively.

Adult Collection Channel Efficiency and Fish-Ladder Selection

At all dams, the longest passage period occurred at the collection channels. However, no major delays were observed between arrival at the tailrace, entrance at the collection channel, and passage through the fish ladders. Passage time was increased as a result of multiple collection-channel entries and exits, multiple trips up and down the inside and outside of the collection channel, multiple arrivals at the base of the fish ladders, and multiple entrances into the fish ladders.

Behavior of radio-tagged fish in the collection channels was species-specific and varied considerably as a result of the design of individual collection channels. In general, only a few collection-channel openings were effective at each dam, despite the total number available to fish.

Similarly, fish displayed distinct preferences between fish ladders. With the exception of Rock Island and Rocky Reach Dams, a large majority of fish chose the left-bank fish ladder at all dams. At Rocky Reach Dam the fish must orient to the left end of the powerhouse to enter the right-bank fish ladder.

Fallback and the Fate of Fallback Fish

The highest incidences of spring chinook salmon fallbacks occurred at Priest Rapids and Wanapum Dams. The majority of these fallbacks were last detected downstream from Priest Rapids Dam: these detections indicate that some fallbacks may result from overshoot of the dams.

Wells Dam had fourteen percent radio-tagged summer chinook salmon fallbacks. Approximately half of those fish terminated their migration downstream from the dam.

With the exception of fish passing Wanapum Dam, at least 10% fall chinook salmon fallbacks were observed at all the mid-Columbia River dams. As with spring chinook salmon at Priest

Rapids and Wanapum Dams, the majority of fall chinook salmon fallbacks were last detected downstream, indicating that some fallbacks may have overshot the dams.

RECOMMENDATIONS

Recommendations for further evaluations to improve adult passage at the mid-Columbia River Dams are as follows:

1) Close all collection-channel openings, with the exception of the openings with the highest activity closest to the base of the fish ladders. This recommendation is based on results obtained at Wells Dam where with only two openings per collection channel, first collection-channel entries were as fast or faster than at any other dam. Similarly, the right-bank adult passage facility at Rock Island has only three functional openings, yet first collection-channel entries were among the shortest, and total passage times were the shortest of all dams evaluated. In addition, positive behavior (movement toward the fish ladder) within the collection channels was not indicative of faster total passage time at dams. Positive behavior for spring chinook salmon at Priest Rapids and Wanapum Dams produced longer total passage times than did negative behavior during the summer chinook salmon run.

2) Modify flows between the openings and the base of the fish ladder to make them laminar, and move diffuser flows in the channels farther upstream, closer to the base of the fish ladder. At present, diffuser flows in the collection-channel/fish-ladder junction pools tend to obscure the flows from the fish ladders, and may confuse the fish.

3) Account for the high incidence of fallbacks and resulting over-counts at dams determining realistic and accurate passage survival and escapement estimates. Until such adjustments are made, estimates at individual dams will remain significantly biased upward. At Priest Rapids, the variability in the spring chinook fallback rates will depend on the program at the Ringold Facility.

ACKNOWLEDGMENTS

Funding and support for various aspects of this research came from the Public Utility Districts (PUDS) of Chelan, Douglas, and Grant Counties of Washington State. The National Marine Fisheries Service thanks the many PUD staff members who provided information and assistance. We especially acknowledge the assistance of Tom Hook and Sue Marcear at Wells Dam, operated by Douglas PUD, for permitting our use of their office and facilities.

We also thank the staff of PUD No. 1 of Chelan County, especially Steve Hays, Dick Nason, and Donald Brawley, for allowing the use of fish-trapping facilities at Rocky Reach Dam.

Chris Carlson of PUD No. 1 of Grant County provided valuable assistance in coordinating equipment acquisition and in the use and operation of the adult trapping facilities at Priest Rapids Dam.

We acknowledge the assistance of Donald Rapelje and the staff at Eastbank Salmon Hatchery for allowing the use of the facility as a base of operations in the Wenatchee area.

We thank the many other people whose assistance contributed greatly to the successful completion of this study. In particular, Dan Gebbers of Gebbers Farms, Inc.; Wayne Marsh; and Bob Whitehall, each of whom allowed us to install monitoring sites on their private property. Eric Hockersmith of NMFS provided technical assistance in reviewing data and developing graphics for this report.

Last, but of equal importance, we acknowledge the help of Cleo Moser, retired Washington Department of Fisheries, Hatchery Manager, for the benefit of his experience and knowledge of fish trapping and handling procedures.

REFERENCES

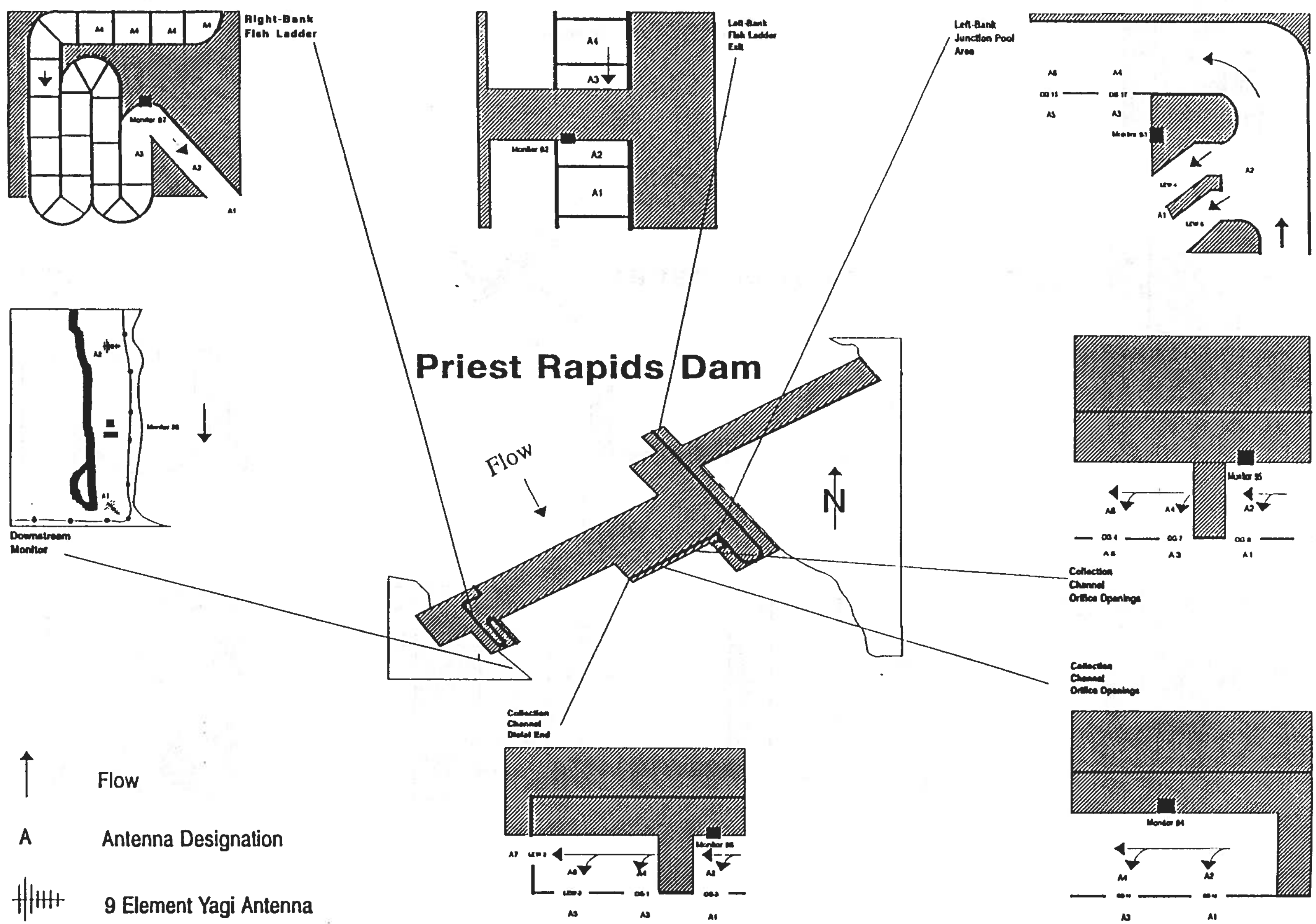
Bickel, P. J. and K. D. Doksum. 1977. Mathematical Statistics. Holden-Day, Inc. San Francisco, California.

Bjornn, T. C., and C. A. Peery. 1992. A review of literature related to movements of adult salmon and steelhead past dams and through reservoirs in the lower Snake River. U. S. Army Corps of Engineers, North Pacific Division, Technical Report 92-1, Portland, Oregon, 125 p. (Available from U. S. Fish and Wildlife Service, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

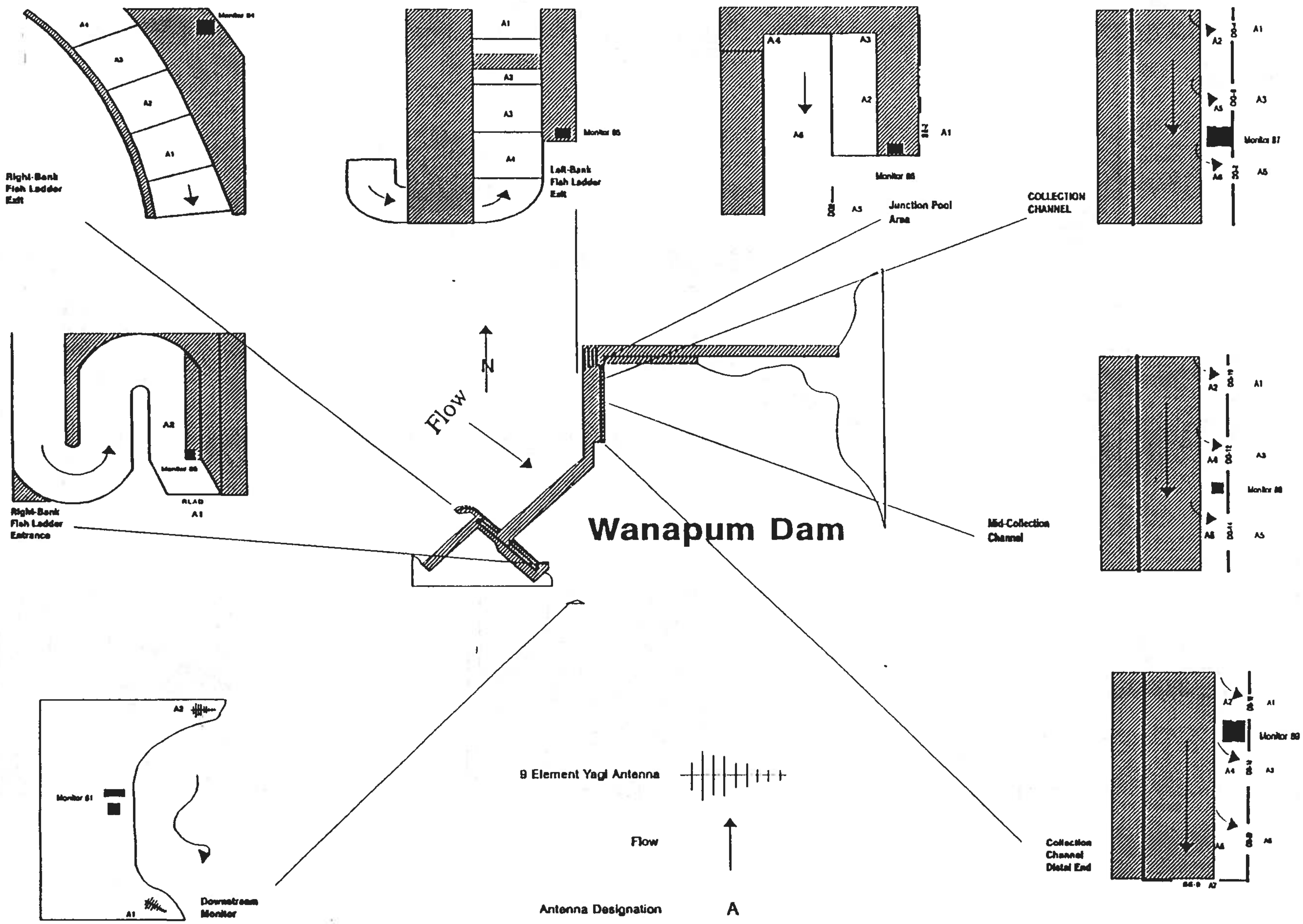
U.S. Army Corps of Engineers. 1993. Annual fish passage report. 20+ p. (Available from U.S. Army Corps of Engineers, North Pacific Division, Portland, OR 97208.)

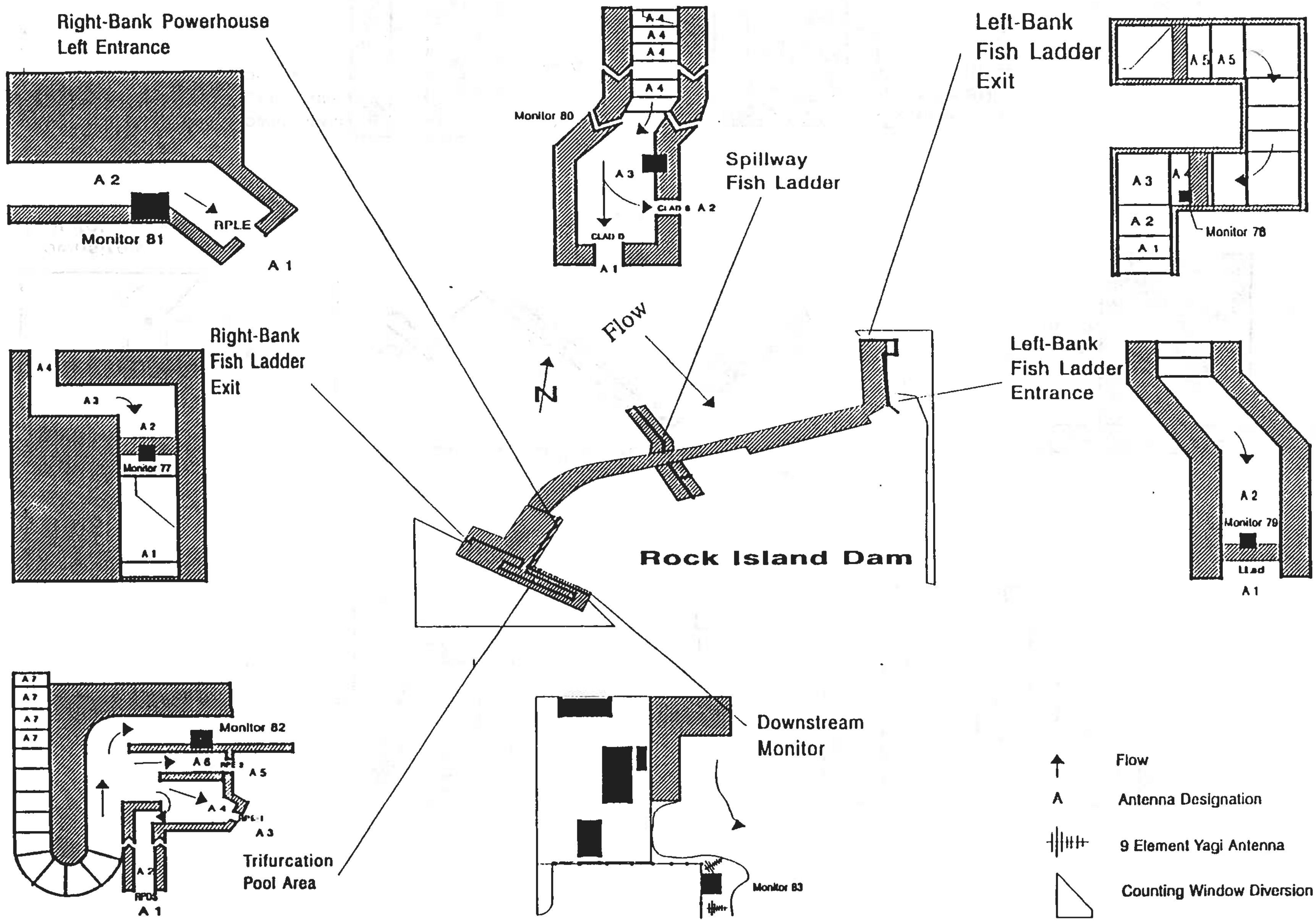
APPENDIX A

Monitor and Antennae Placement

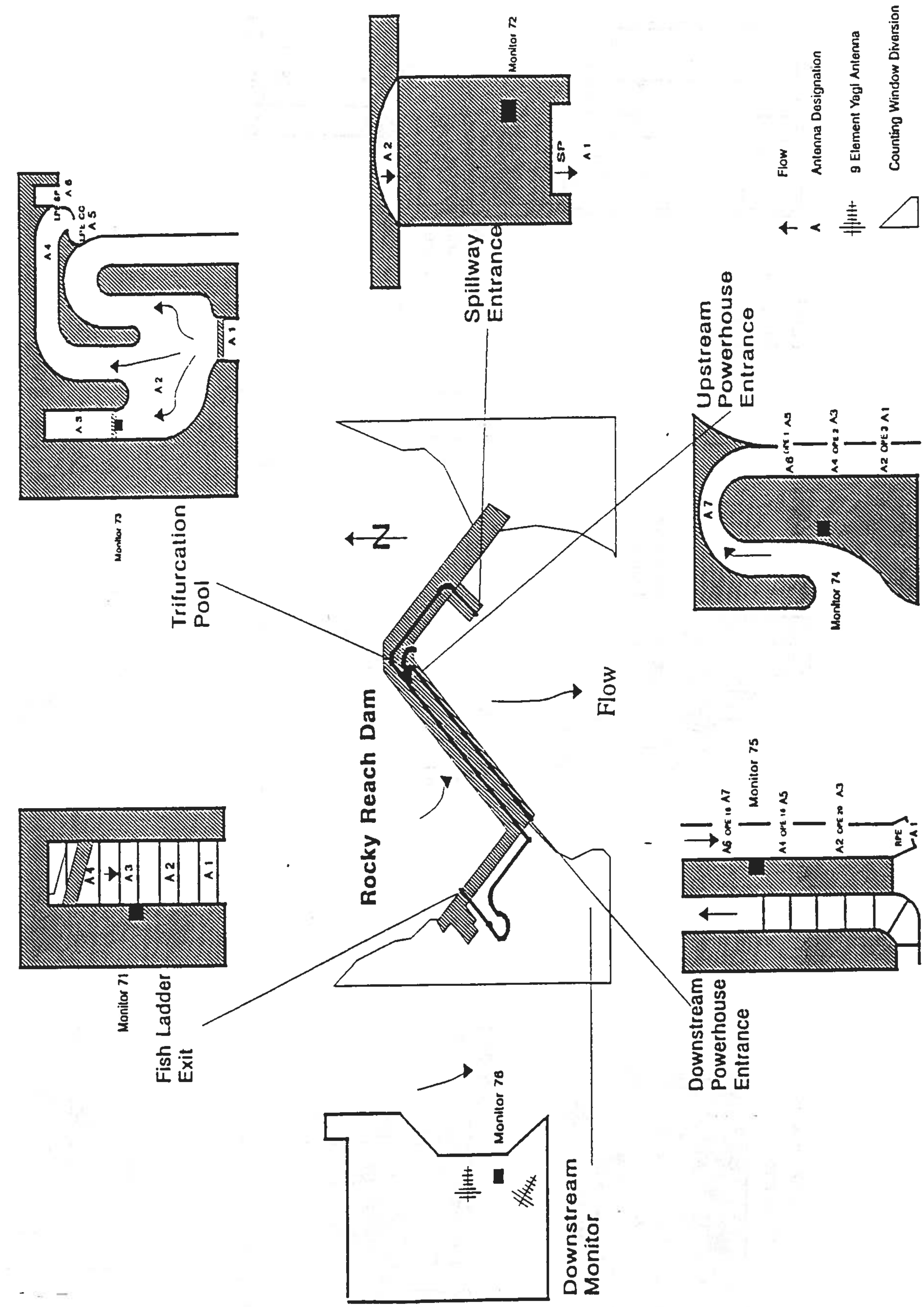


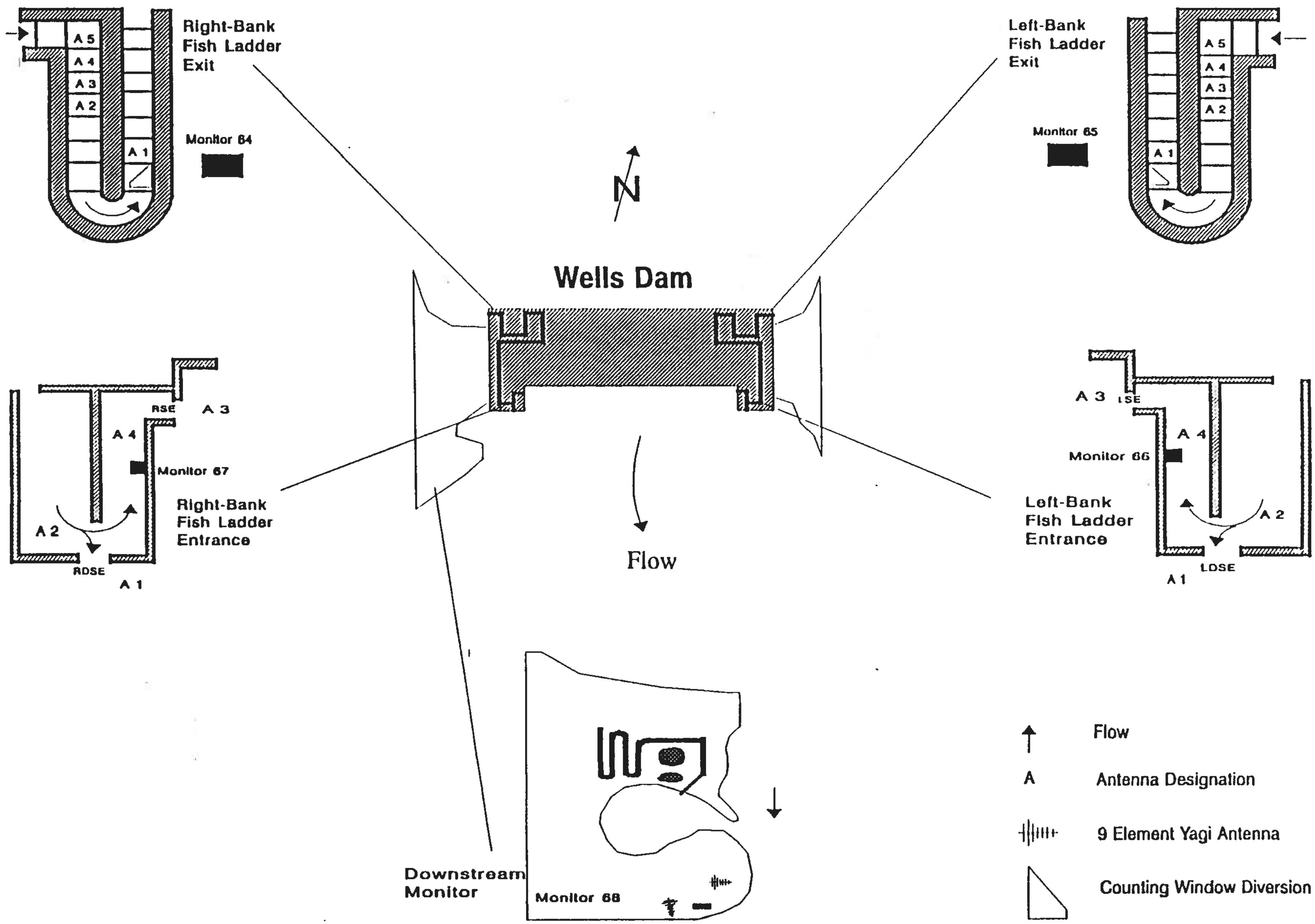
Appendix Figure A1.--Priest Rapids Dam monitor and antennae placement.


Wanapum Dam
Right-Bank
Fish Ladder
Exit
Left-Bank
Fish Ladder
Exit
Monitor 85
Junction Pool
Area
Monitor 86
COLLECTION
CHANNEL
Monitor 87
Right-Bank
Fish Ladder
Entrance
Flow
N
Mid-Collection
Channel
Collection
Channel
Distal End
Monitor 89
Downstream
Monitor
Monitor 81
A1
A2
A3
A4
A5
A6
A7
9 Element Yagi Antenna
Flow
Antenna Designation
A



Appendix Figure A3.--Rock Island Dam monitor and antenna placement.

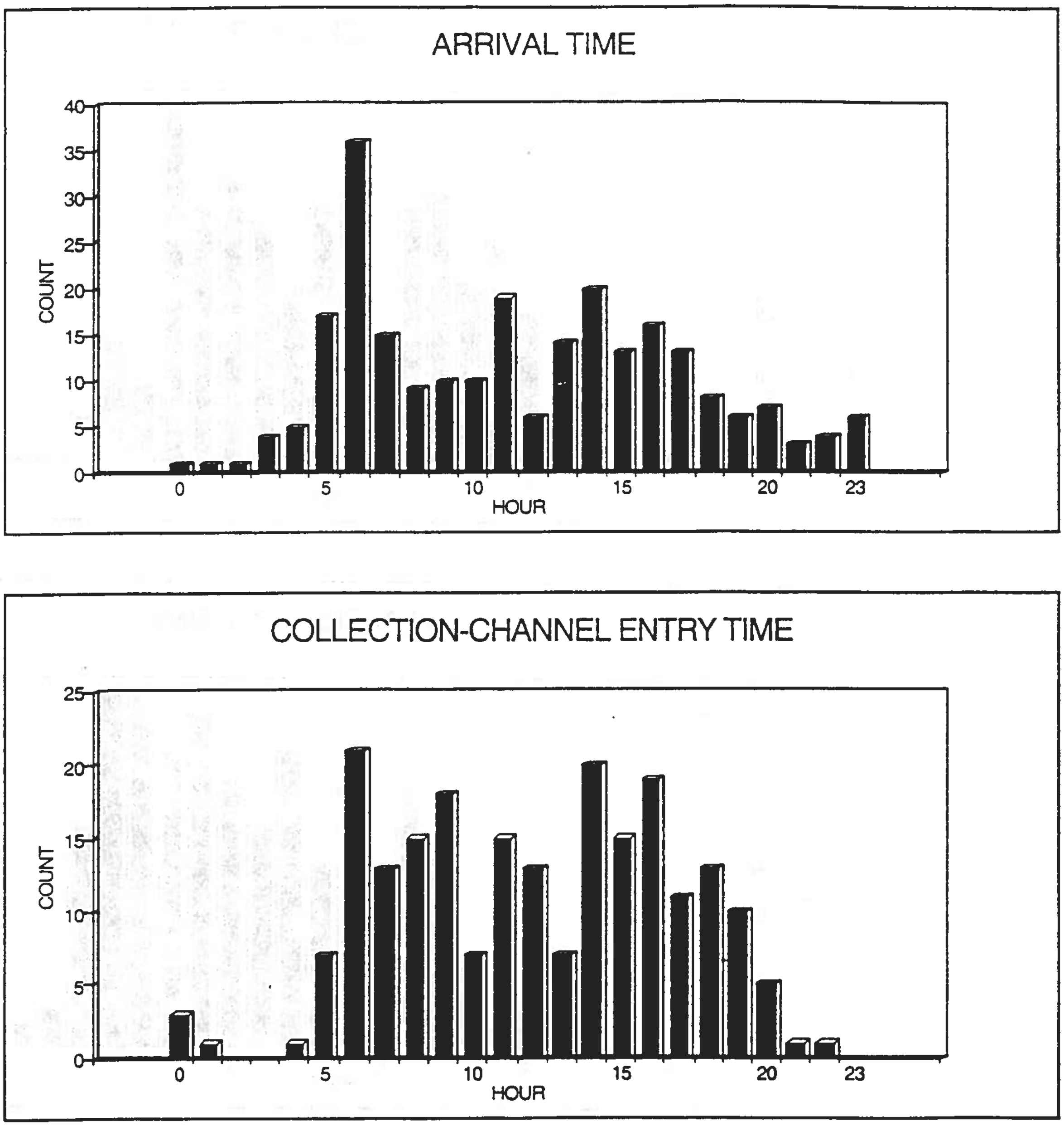

Rocky Reach Dam
Trifurcation Pool
Spillway Entrance
Upstream Powerhouse Entrance
Downstream Powerhouse Entrance
Fish Ladder Exit
Downstream Monitor
Flow
Monitor 71
Monitor 72
Monitor 73
Monitor 74
Monitor 75
Monitor 78
N
Flow
Antenna Designation
9 Element Yagi Antenna
Counting Window Diversion



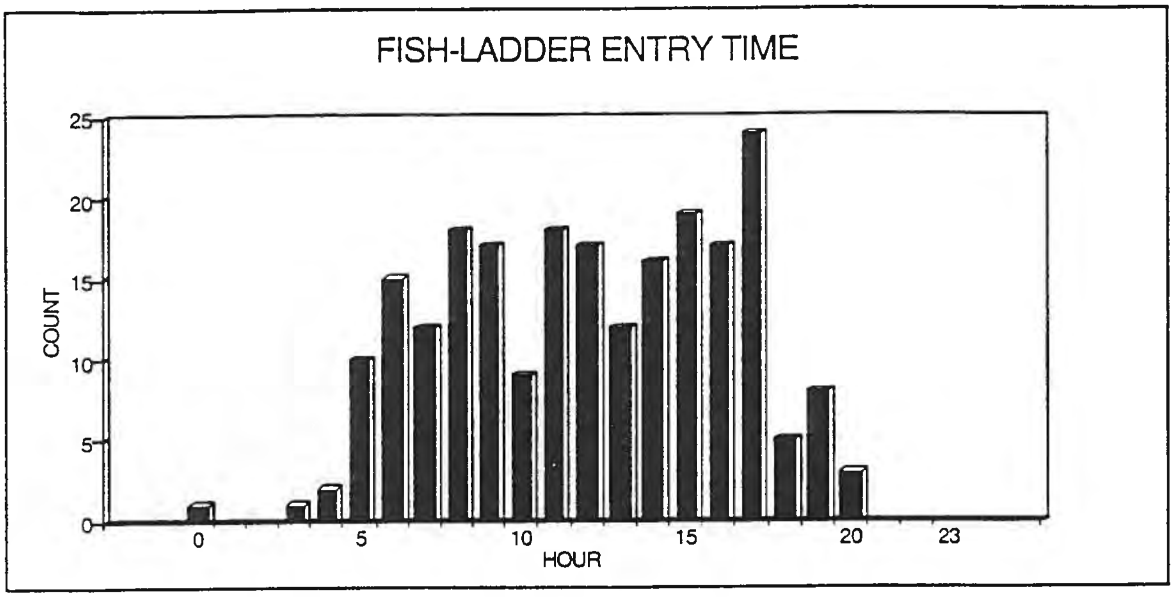
Appendix Figure A5.--Wells Dam monitor and antennae placement.

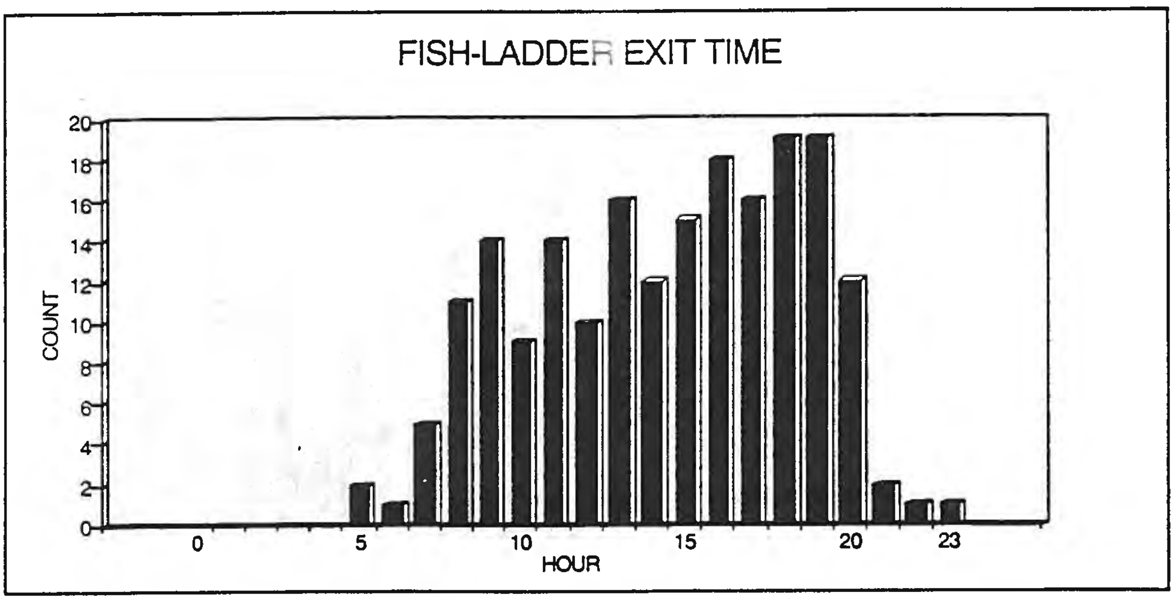
APPENDIX B

Diel Activity

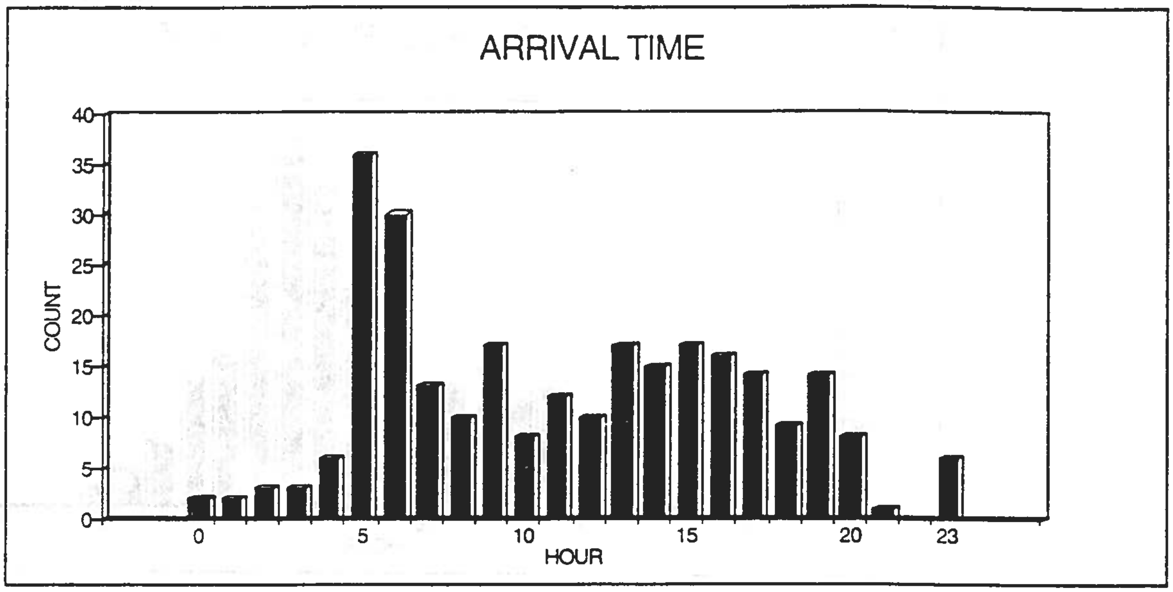


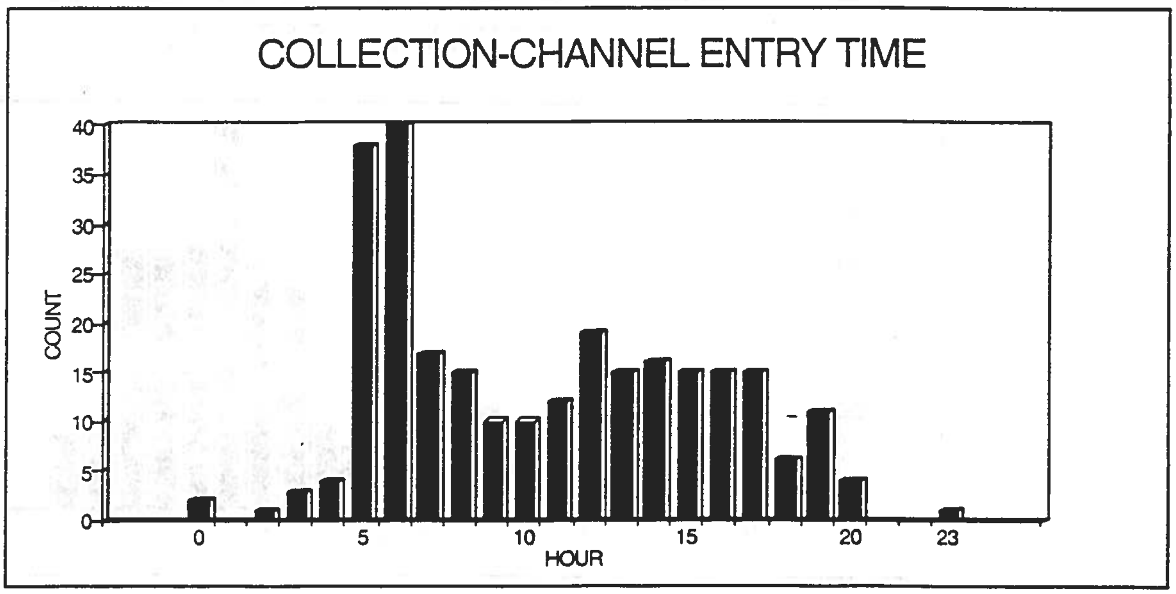
Appendix Figure B1.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Priest Rapids Dam, 4 May-28 July 1993.



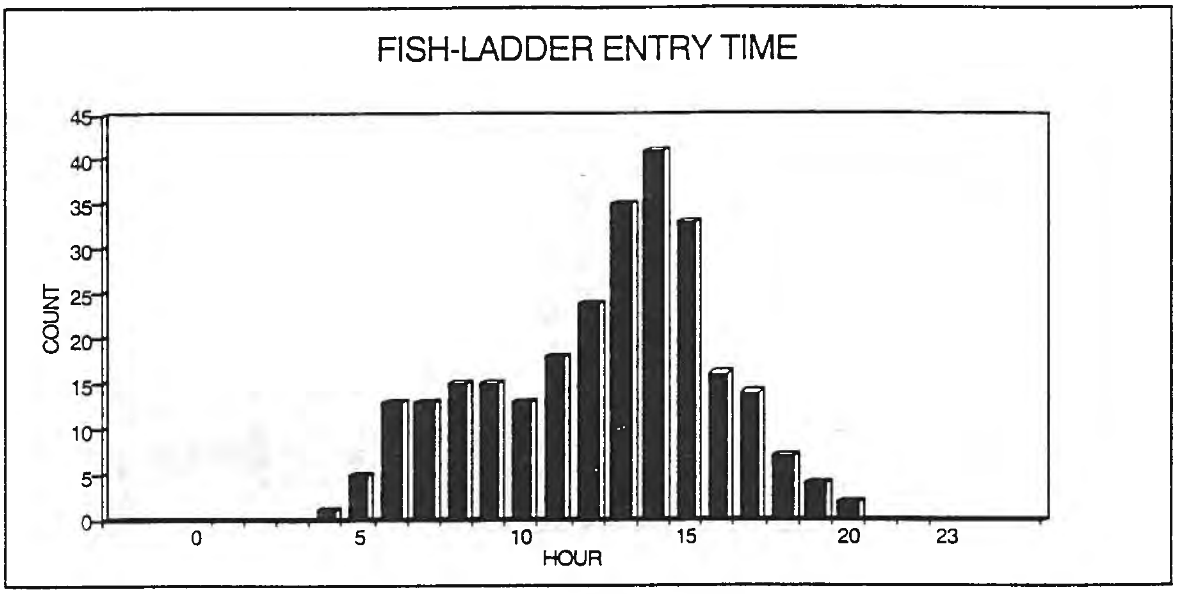


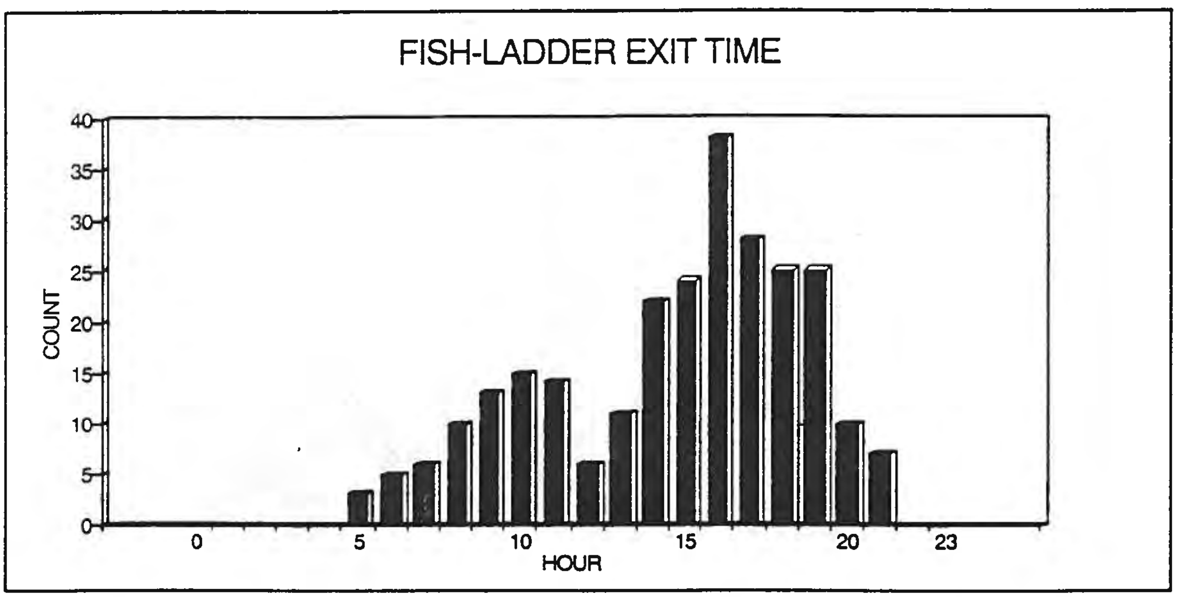
Appendix Figure B2.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Priest Rapids Dam, 4 May-28 July 1993.



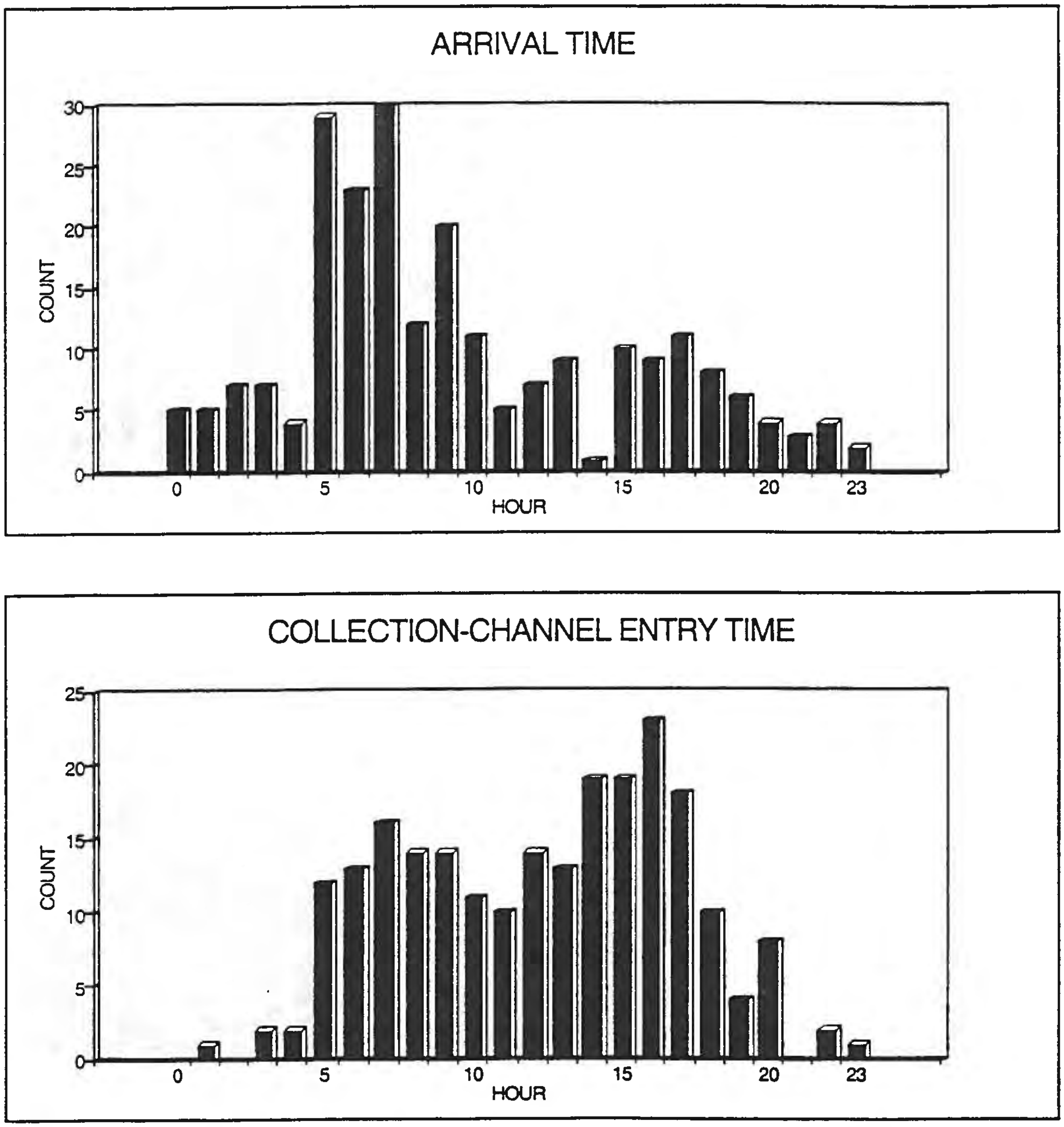


Appendix Figure B3.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Priest Rapids Dam, 13 June-21 August 1993.

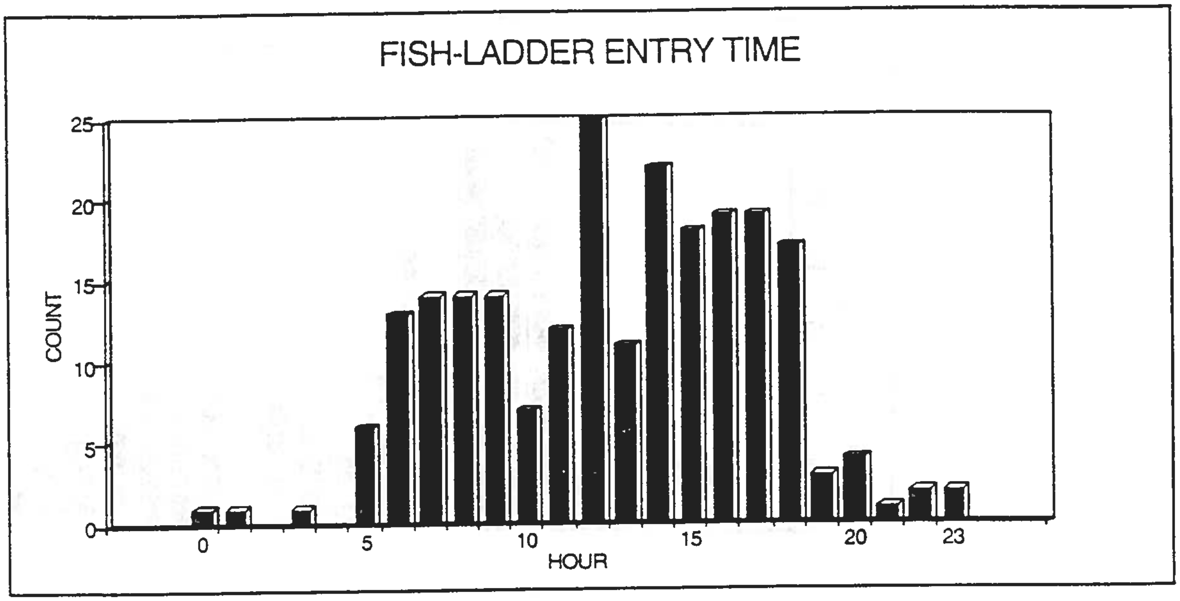


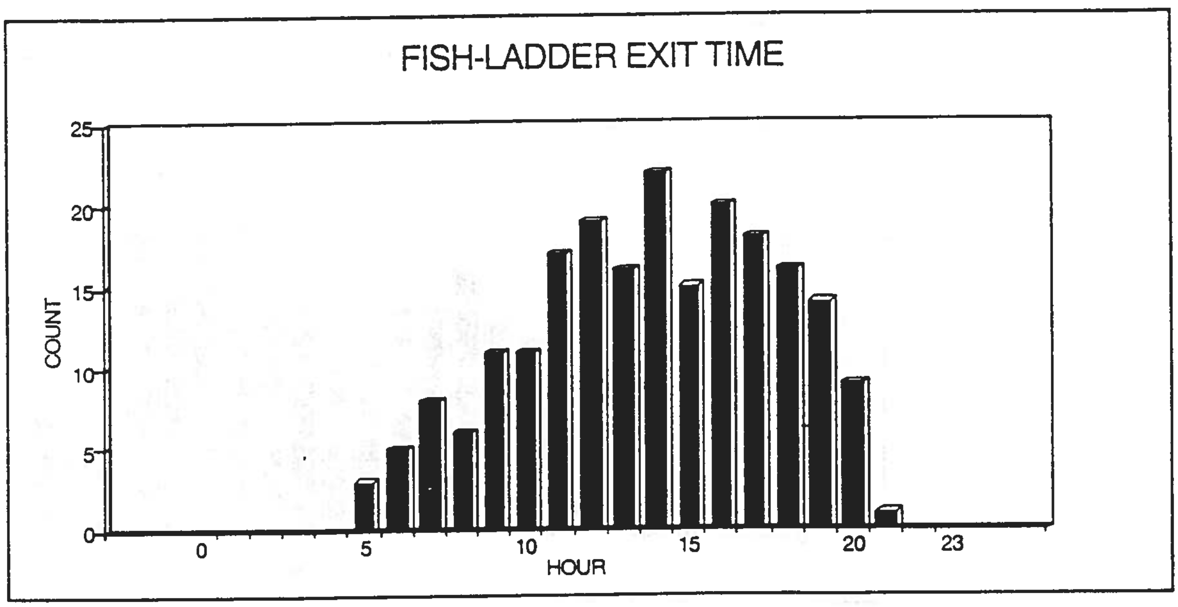


Appendix Figure B4.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Priest Rapids Dam, 13 June-21 August 1993.

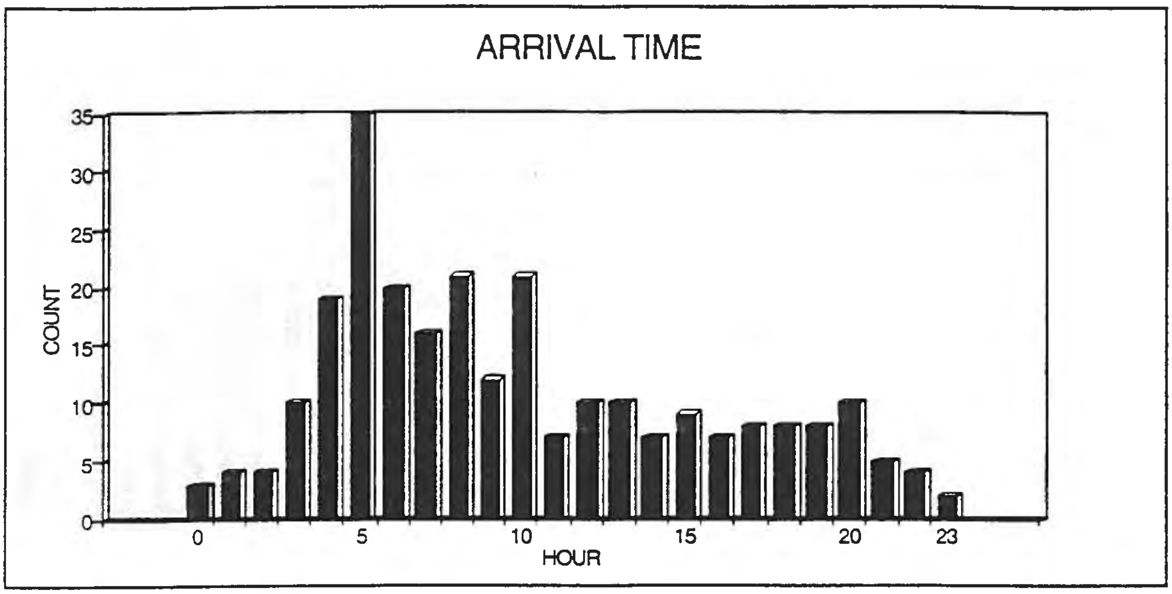


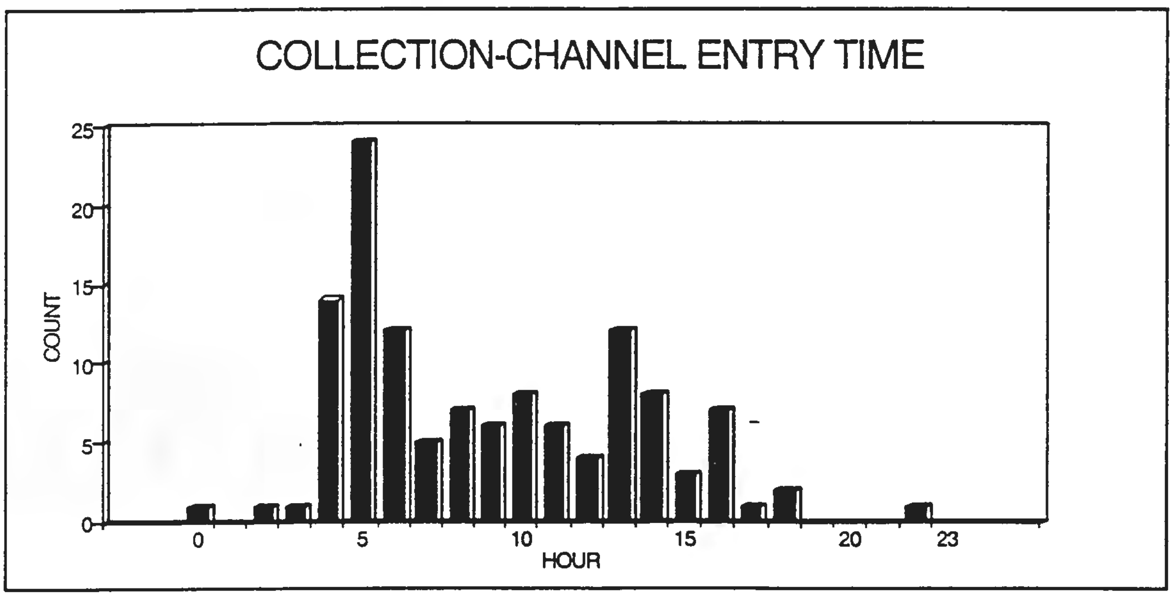
Appendix Figure B5.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Wanapum Dam, 7 May-31 July 1993.



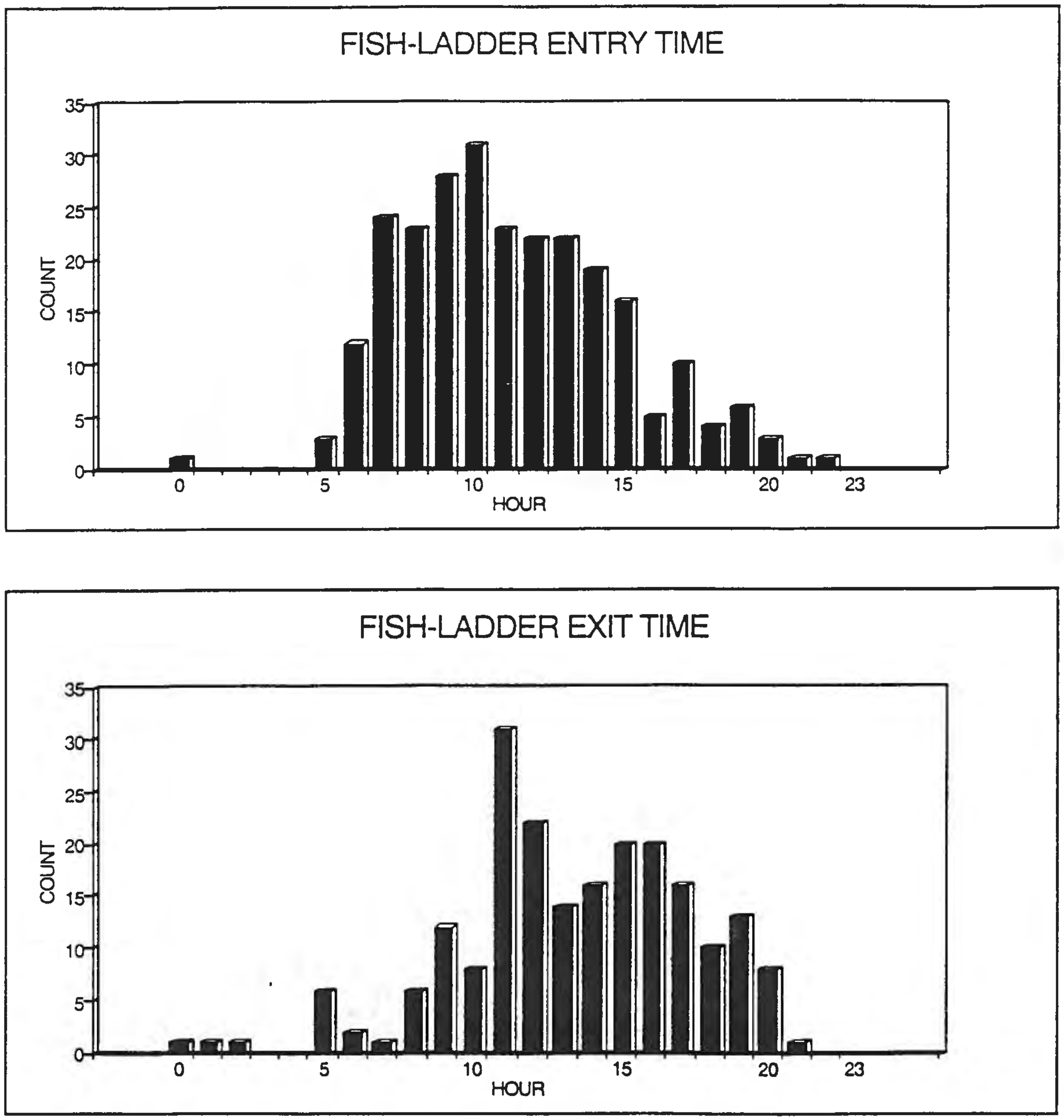


Appendix Figure B6.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Wanapum Dam, 7 May-31 July 1993.

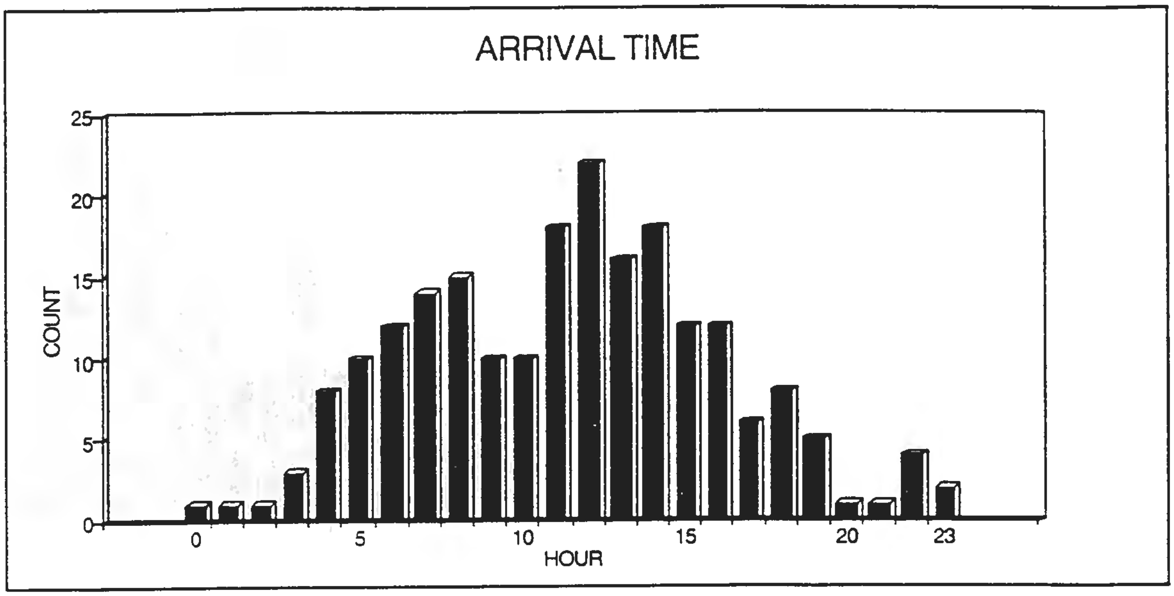


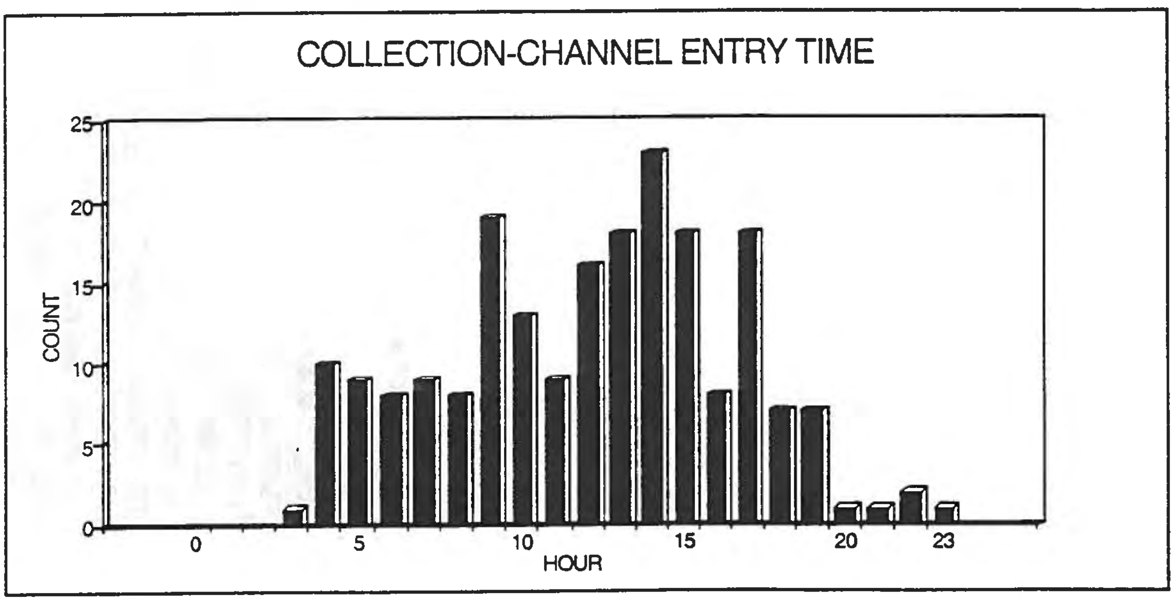


Appendix Figure B7.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Wanapum Dam, 14 June-25 August 1993.

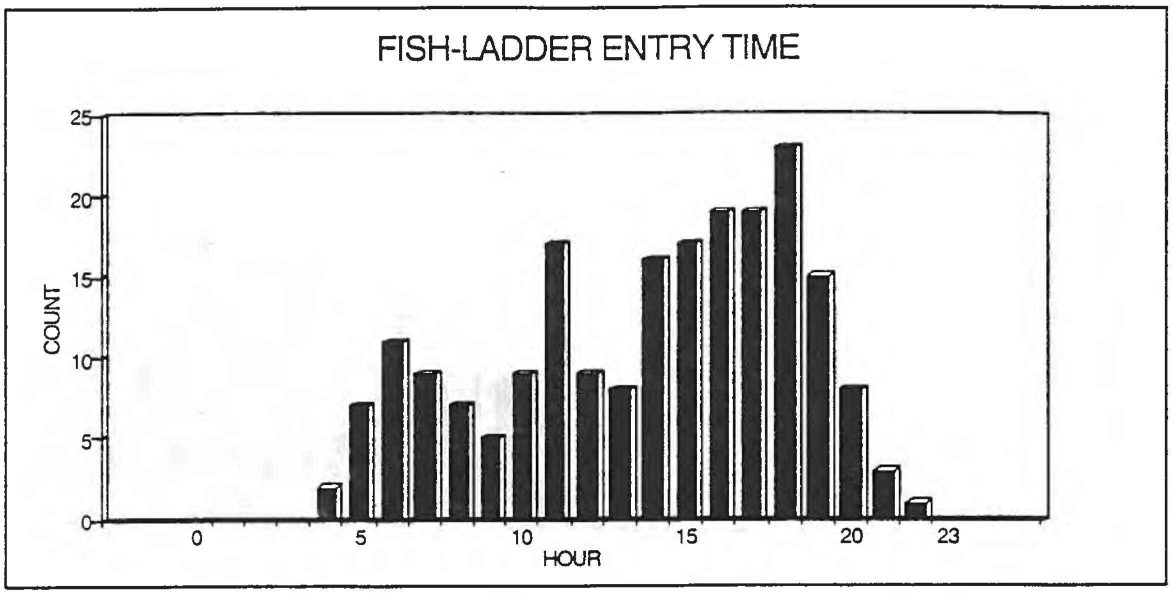


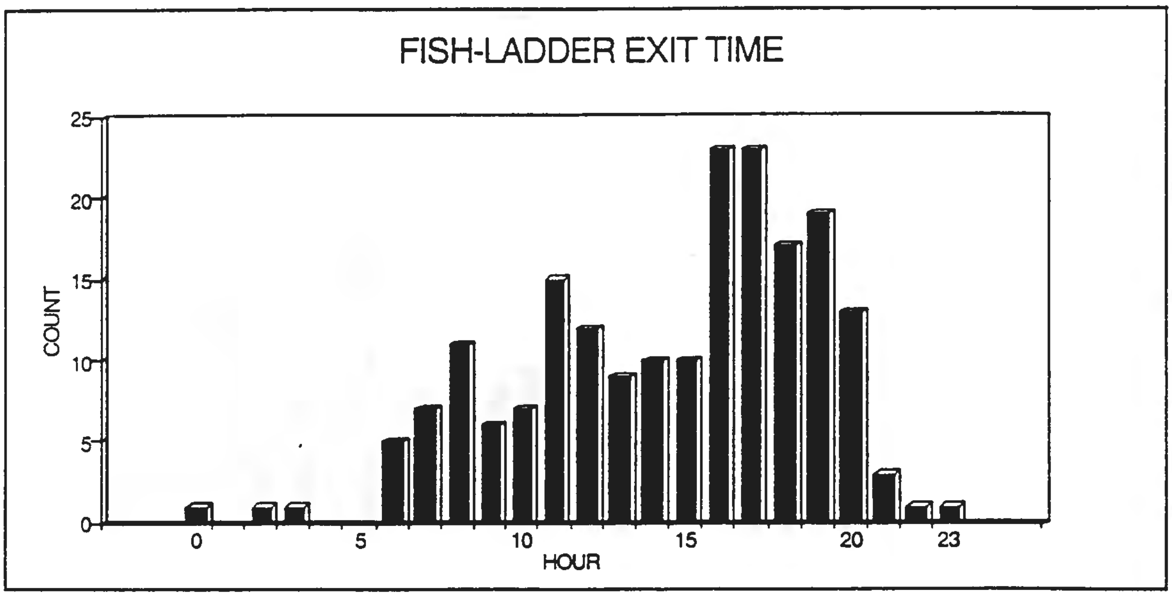
Appendix Figure B8.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Wanapum Dam, 14 June-25 August 1993.



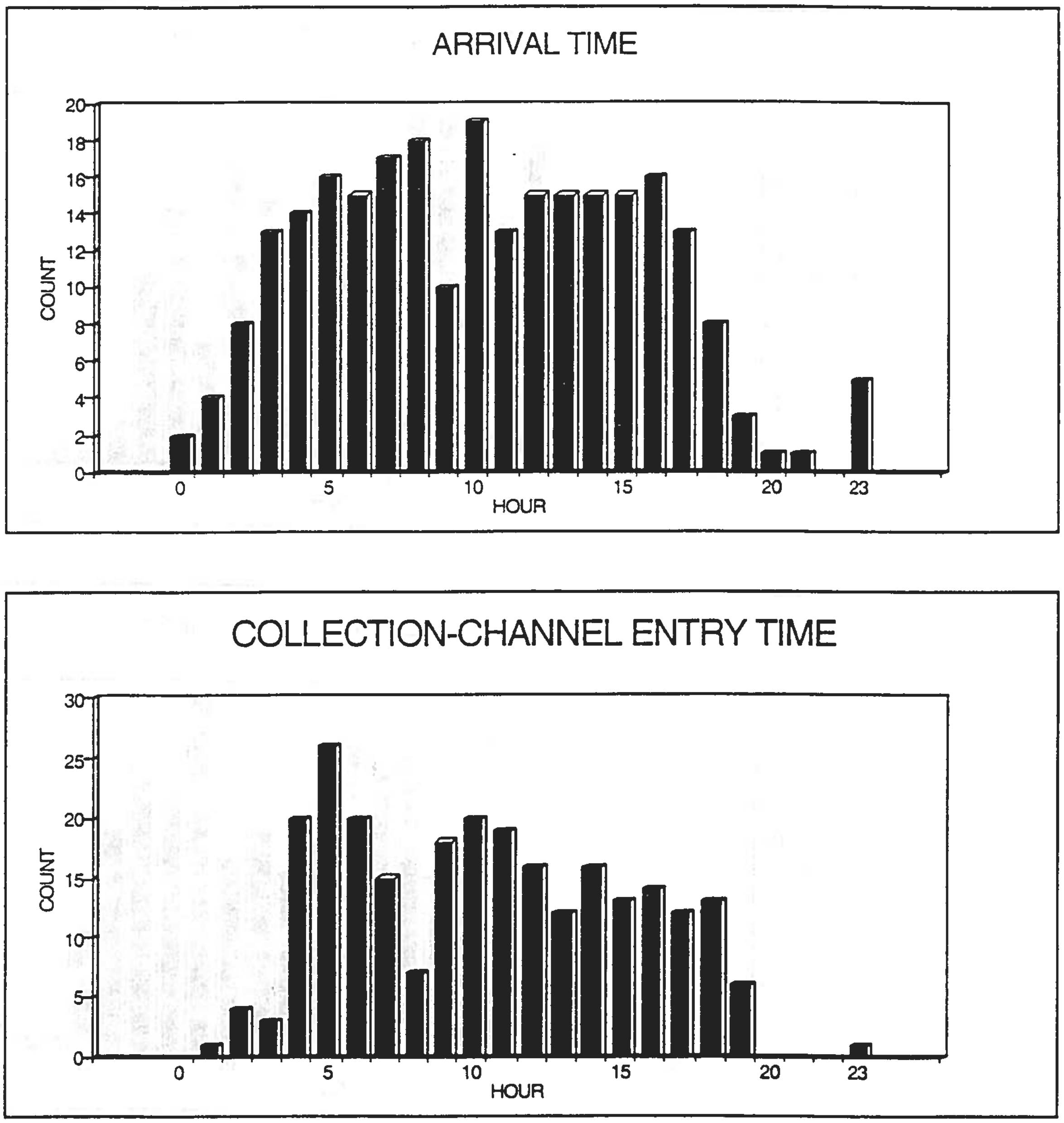


Appendix Figure B9.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Rock Island Dam, 6 May-2 July 1993.

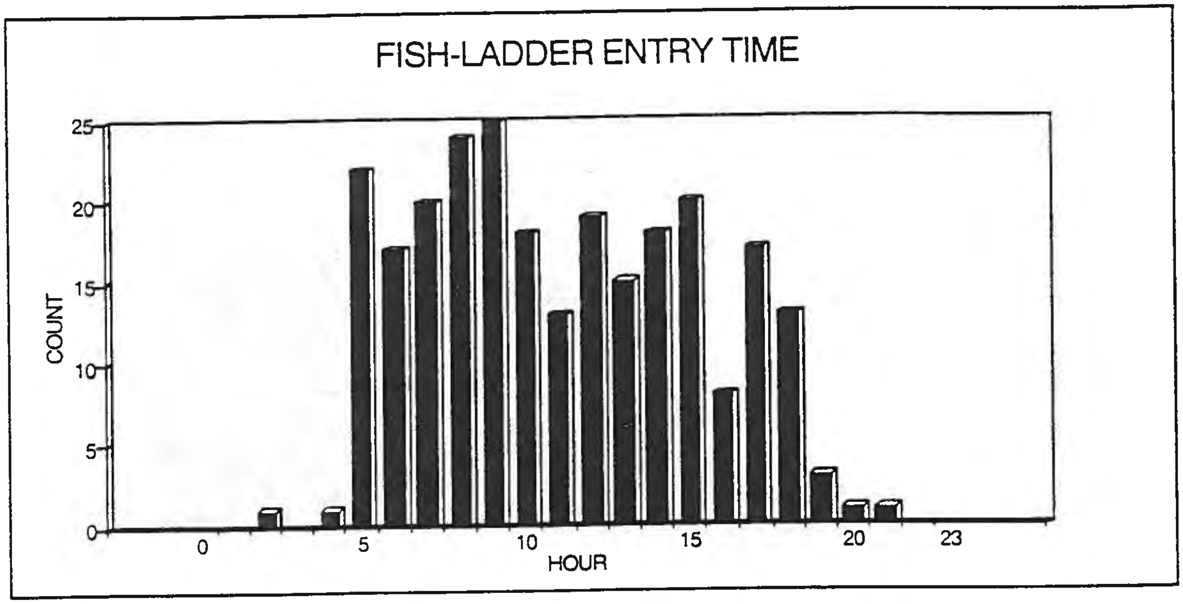


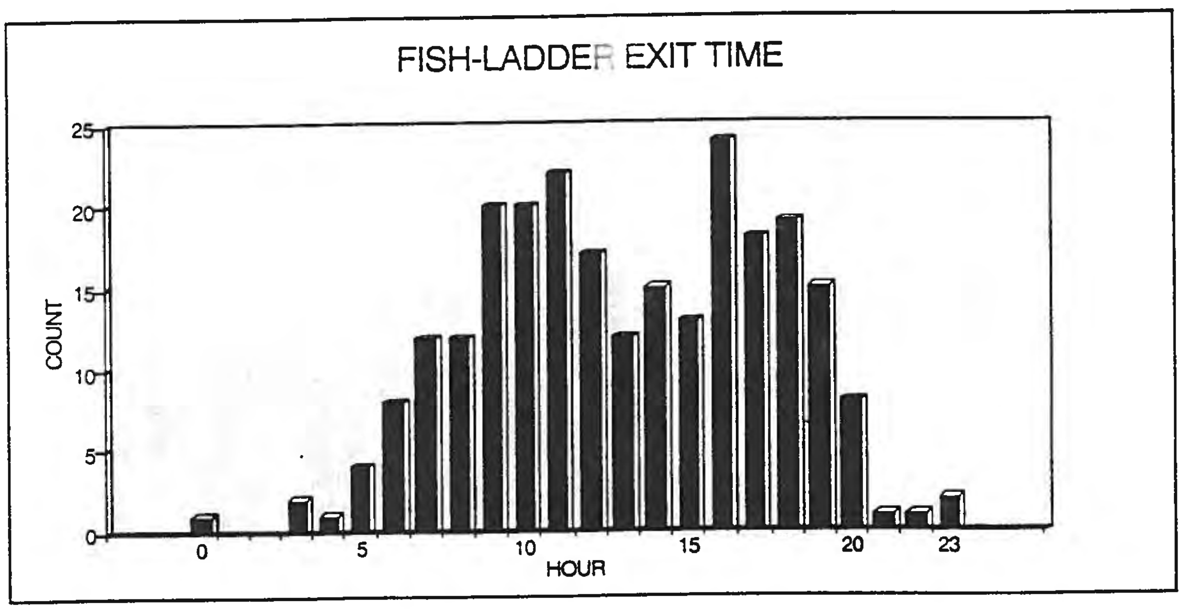


Appendix Figure B10.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Rock Island Dam, 6 May-2 July 1993.

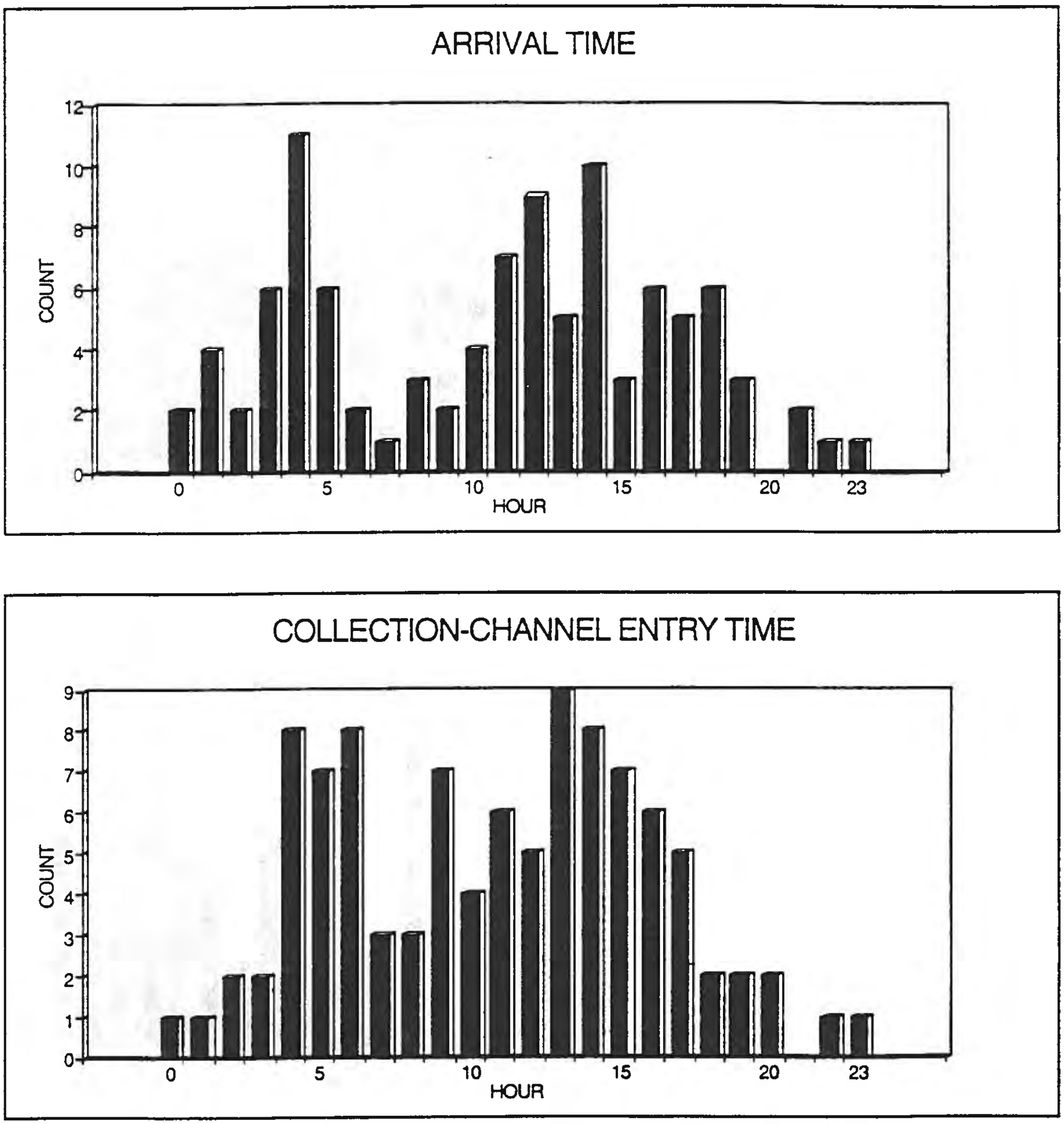


Appendix Figure B11.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Rock Island Dam, 16 June-8 September 1993.

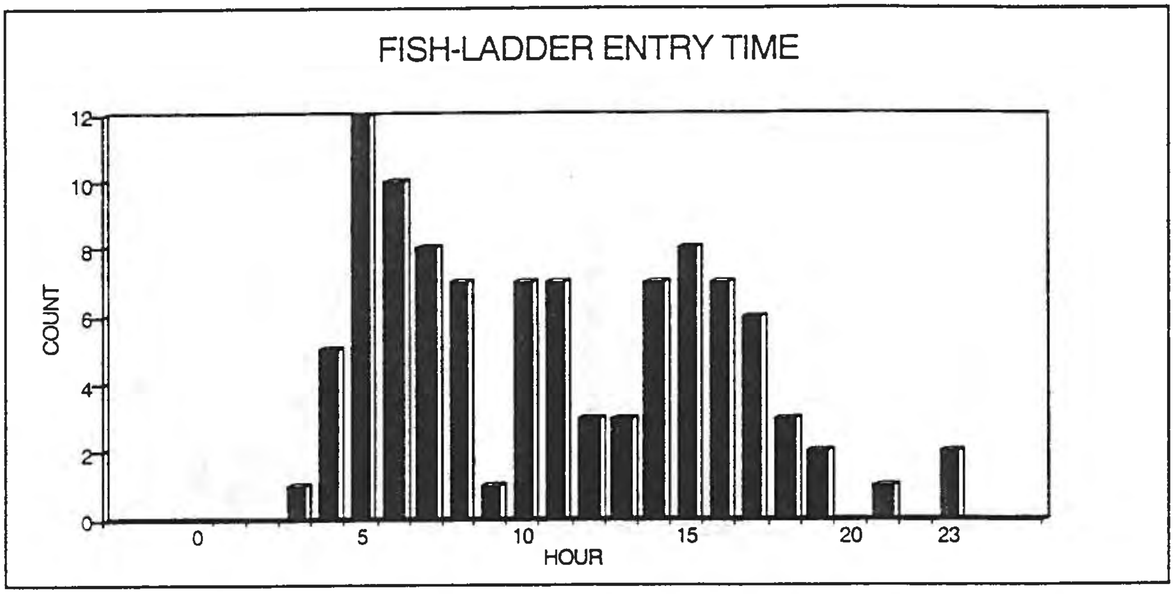


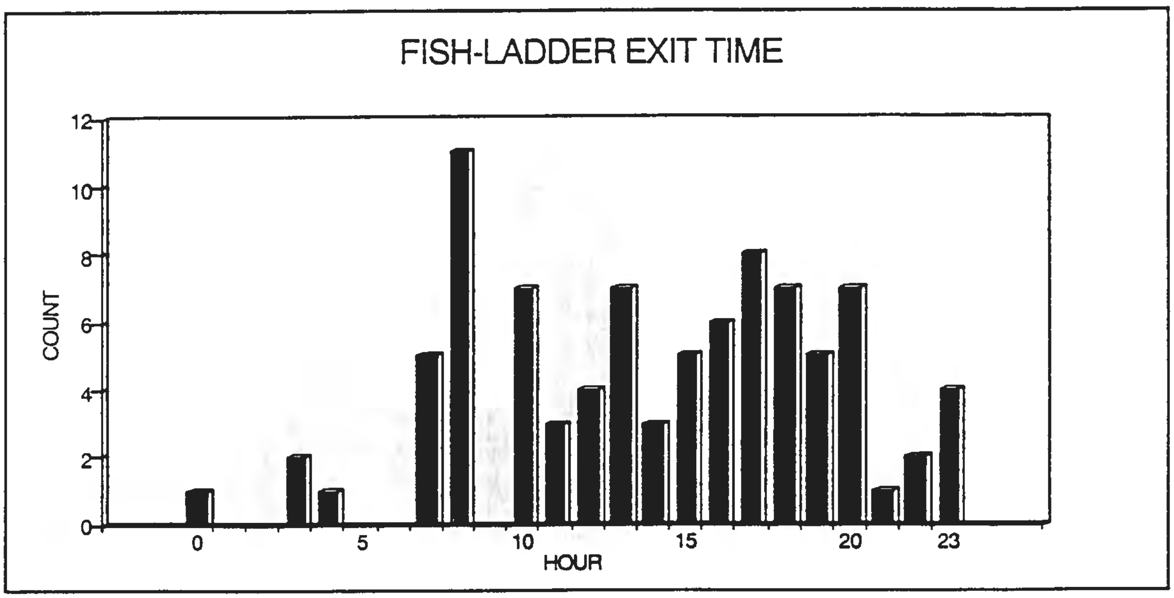


Appendix Figure B12.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Rock Island Dam, 16 June-8 September 1993.

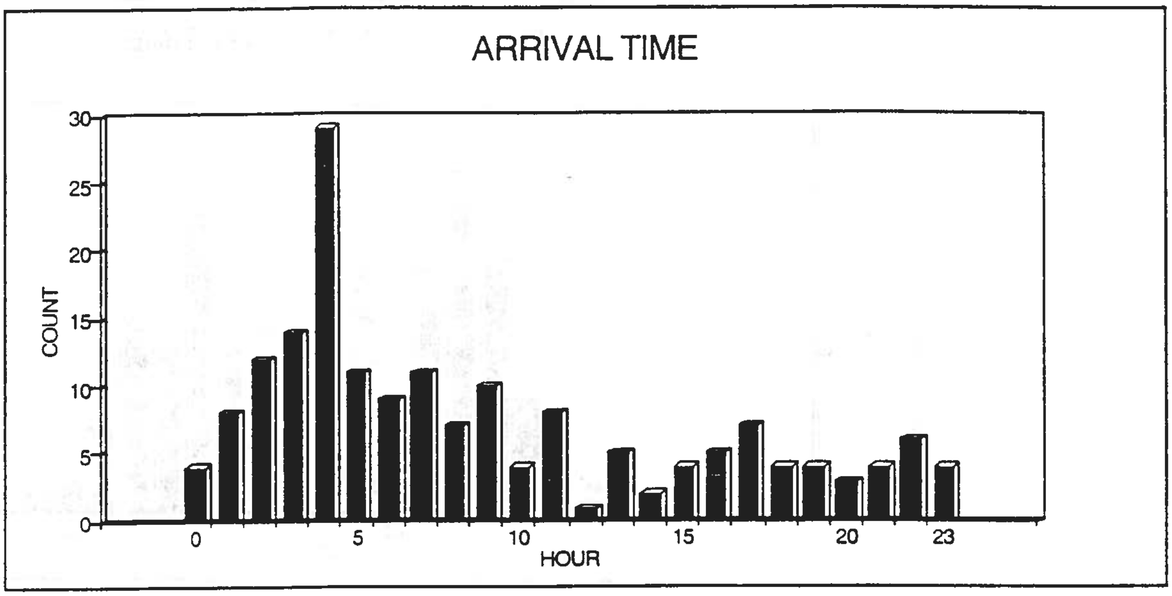


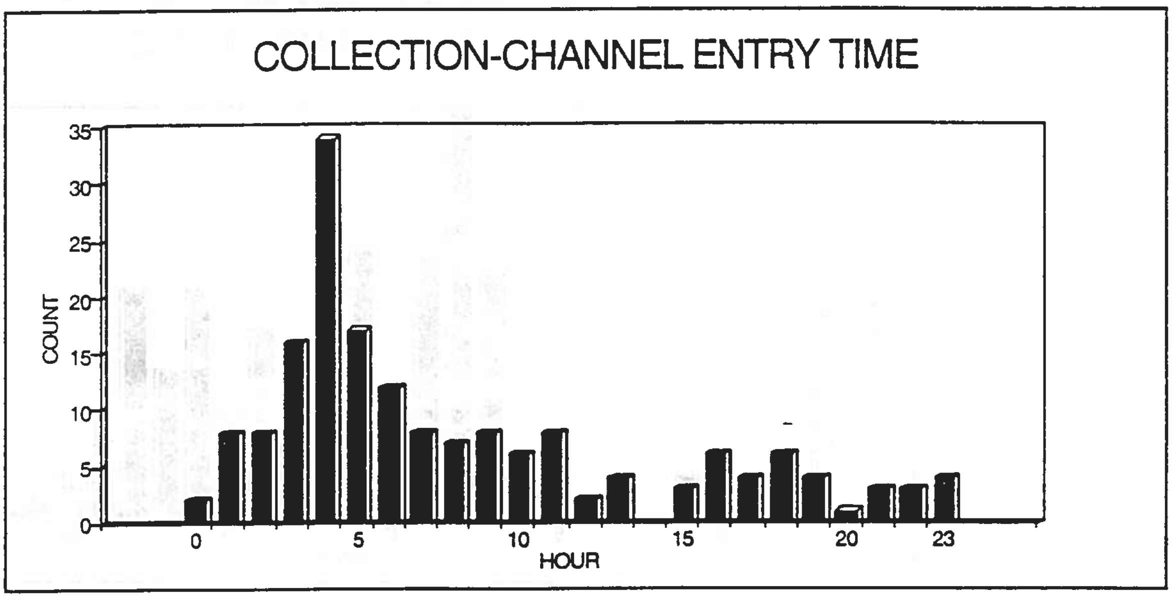
Appendix Figure B13.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Rocky Reach Dam, 7 May-3 July 1993.



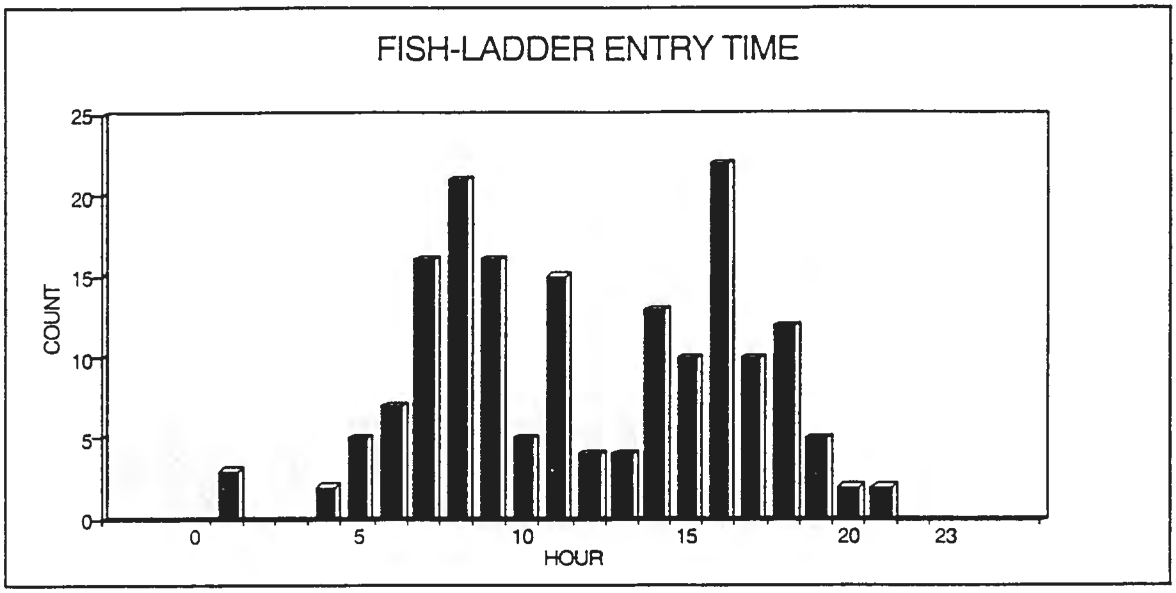


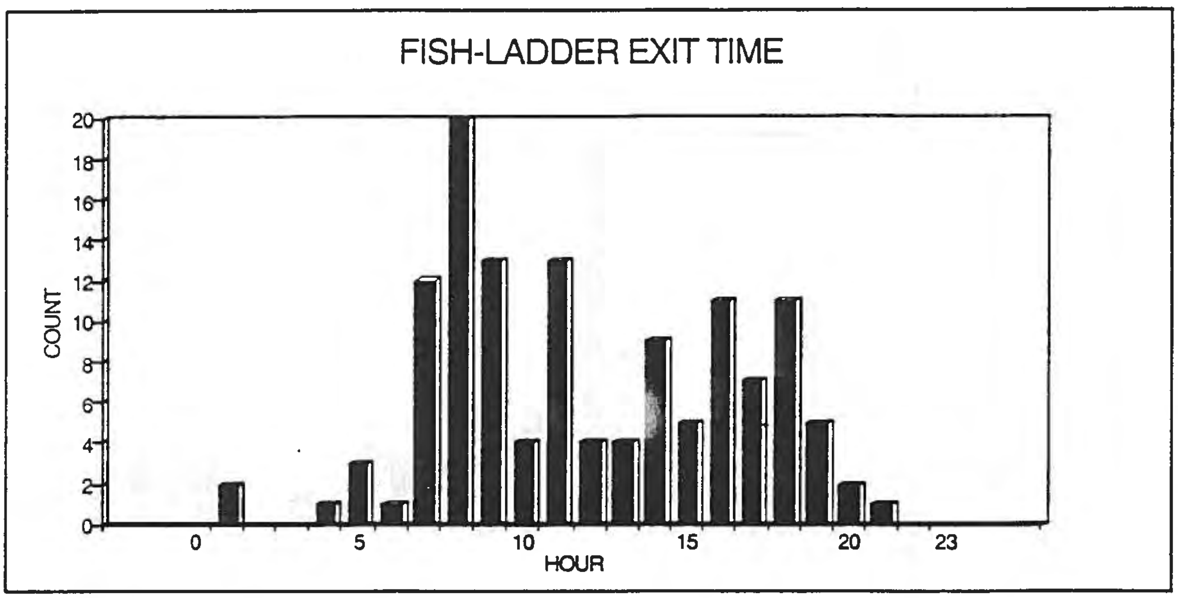
Appendix Figure B14.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Rocky Reach Dam, 7 May-3 July 1993.



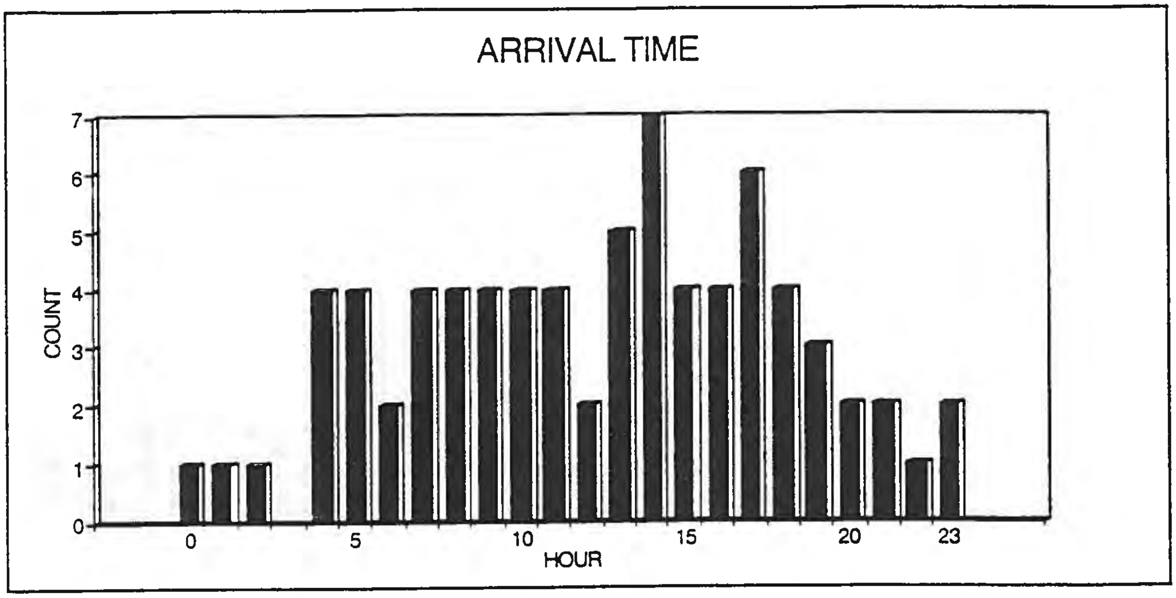


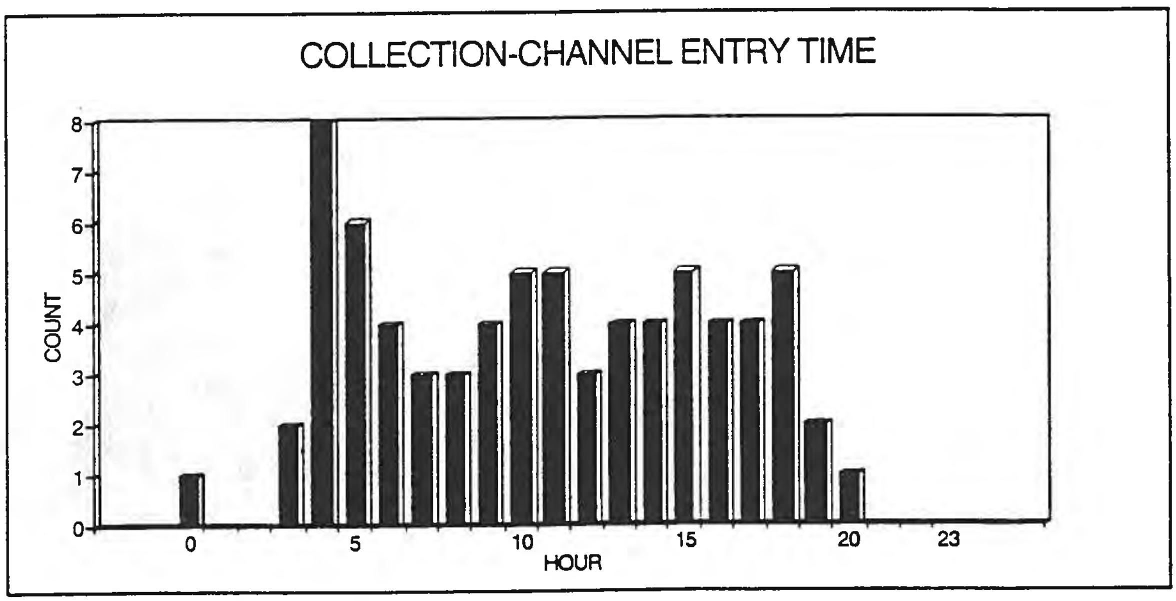
Appendix Figure B15.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Rocky Reach Dam, 18 June-8 October 1993.



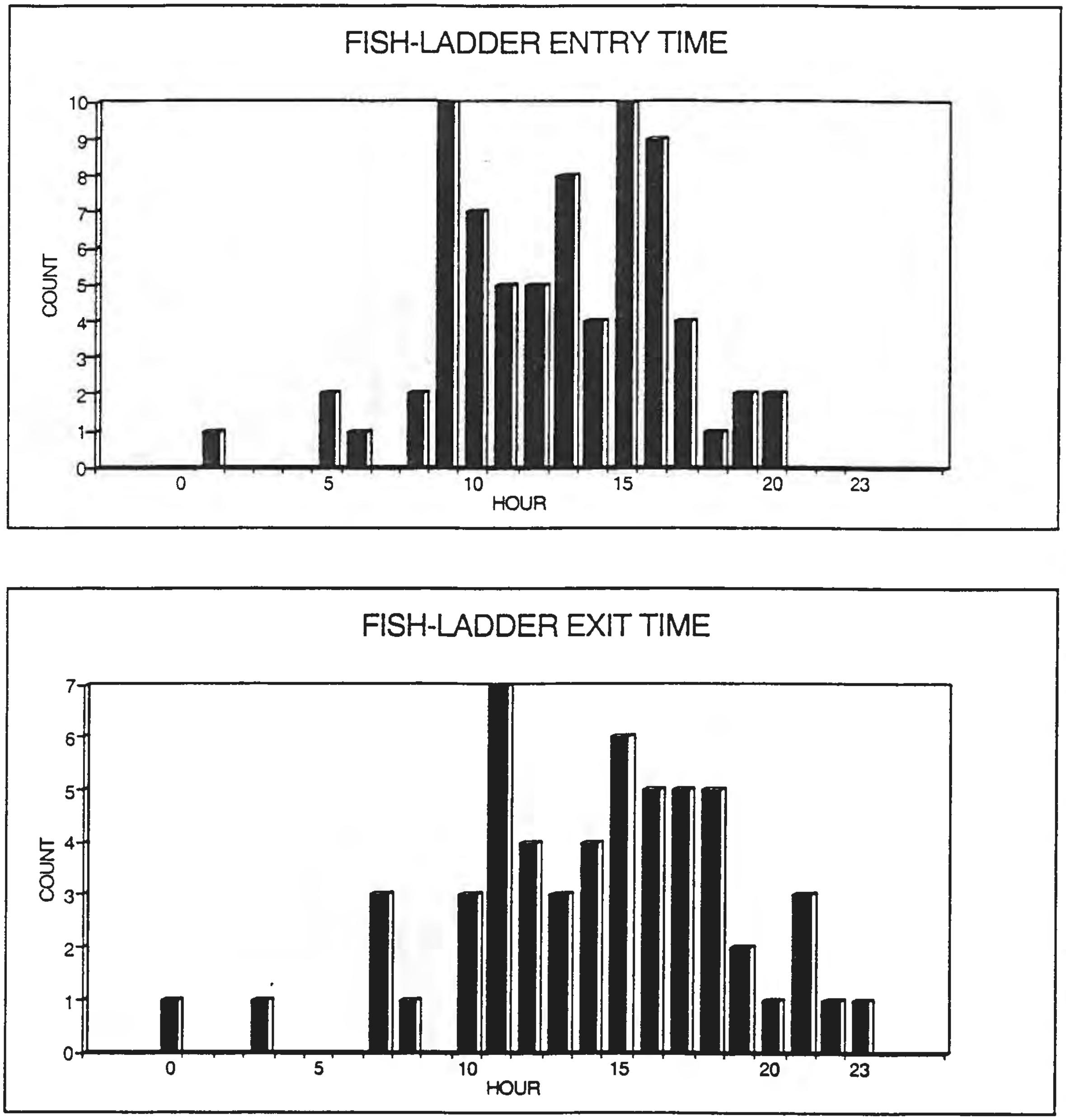


Appendix Figure B16.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Rocky Reach Dam, 18 June-8 October 1993.

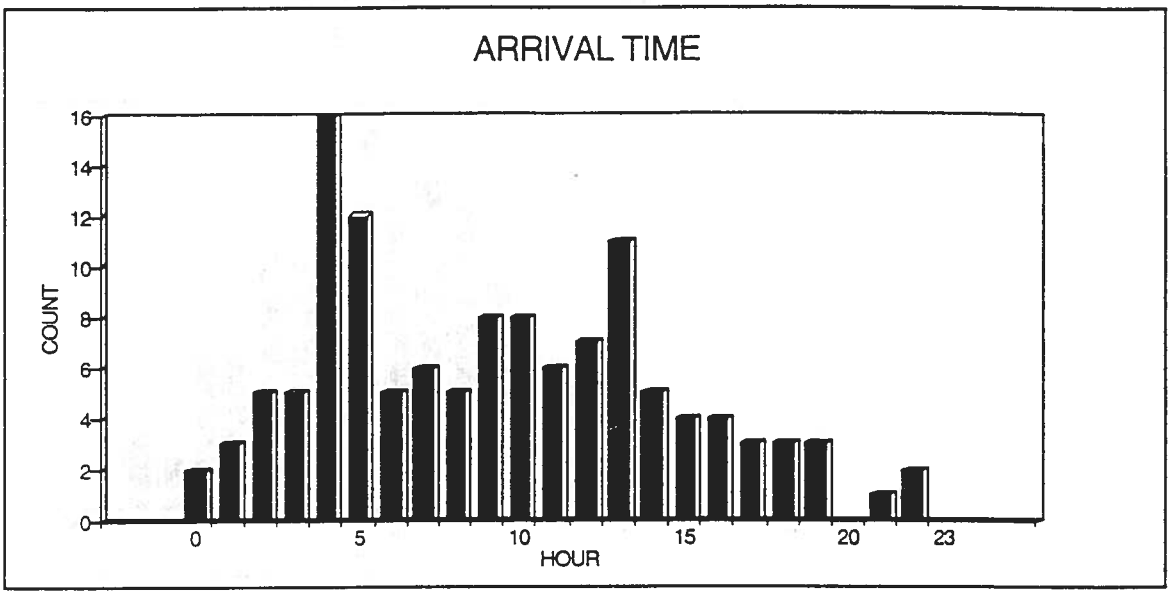


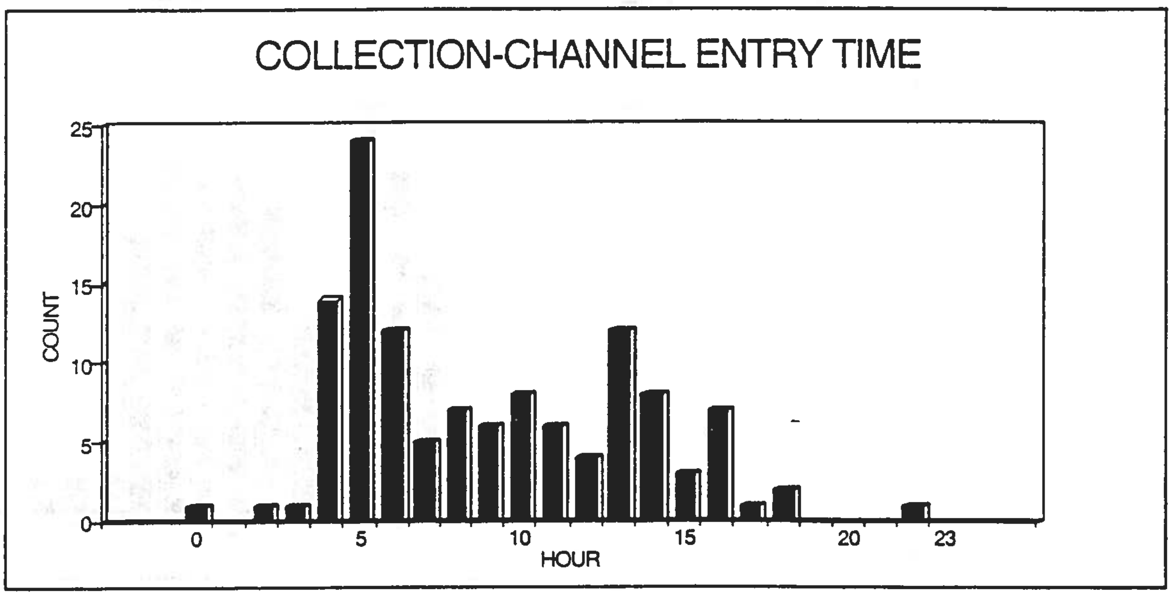


Appendix Figure B17.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Wells Dam, 16 May-15 July 1993.

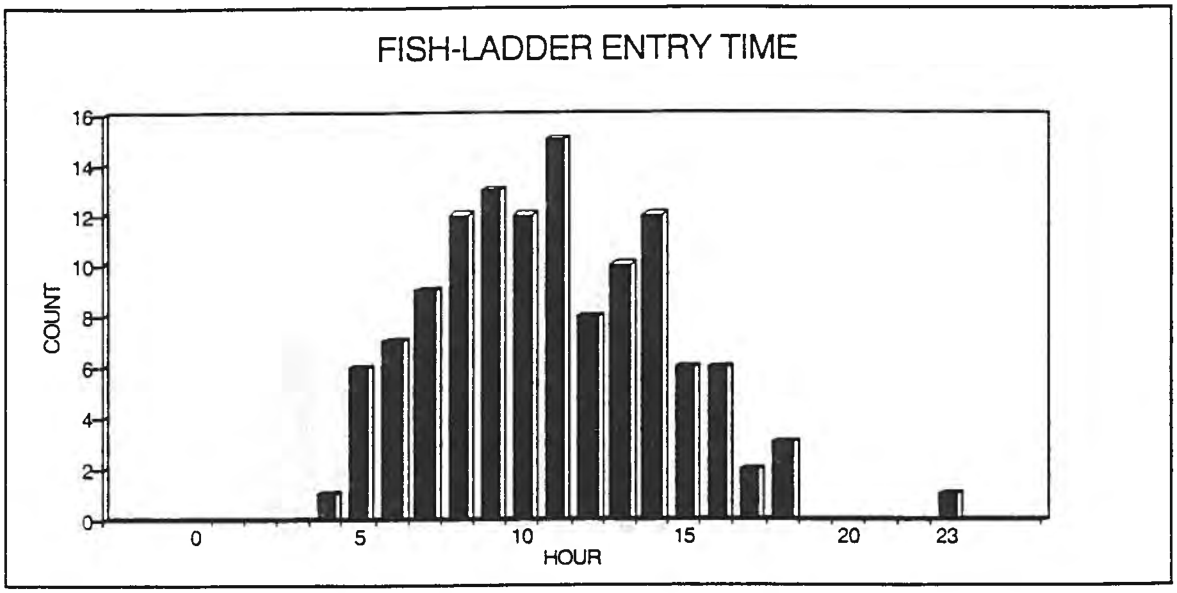


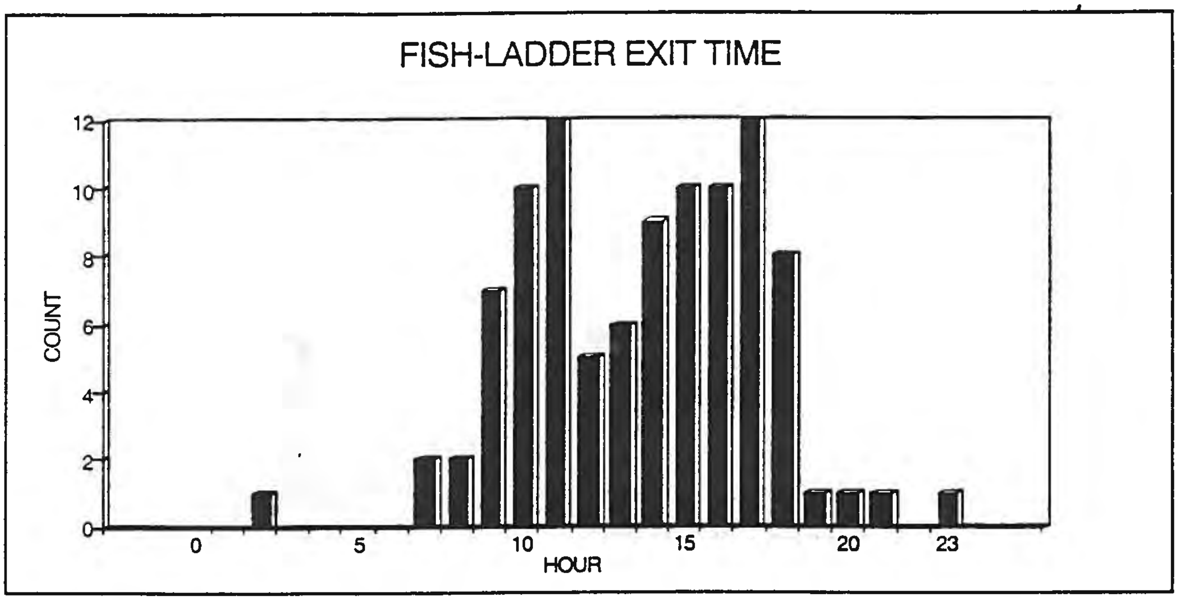
Appendix Figure B18.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Wells Dam, 16 May-15 July 1993.





Appendix Figure B19.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Wells Dam, 20 June-19 August 1993.

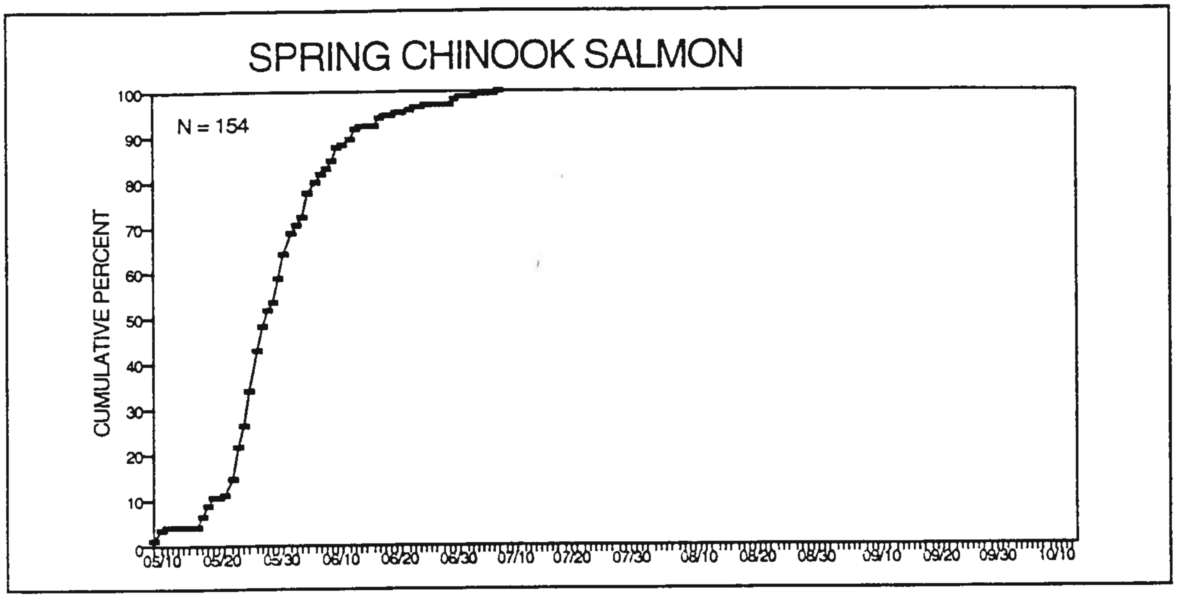


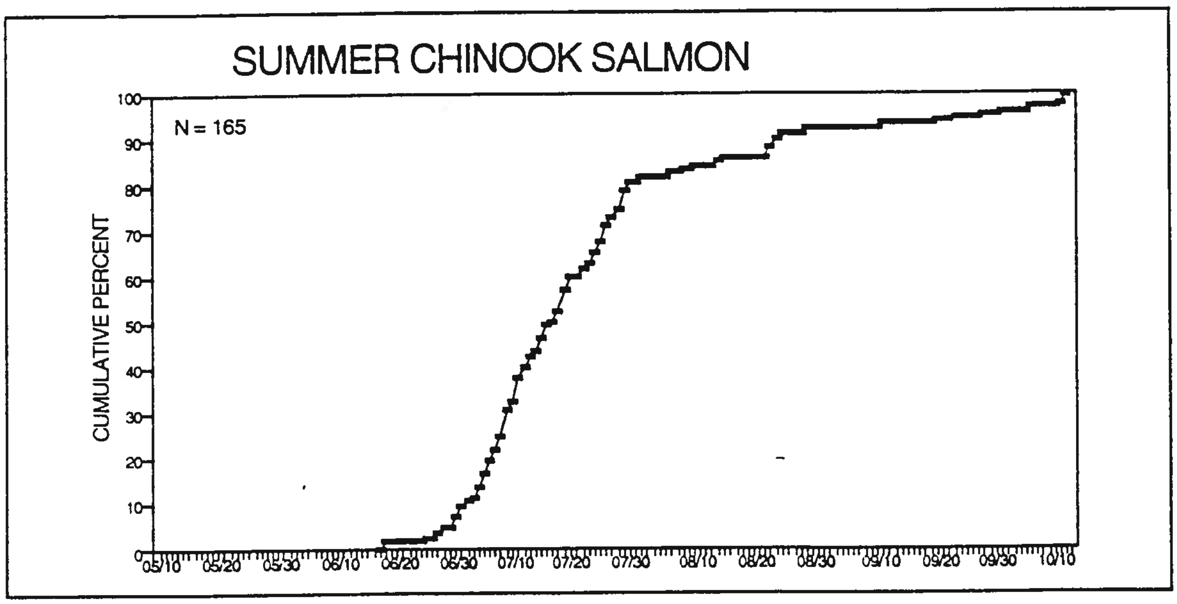


Appendix Figure B20.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Wells Dam, 20 June-19 August 1993.

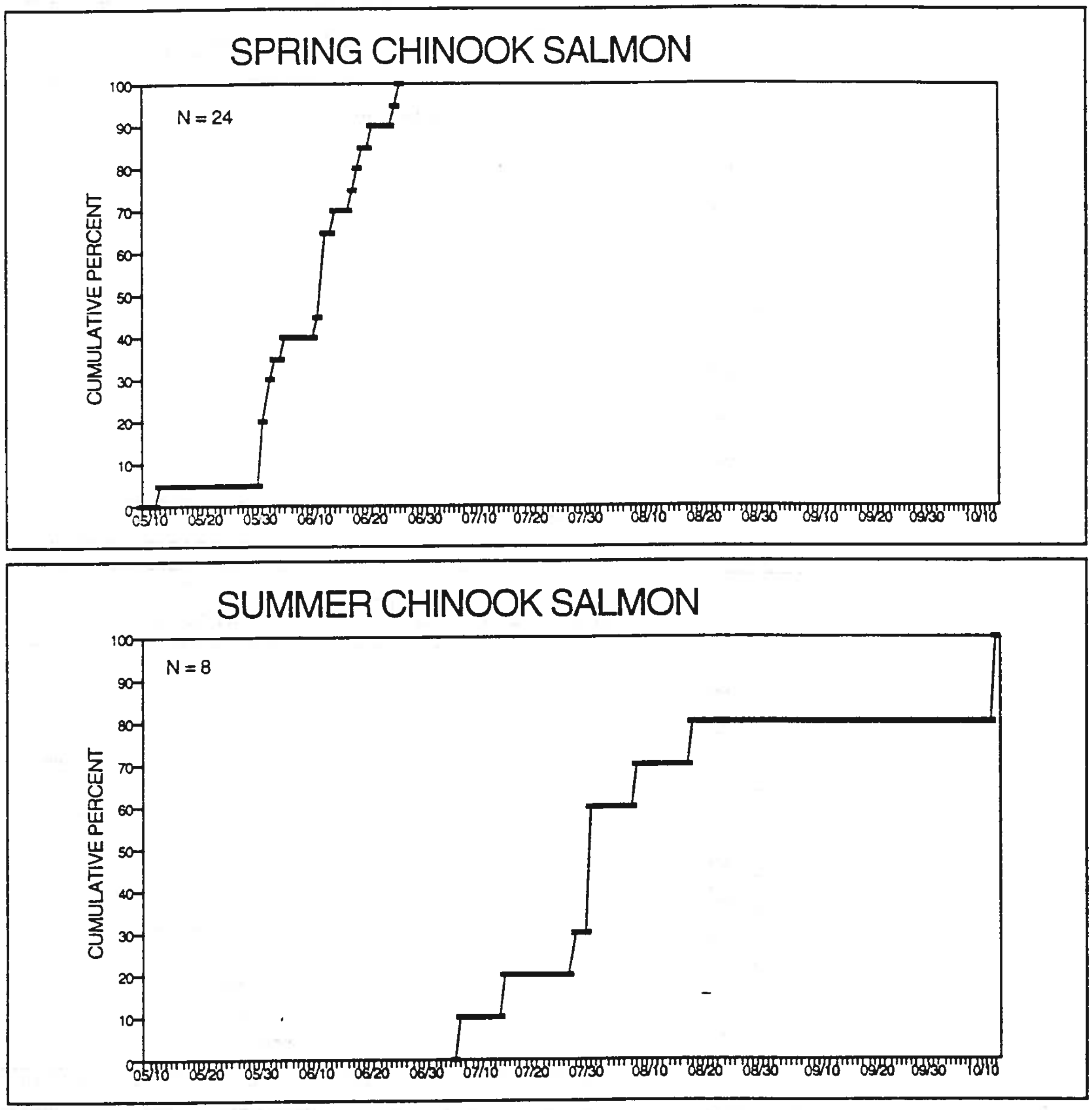
APPENDIX C

Tributary Entry Dates

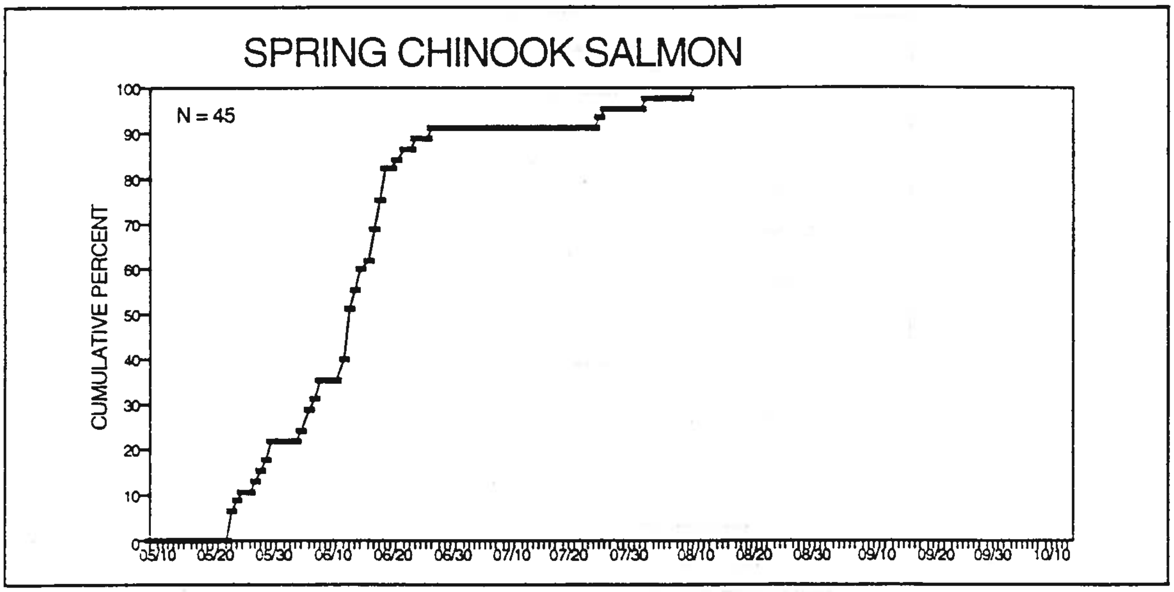


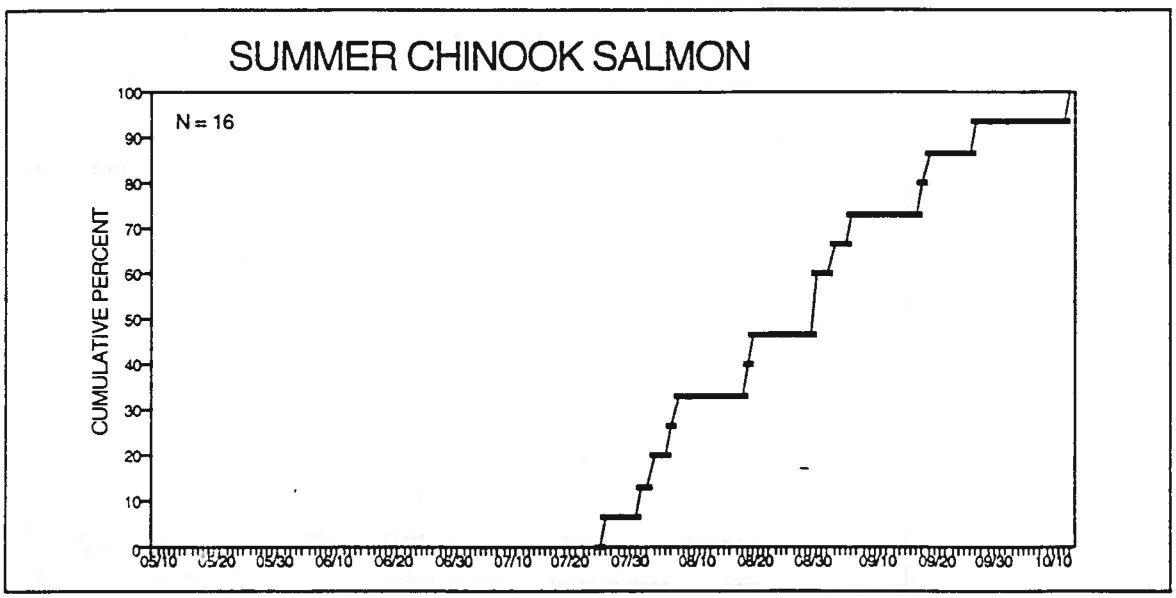


Appendix Figure C1.--Entry dates of radio-tagged chinook salmon into the Wenatchee River, 1993.

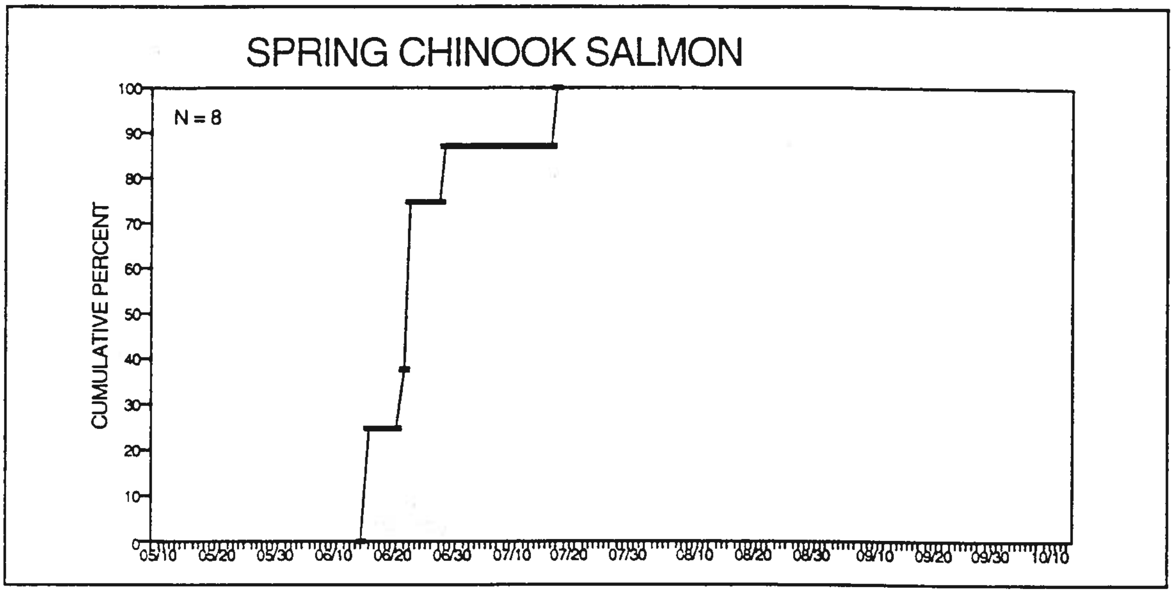


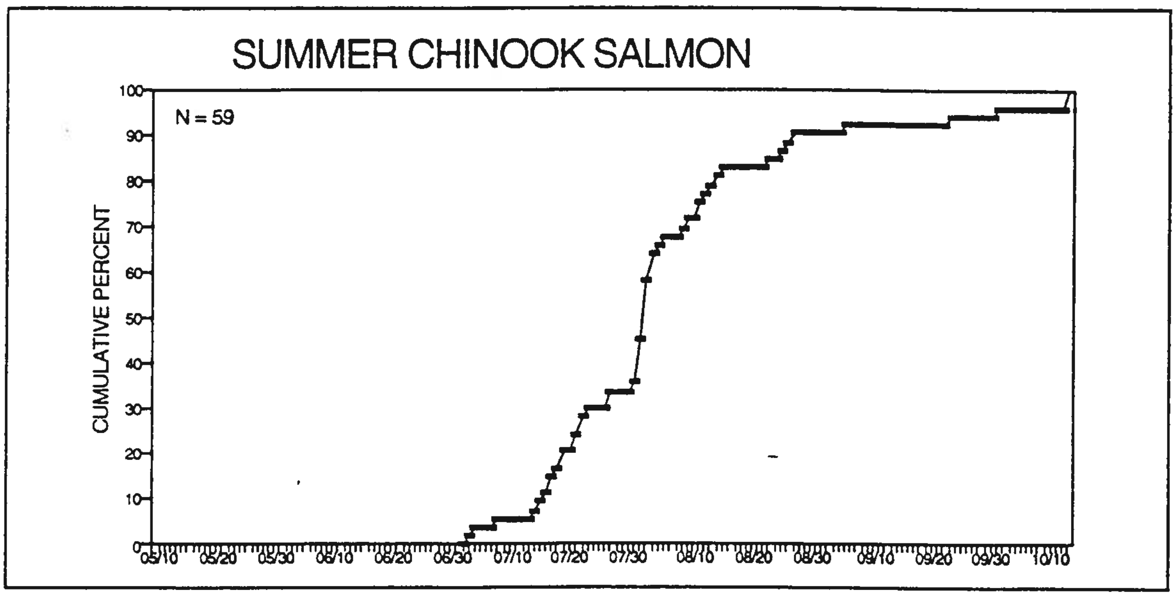
Appendix Figure C2.--Entry dates of radio-tagged chinook salmon into the Entiat River, 1993.





Appendix Figure C3.--Entry dates of radio-tagged chinook salmon into the Methow River, 1993.

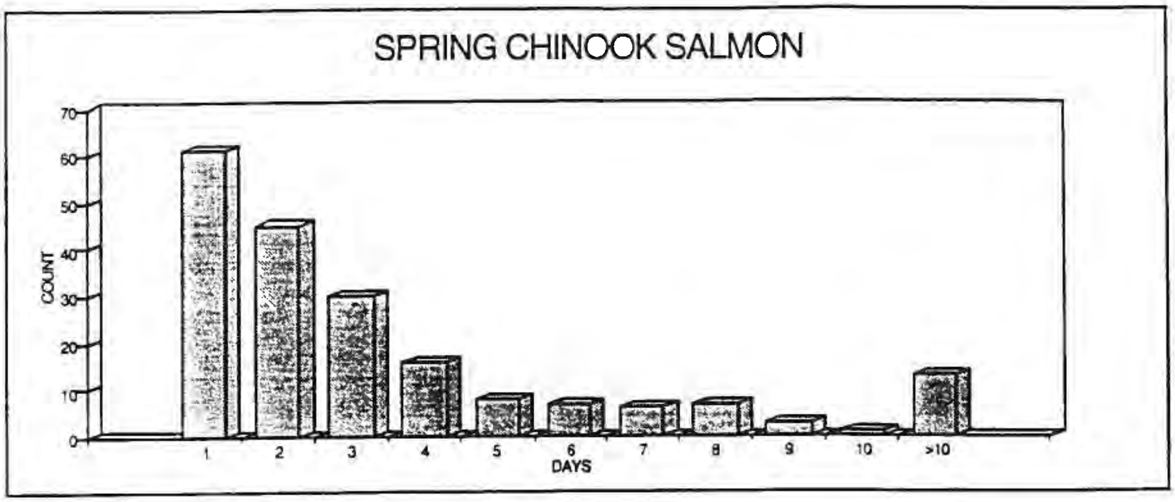


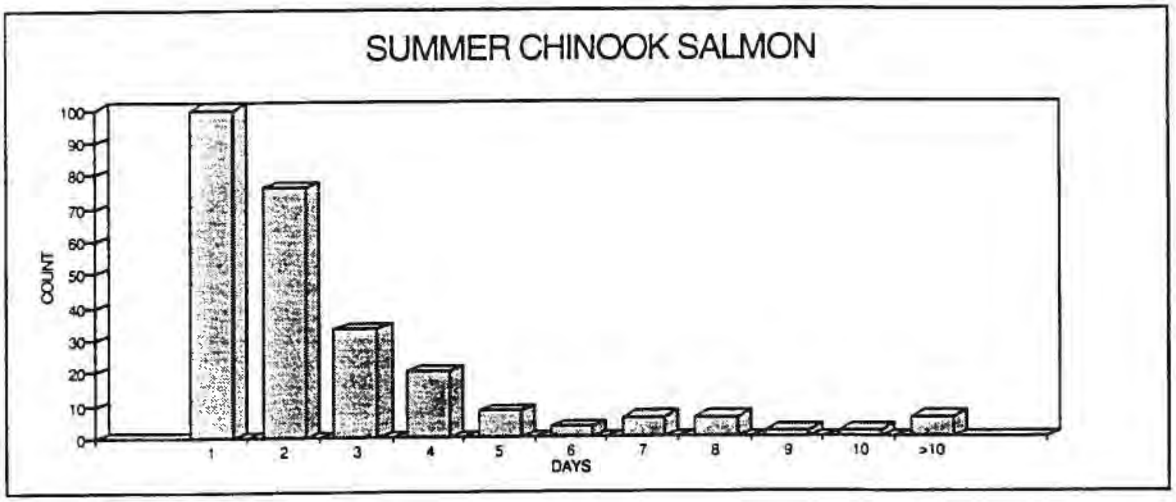


Appendix Figure C4.--Entry dates of radio-tagged chinook salmon into the Okanogan River, 1993.

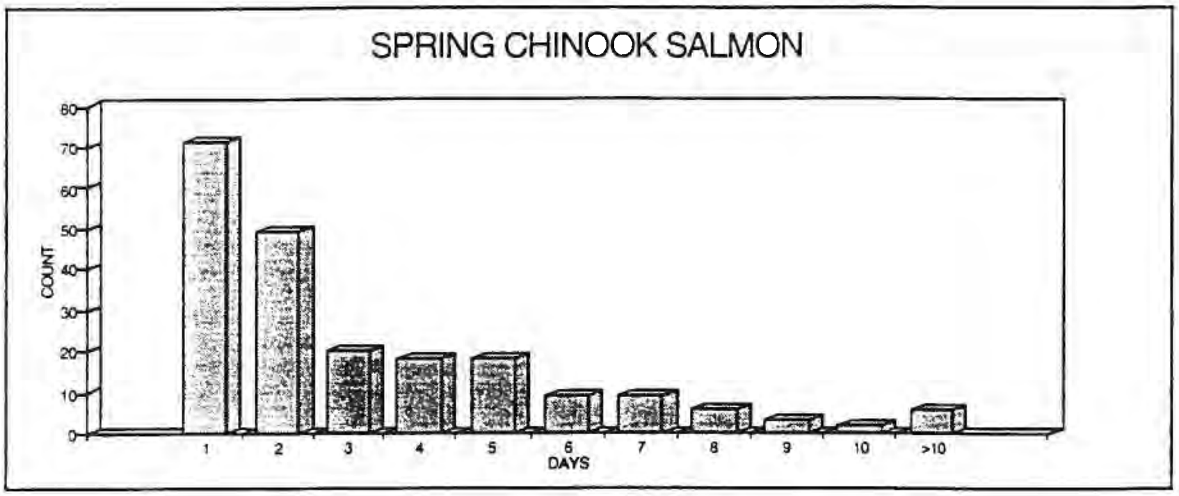
APPENDIX D

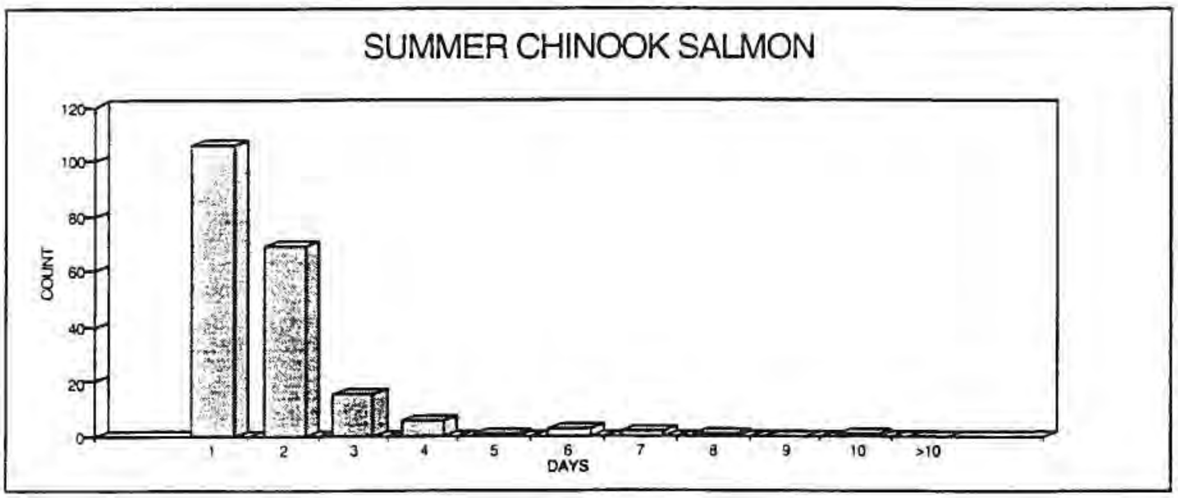
Dam Passage Time

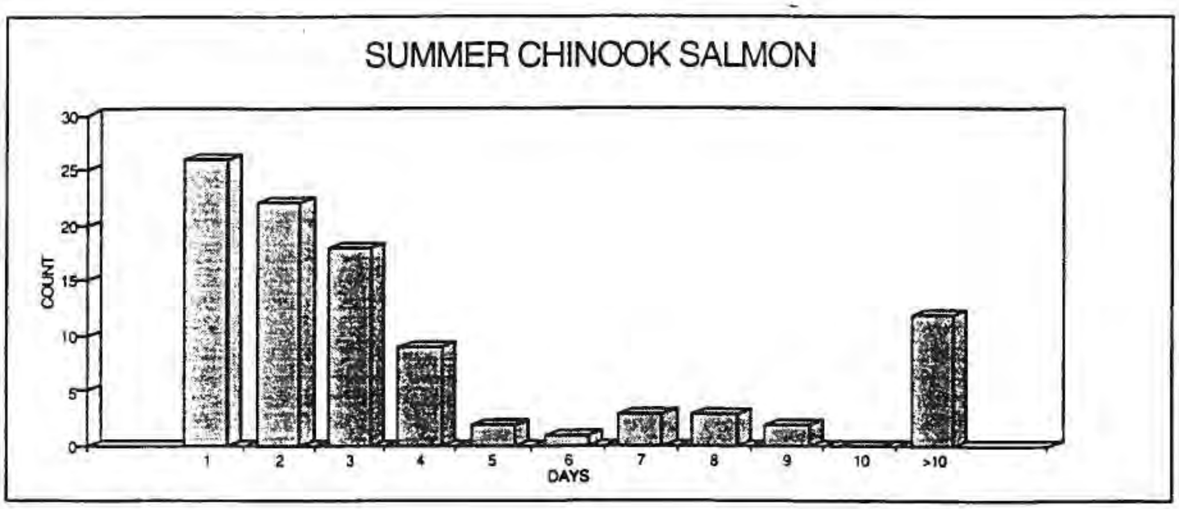




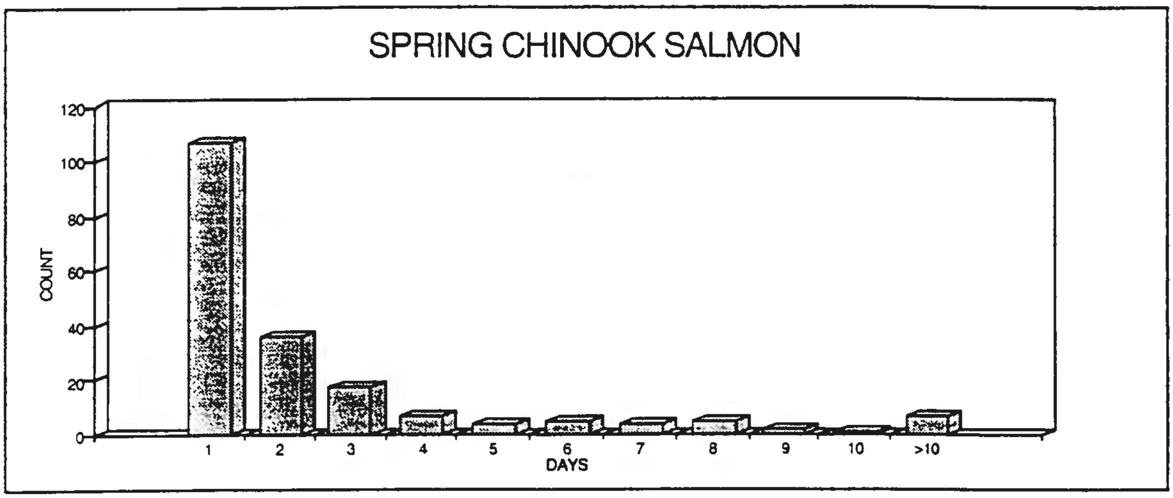
Appendix Figure D1.--Radio-tagged chinook salmon total passage times at Priest Rapids Dam, 1993.

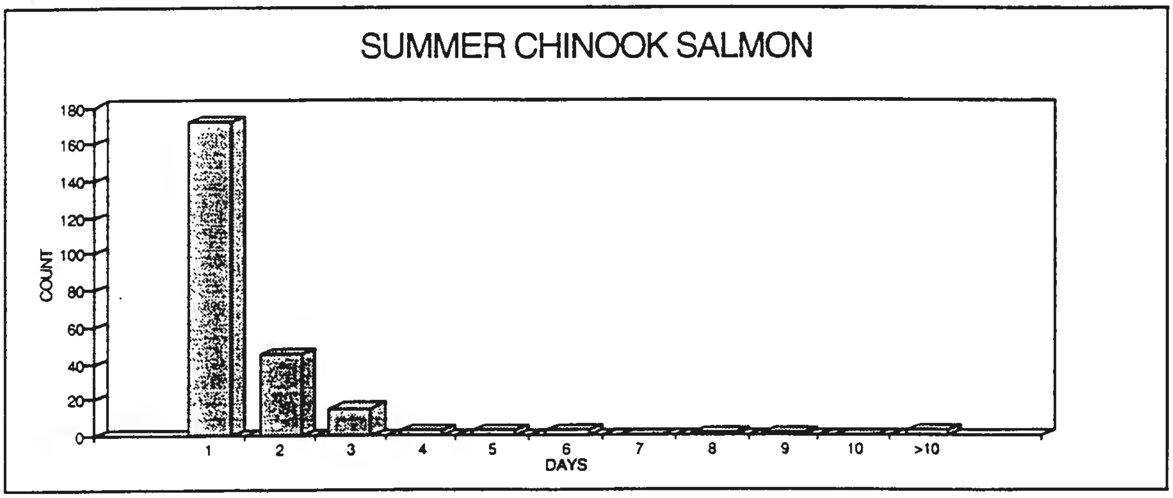


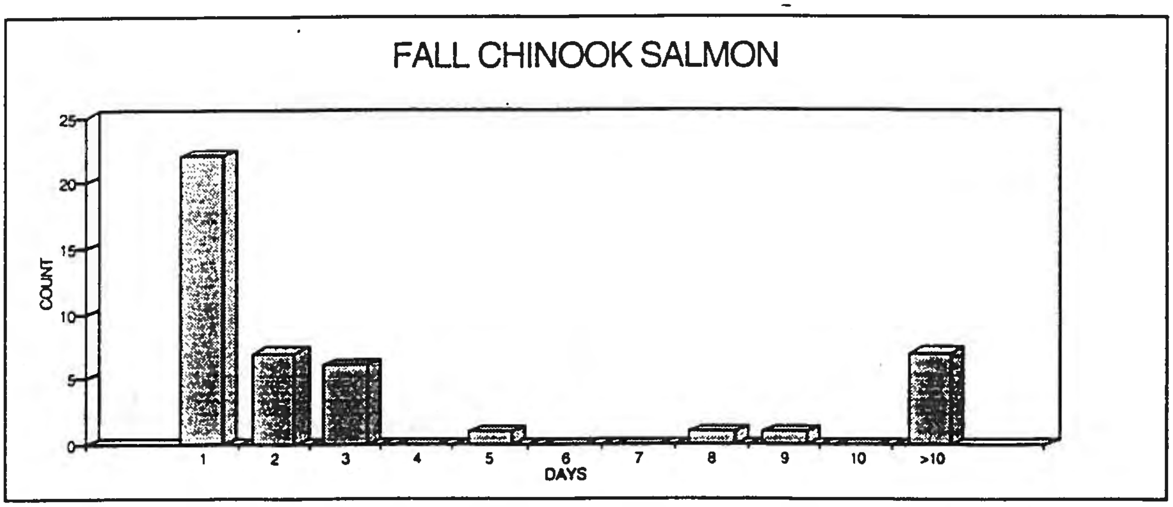




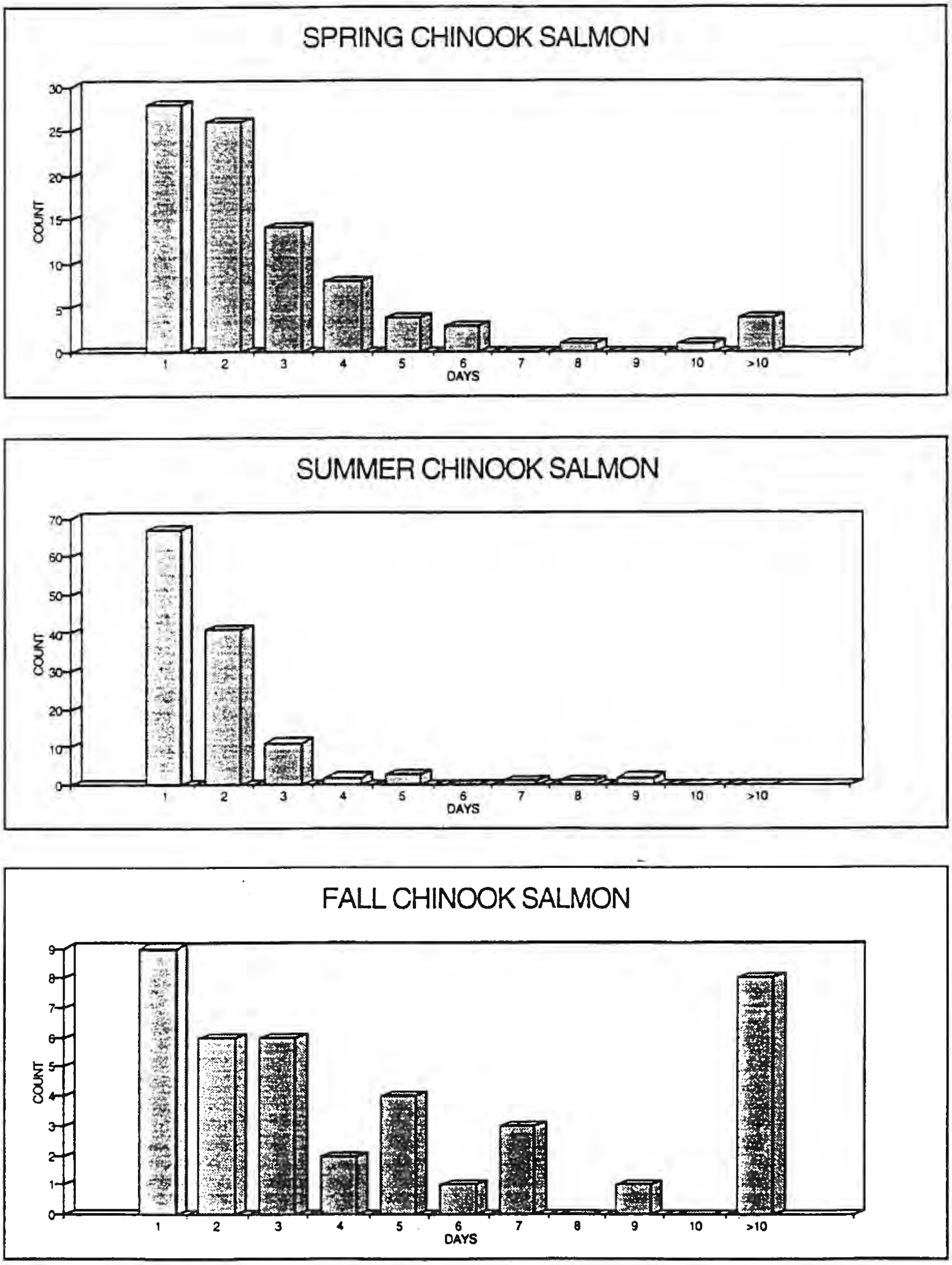
Appendix Figure D2.--Radio-tagged chinook salmon total passage times at Wanapum Dam, 1993.



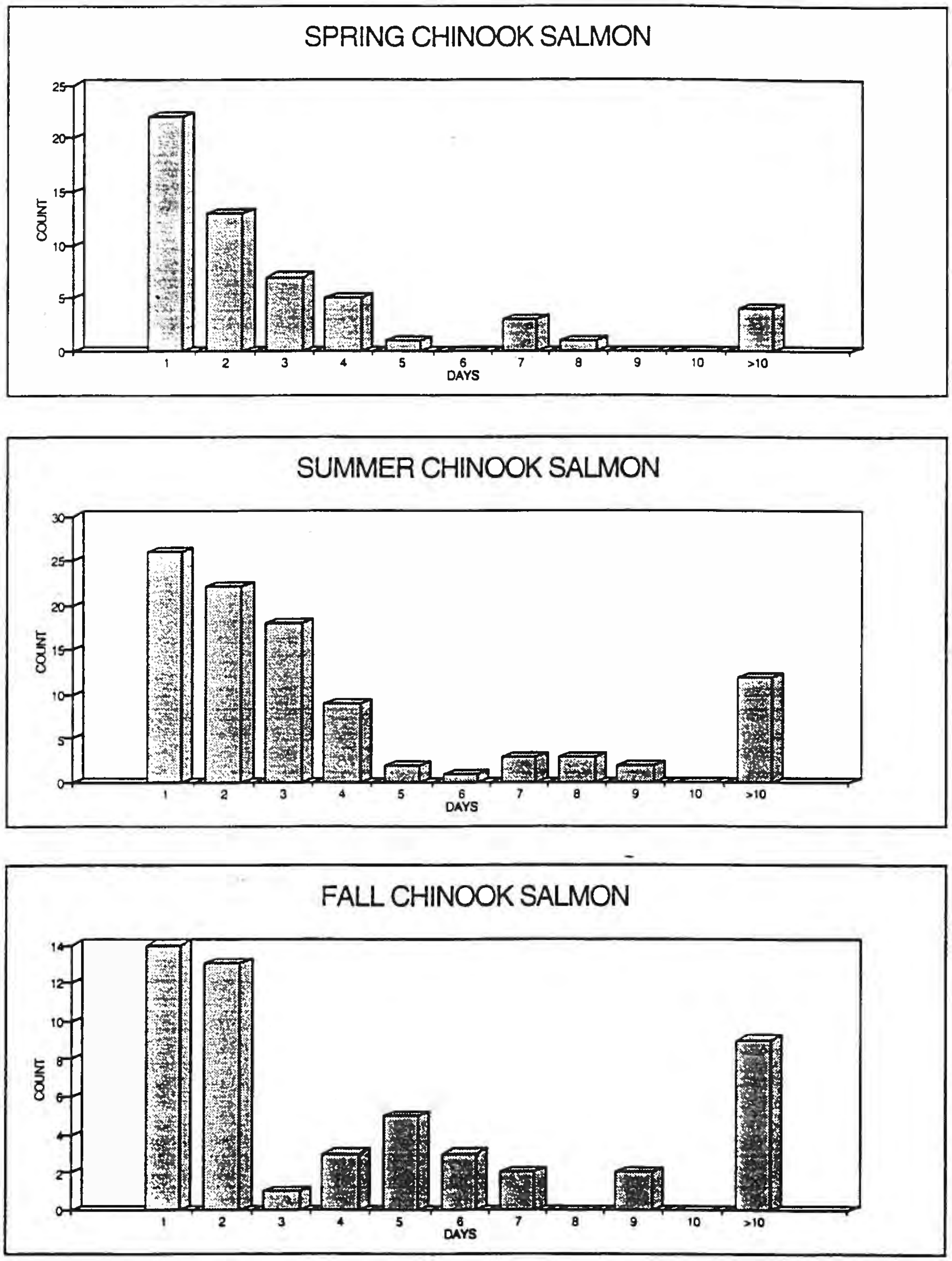




Appendix Figure D3.--Radio-tagged chinook salmon total passage times at Rock Island Dam, 1993.



Appendix Figure D4.--Radio-tagged chinook salmon total passage time at Rocky Reach Dam, 1993.



Appendix Figure D5.--Radio-tagged chinook salmon total passage times at Wells Dam, 1993.

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES AND WILDLIFE
COLUMBIA RIVER PROGRAM

DECEMBER 8, 1994

MEMORANDUM

TO: **Chris Carlson, Senior Fisheries Biologist**
Grant County PUD

FROM: Rod Woodin *RW*

SUBJECT: Comments for draft report: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING ,SUMMER,AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER

GENERAL COMMENTS

The report is well organized and clearly written. It represents an excellent effort for summarization and presentation of a voluminous data base.

SPECIFIC COMMENTS

P.19. Results and Discussion. Since the time/location patterns of adult fish activity are the principal data being assessed, much more information should be presented on the timing of initial marking and the relationship of marking activity to "run at large". This should be done for each chinook race and marking site. If the John Day marking data is presented in another report, the appropriate portions of the report could be included as an appendix. In general the Median, Maximum and Minimum statistics presented are useful descriptive data for the population at large. I realize that the data base for this report is awkward and difficult to work with, however more detail on the fish which had passage times greater than the Median may be useful in identifying problem areas. The Maximums far exceed the Medians in most of the passage categories. Any common behavior patterns for fish at or near the maximums may be more illustrative of facility problems than medians.

P.24. Travel Time. It should be specified that Median data is being presented.

P. 25 Table 3. This comment applies to all travel time tables. It is physically impossible for any time intervals between two points to be **zero**. Either data is being included for fish which were not detected at one of the two points of the interval of interest or the time was less than the minimum measurement which appears to be 0.1 hours. This should be cleared up and corrected! There should not be zero values in the travel time tables. Also in several of these tables there are greater values for channel exit than for total passage time. These values are in the max. column. This is probably due to fish which entered the collection channel but did not pass the dam. If so a footnote should be included to clarify this issue.

P.37. Figure 8. This is a helpful illustration. It would be more useful if it were enlarged.

P.38. Table 8. This is the first specific indication that the fish marked at Priest Rapids and Rocky Reach are being utilized in the data base. The segregation of these fish as done here seems appropriate. These fish should probably also be segregated in the Travel Time tables (if they were included). If the authors have a convincing rationale for not segregating the fish marked at Priest Rapids and Rocky Reach it should be presented in the methods discussion. Also, was there a cross check done to verify that no fish detected or tagged in the Mid-Columbia entered the Snake River? That appears to be the case from table 8.

P. 73. Fate of Radio-Tagged Fish. The fall chinook discussion should include the fallbacks at Priest Rapids. from the fallback description it appears that about 10% of the fall chinook had a final "fate" of mainstem below Priest Rapids.

P. 73. para.3. What is the threshold for significance in passage delay? I did not see this defined! Median values for passage do look reasonable in most cases. Some of the greater than median values in and around the collection channels could be a concern! More information on these timing distributions could be useful.

P. 74. para.1. The statement regarding selection of left-bank ladders can not apply at Rocky Reach. It only has one ladder which is on the right bank. Statement should be modified.

P. 75. Recommendations.
1) This recommendation appears out of place! There is no rationale or data summary presented to justify such a radical recommendation! Also if such recommendations are to be made they must be specific to each dam and specify a mechanism for accomplishment of the recommended operating strategy. My review of the report leads me to the conclusion that substantial positive passage occurs via entrances other than those nearest the base of the ladder(s) at Priest Rapids, Wanapum and Rocky Reach.

2) This recommendation is interesting, but, are the logistics of such flow modifications within the realm of practicability? The diffuser flow systems are literally cast in concrete.

3) The concept of more accurate data is desirable. However, unless there is high annual variability in fallback, the existing data base should be a highly reliable **index** of escapement.

P. 107. Appendix C. The inclusion of sample size for each of these figures would be helpful.

Thank you for the opportunity to provide comment on this draft report. If you have question regarding this response please call at (206) 586-4345.

FISH PASSAGE CENTER
2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

MEMORANDUM

DATE: January 9, 1995

TO: Chris Carlson, Sr. Fisheries Biologist
Grant Co. PUD

FROM: Larry Basham, FPC

RE: Comments on 1993 Radio Telemetry Study Conducted by NMFS at the Mid-Columbia Dams and Tributaries Entitled: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING, SUMMER, AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER.

I'm sure that the data base provided a tremendous amount of information to sift through in order to confine the report to the objectives listed, and the authors summarized the data in a fairly well-organized manner. My comments will be directed mainly to the Recommendation Section, but general or specific comments will be listed as well. Editorial changes are made on the draft report and attached to this memo. I received a copy of Rod Woodin's comments regarding the report and basically agree with the changes he recommended, but will expand ideas I have on the recommendations which the authors proposed.

COMMENTS

In general, nomenclature of main fishway entrance and orifice gates should be consistent with the design drawings. There were some differences in this report, which made it somewhat confusing to follow where and what the authors were referring to at the various fishways. The author should recheck to confirm labelings.

Also, it might be beneficial to give a brief description of the adult fishways at each project, e.g., see project descriptions of adult fishways in the 1994 Draft DFOP for the mid-Columbia dams.

p. 4 & 8. - It would be helpful if the authors included a Figure that illustrated size of the radio tag and tagging procedure.

p. 7 & 9. - Label Figures 3 & 4 (Plan View, Sectional, etc.) similar to Figure 2.

p. 46, 48, 54, & 59. - Figures 12, 14, 19, and 23 need clarification in their labeling. Does the author mean that 100% of the fish at the Rock Island Dam's Center and Left Powerhouse ladders fell out of the channel before ascending the fish ladder; I doubt it.

p. 55, 57, 58, & 59. - Figures 20, 21, 22, and 23 should change OPE labels on OPE4, OPE5, and OPE6 to OPE16, OPE18, and OPE20 to coincide with the actual openings at the project.

p. 50. - Figure 15 lists LEW (Left Entrance Weir); it does not exist at Wanapum Dam. Mislabel.

p. 49. - The text does not even list the left bank fishway or the center fishway. To help clarify the right bank fishway entrances, I suggest that the author consider renaming the RPE to RBLPE, as this entrance is on the right bank and actually is located at the left end of the powerhouse.

p. 16. - The terms listed on page 16 are keys to understanding what the author is trying to portray and should be noted by bullets, underlining, or bold print.

p. 19. - Under the heading **Fallback**, the authors assigned a route to below the project for each fallback; however, no record of which avenue of fallback is listed in a table or in the text. No mention was given of spill Q during daytime hours. This may or may not be a factor but should be given consideration since mortality of a fish over a spillbay would certainly be less than through a turbine unit.

p. 20. - The authors listed that the run timing of spring and summer chinook at the Wenatchee River, Priest Rapids, Wanapum, and Rock Island dams was considerably more advanced than run timing for fish that passed Rocky Reach and Wells dams. Does this mean there was a problem in passage at the lower dams or was the difference due to tagging (Fig. 7), or is this insignificant?

p. 26. - A handling associated delay was suggested by the authors. Part of the delay could be due to the time of day and specifically when the tagged individual was released at the Priest Rapids trapping site. I suspect that part of any delay is due to time of release of an individual fish which has been anesthetized and is recovering from that stress. Did fish released late in the afternoon take 10-12 h longer to make it to Wanapum Dam than fish released during the morning hours? Additional detail should be added to the report.

p. 30. - It should be noted that the ladders at Rock Island Dam are about half the height of the other dams, and one would expect salmon to pass this project more quickly than at the higher head dams.

p. 35. - After the first paragraph, a new heading should be placed to denote a general summary of the passage through the projects and reservoirs.

p. 56. - The authors should break out the passage between the two LPEs at Rocky Reach Dam. It is also unclear in the text whether the fish entering the LPEs and moving to the junction pool area turn around and drop back out the LPEs or through the OGs along the powerhouse channel. This should be clarified.

p. 65 & 68. - Combine Table 13 with Table 11.

p. 64-71. - It appears that fallback was a problem at some dams: Priest Rapids & Wanapum during the spring passage season (apparently most fallbacks were from Ringold Hatchery), Wells Dam during the summer, and four of the five projects during the fall season had fallback rates of near 11% and up to 21%. The authors should determine route of fallback during these time frames. The other question that will face fish passage specialists, is whether or not this fallback can be reduced at the various dams and whether a safer fallback route is available for fish which overshoot a tributary or hatchery located below the dam. This information should alert managers that fallbacks and overcounts are occurring at individual projects.

p. 73. - The authors indicated that there was no significant delay associated with various routes of passage. Based on the tables, some of the fish spend considerable time attempting to pass through a collection channel. Delay should be qualified and defined by the authors since there are fish that take considerable time to pass the projects.

RECOMMENDATION SECTION

p. 75. - In the first recommendation by NMFS, closure of all collection channel openings, with the exception of the main openings closest to the base of the fish ladders, was recommended for improving adult fish passage. Does this include closing gates LEW-2 at Priest Rapids, SE-3 at Wanapum, the left powerhouse entrance and the downstream entrance at the right bank fishway at Rock Island, the spillway and the right powerhouse entrance at Rocky Reach Dam? Not only would this be debatable, but would likely be detrimental to adult fish passage. Without a test to assess a radical change in operation, the proposed closure could result in a total block of fish passing a facility, e.g., if powerhouse units, particularly Unit 10 at Priest Rapids, were operated at an overload condition, passage through the LEW-4 gate could be completely blocked with no other gates open to pass fish. The 1993 study did not test turbine unit operation and as such I question whether a blanket recommendation could ever be accepted without further testing to validate a change such as recommended.

I believe that any reduction in flow from the orifice gates should be followed by adding flow to the main fishway entrances. Even then, this premise needs careful consideration since flows added into a particular area (junction pool) may cause fish to reject or refuse passage through an area.

I also do not agree that main entrances such as LEW-2 should be closed. For an example, during the past year or two, there were times when LEW-4 was closed (repairs required), and adult passage appeared satisfactory when using the far entrance and orifice gates to attract fish to the channel and up past the counting station. Although this does not prove that passage was improved without operating LEW-4 (closest to main fish ladder), it did show that fish passed through the channel at a "satisfactory" rate while the LEW-4 was out of service.

I am certainly open to closure of some orifice gates at each project, but don't believe the study would indicate closure of all orifices.

Recommendation 2 from NMFS, which was to modify flows between the openings and the base of the fish ladders and moving the diffuser flows upstream and closer to the base of the fish ladder, would require lots of dollars, logistical concerns, hydraulic concerns and possibly constraints; I am assuming that potentially wall diffusers would replace floor diffusers. Whether this would be the panacea to improve passage through the junction pools and into the fish ladders must be evaluated. At present, there are wall diffusers at Rock Island Right Bank Fishway and both fishways at Wells Dam. The authors should pursue this issue further. Adding several thousand cfs of water to a small localized area will not promote a smooth laminar flow.

Recommendation 3 from the report related to fallback of fish at the project and resulting over counts of fish passing a project. This report was the first real data to show that fallback exists at each of the mid-Columbia dams. As earlier stated, I believe that managers will now be more aware that fallback occurs and counts at a project may be inflated. If fish were available for additional radio telemetry studies, fallback could be indexed over a range of flows and spill throughout a series of years; however I must be dreaming to think that a study or better yet, that sufficient salmon would be available to even have fish available to mark for a test.

Some items not noted in the report:

- effects of turbine unit operation on fish passage at each project.
  flow levels through the powerhouse, spillway, and combinations thereof that affect fish behavior, i.e., passage into a particular entrance of a fishway.
- I believe that at Wells Dam only one of the two gates at the east and west bank fishways is required to improve fish passage. It appears that opening the end gates to a maximum of 8.0 feet open would supply more attraction flow and hopefully less fallout from the entrance channel than using the side gate as well. It may be that the inside gates (also open 8.0 feet) would be the best to use during non spill periods. Again, this should be brought up in the proper forum for discussion and hopefully tested if and when another radio telemetry study is proposed.
- Based on visual observation only, I believe that removing Orifice Gate 20 at the right end of the Rocky Reach powerhouse would provide much better passage and attraction conditions for adult fish than continued operation of both RPEs. The flow from the open slot would project into the tailrace at a better angle than flow from the RPEs. This should be tested in future telemetry studies.
- Related to the second item above, daytime spill and its effect on passage, fallback level, and overall fish passage should be covered in this report or another short report.
- Also, in-season data transmission was not covered in the report. It would be very helpful in future studies to improve data collection and transmission (table form) throughout the fish passage season if possible.

The Fish Passage Center appreciated the opportunity to comment on the Draft NMFS Radio Telemetry Study conducted in the Mid-Columbia River during the 1993 adult fish passage season. Please feel free to call me if there are questions regarding these comments. My phone number is (503) 230-4287.

SUBJECT: Response to comments on draft report: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING, SUMMER, AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER.

Rod Woodin's comments (December 8, 1994)

P.19. Results and Discussion. Text was added to pages 20 and 24 to explain differences between the number of spring chinook salmon passing John Day Dam and the number of fish tagged throughout the run.

Appendix D was added to show the distribution of total passage times for each race at each dam. Given that the median passage times at the mid-Columbia River dams were within the range observed at other mainstem Columbia River dams, detailed analysis of individual passage problems was not completed.

P.24. Travel Time. The word median was added to the text as appropriate.

P.25. Table 3. Zero values were changed to <0.1 in the travel time tables. Very short (seconds) transitions between at dam sites were previously reported as 0 hours of time.

An asterisk was added to each travel time table for maximum individual passage times that were greater than the maximum total dam passage time.

P.37. Figure 8. Figure 8 was enlarged.

P.38.Table 8. Text was added to page 17 to explain why fish marked at Priest Rapids and Rocky Reach Dams were not separated in the travel time tables.

Fish with fates in the Snake River were included in the last location tables.

P.73. Fate of Radio-tagged Fish. Text on pages 72 and 73 addresses fallback of fall chinook salmon at Priest Rapids Dam. No changes were made.

P. 73 para.3. There is no information on when total passage time at a dam becomes significant. The medians passage times in this report are within the range of those observed at other Columbia River dams. No changes were made in response to this comment. The word delay was removed from the report. It was replaced with an appropriate travel time estimate.

P.74. para.1. The text on page 72 was changed to qualify the right bank ladder at Rocky Reach Dam.

P.75. Recommendations. 1) The rationale for the first recommendation follows the recommendation. In addition, nearly every evaluation of adult collection channels has recommended closure of openings to the long powerhouse channels. Despite those recommendations, very little has been done.

This study was designed to identify areas where there may be concerns about adult passage at the mid-Columbia River dams. The area with the greatest potential for reducing total passage time at the dam is between the junction pool and the base of the fish ladders. Each dam has different physical structure and flows in that area. The engineering of structure and flows is beyond the scope of this research project and was not addressed.

At dams with long adult collection channels across the face of the powerhouse, there is substantial net positive entrances occurring at the distal end of the channels. Our analysis indicates that this activity may be at great expense to total passage time at the dams.

Recommendation. 2) No changes were made based on this concern. The engineering of structure and flows is beyond the scope of this research project.

Recommendation. 3) No changes were made based on this concern. The fallback estimates obtained in 1993 may be good for the conditions that existed. However, changes in daytime spill rate, total river discharge, and the success of the Ringold Hatchery program will cause major deviations from the 1993 estimates.

P.107. Appendix C. Sample size (N) was added to each figure in Appendix C.

Larry Basham's comments (January 9,1995)

COMMENTS The nomenclature of the main fishway entrances and orifice gates were changed based on the recommendations given.

No changes were made to the description of the adult fishways. Drawings of the facility at each dam are presented in Appendix A.

p. 4 & 8. Information on the tag size and weight were already given in the text (page 4) and tagging procedure was described on page 8. No figures were added to supplement this information.

p. 7 & 9. The labels for Figures 3 and 4 were changed.

p. 46, 48, 54, & 59. The titles for the base-of-the-fish-ladder figures were changed to reflect the formula (2) in the Methods section.

p. 55, 57, 58, & 59. Nomenclature changes were made in the text and figures.

p. 50. The error in the title for Figure 15 was corrected.

p. 49. Text was added to the report to address the information at the center and left fish ladders.

p. 16. Bullets and bold print were added to the definitions of dam passage terms.

p. 19. Determination of fallback location was not possible due to long periods between fish ladder exits and the next record downstream from the dams. Fallback location was removed from the Methods section of the report.

p. 20. Two areas come to mind when addressing run timing of individual stocks. The first is which stocks are being harvested in limited seasons. The second is the selection of brood stock at the dams that have adult collection facilities.

p. 26. Fish tagged at Priest Rapids Dam had significantly longer travel times to Wanapum Dam than fish tagged at John Day Dam whether released in the morning or afternoon. No changes were made.

p. 30. Ladder passage time at the Snake and Columbia River dams is the same regardless of ladder height or length. Counting stations likely affect passage time much more than ladder height or length. No changes were made.

p.35. The general summary information was moved to the Summary section of the report.

p. 56. Net passage rates at the two LPEs at Rocky Reach Dam were separated and new figures created.

p. 65 & 68. Tables 11 and 13 have been combined.

p. 64-71. Because fallback routes could not be determined, no changes were made.

p. 73. "Delay" was removed from the report and the appropriate passage time estimates were inserted.

p. 75. Virtually every study on adult collection channels has recommended closure of orifices. Given the fish behavior observed in this study, we believe our first recommendation should be evaluated as a means of reducing the passage time associated with multiple entries and wandering in the adult collection channels.

Items not noted in the report:

First bullet - Based on total passage times and an interest in timely completion of the report, we did not attempt to correlate fish behavior with dam operating conditions.

Fourth bullet - Due to the long period between ladder exit and verification of a fallback below the dams, fallback times and locations could not be determined. In addition, cause and effect cannot be determined from uncontrolled tests of fish behavior during 1 year's spill conditions. Studies with test and control observations over a wide range of flows are needed before observations will become meaningful.

Fifth bullet - We are somewhat unsure about the meaning of "data transmission" in this bullet. We added a sentence to the end of the radio-tracking section (page 10) to indicate how the data were moved to the Pasco, WA data center. If the intent was to have raw data available outside of the research group, the nature of radio-telemetry raw data (RF noise) precludes this turn-key approach. Preliminary summaries are highly unreliable, take immense amounts of time, and lead to premature conclusions that may not be supported in a final report.

We appreciate the comments of the reviewers. The quality of this and future telemetry studies will benefit from their comments.

SIGNIFICANCE OF PREDATION IN THE COLUMBIA RIVER FROM PRIEST RAPIDS DAM TO CHIEF JOSEPH DAM

BY

THOMAS POE, WDFW

APPENDIX - I

SIGNIFICANCE OF PREDATION IN THE COLUMBIA RIVER FROM PRIEST RAPIDS DAM TO CHIEF JOSEPH DAM.

March 1993 - January 1994

Edited by

Craig C. Burley
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and

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Contract 430-486

January 1994

TABLE OF CONTENTS

EXECUTIVE SUMMARY

We report on the results of a one year study to determine the relative predation by northern squawfish (*Ptychocheilus oregonensis*) on outmigrating juvenile salmonids (*Oncorhynchus spp.*) in the mid-Columbia River reservoirs from Priest Rapids Dam tailrace to Chief Joseph Dam tailrace. Previous work has indicated that predation by resident predators accounted for a significant portion of the in-reservoir losses of juvenile salmonids in the lower Columbia and Snake River reservoirs.

This work was conducted to determine the relative predation indices values for each of the five reservoirs (Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells reservoirs) and Priest Rapids tailrace, and to compare these results to predation indices values observed in John Day Reservoir as well as other reservoirs in the lower Columbia and Snake rivers.

The following points summarize the major results of the predation indexing study on the mid-Columbia River conducted by the Washington Department of Wildlife and the National Biological Survey (formerly the U.S. Fish and Wildlife Service) in 1993.

1. Northern squawfish (4,537) was by far the most abundant predator collected followed by smallmouth bass (528) and walleye (193).

2. Northern squawfish abundance was highest in tailrace areas followed by mid-reservoir and forebay areas.

3. The density index values of northern squawfish in reservoirs of the mid-Columbia were as high as many of the reservoirs of the main-stem Columbia and Snake River.

4. Abundance index values (AI) for northern squawfish ranged from 0.02 in Chief Joseph tailrace boat restricted zone (BRZ) to 3.36 in Wanapum mid-reservoir and were generally highest in mid-reservoir areas because of the larger size of these areas.

5. Consumption index values (CI) for northern squawfish predation on juvenile salmonids ranged from 0.0 (at several areas both spring and summer) to 3.9 at Rocky Reach tailrace in summer and were generally highest at tailrace BRZs.

6. The integrated predation index values (PI) for northern squawfish ranged from 0.00 (at several areas both spring and summer) to 1.48 at Rocky Reach tailrace in summer.

7. Mid-Columbia reservoir 1993 predation index values were less than John Day Reservoir 1993 predation index value.

8. Comparisons of mid-Columbia PIs to previous estimated of PIs for the lower Columbia River and Snake River reservoirs indicate that mid-Columbia PIs are within the same range as the lower Snake but lower than the rest of the Columbia.

9. Incidental catch was high with over 25 fish species recorded. Catostomids were by far numerically dominant.

10. Juvenile salmonids appear to be a significant component of northern squawfish diets in the mid-Columbia River reservoirs, especially in tailrace areas.

11. A feeding response by northern squawfish to a release of summer chinook juveniles from Wells Hatchery was observed in mid April.

12. Female northern squawfish dominated the catch and were significantly larger than males, as was the case for indexing studies in previous years.

REPORT A

Significance of Predation in the Columbia River from Priest Rapids Dam to Chief Joseph Dam: Predator Consumption Indexing

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and James H. Petersen
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ACKNOWLEDGEMENTS

Special thanks to Mark Hack and Dave Schultz of the Washington Department of Wildlife for their excellent assistance during the field season and gut analysis. Many thanks to Bob Perleberg (Washington Department of Wildlife, Wenatchee) and Jack Boss (Project Manager, Priest Rapids Dam) for providing boat storage that was much appreciated. Throughout the field season, the cooperation from PUD biologists, control room personnel and other project personnel was outstanding. Their assistance and on-site support was an important contribution to the success of the field season.

INTRODUCTION

The northern squawfish (Ptychocheilus oregonensis), a large cyprinid native, has long been implicated in predation of juvenile salmonids in the Columbia River and other freshwater systems (Foerster and Ricker 1941; Ricker 1941; Jeppson and Platts 1959; Thompson 1959; Thompson and Tufts 1967; Rieman et al. 1991). Unexplained losses of outmigrating juvenile salmonids in John Day Reservoir prompted investigation of predation rates and salmonid losses in the reservoir. Research indicated northern squawfish were the major predators of juvenile salmonids in the system. Predation rates were especially high near hydroelectric facilities in John Day Reservoir (Poe and Rieman 1988; Rieman et al. 1991), although the large number of northern squawfish in the mid-reservoir may also have caused significant losses of juvenile salmonids (Rieman et al. 1991).

Predation is an important mortality factor in river passage models that are designed to assist in the rebuilding of depleted anadromous salmonid stocks in the Columbia River system (MEG 1989; Bledsoe et al. 1990; CQS 1991; Lee 1991). Baseline predation data supply management agencies and modelers with information necessary for planning and implementing predation control measures, including strategic siting and operation of salmonid bypass facilities at hydroelectric projects, northern squawfish removal programs, and barge transportation operations.

In 1989, a study was initiated by the U.S. Fish and Wildlife Service (USFWS) and the Oregon Department of Fish and Wildlife (ODFW) to estimate the system-wide magnitude of predation on juvenile salmonids as they migrate through the rivers on their seaward journey. The size of the Columbia River basin made an indexing approach the most efficient means of estimating abundance and assessing relative consumption rates between locations throughout the system (Petersen et al. 1990; Vigg and Burley 1990). Indexing in previous years has been on the lower Columbia River from Ice Harbor Dam tailrace on the Snake River to Bonneville Dam forebay (1990), the Snake River from the confluence of the Clearwater and Snake Rivers at Lewiston, Idaho to Ice Harbor Dam forebay (1991), and the lower Columbia River from Bonneville Dam tailrace to Jones Beach, Oregon (1992). Consumption indexing in the mid-Columbia River from Chief Joseph dam tailrace downriver to Priest Rapids dam tailrace in 1993 completes the survey, providing a comprehensive system-wide database of northern squawfish predation on juvenile salmonids.

The purpose of this report is to present the 1993 data on consumption indexing collected by the National Biological Survey (NBS, formerly the USFWS). Extensive information was also collected on northern squawfish diet, habitat use, feeding patterns, and population parameters. Salmonid consumption rates and diets were also characterized for other predaceous fishes, primarily smallmouth bass (Micropterus dolomieui) and walleye (Stizostedion vitreum). Consumption indexing for northern squawfish was integrated with abundance index results (Report B) from the Washington Department of Wildlife (WDW) to produce indices of predation loss.

METHODS

Sampling Efforts

Beginning in March 1993 in conjunction with WDW, sampling locations (approximately 5 km long) were selected and divided into 24 transects. Locations ran from Chief Joseph Dam tailrace downriver to Priest Rapids Dam tailrace. There were 16 mid-Columbia River sampling locations: 6 tailrace, 5 forebay and 5 mid-reservoir locations (Figure 1). Mid-reservoir CI sampling provides an index of northern squawfish predation on juvenile salmonids at reservoir locations not directly influenced by hydroelectric facilities. Fish passage through hydroelectric facilities tends to concentrate and disorient emigrating juvenile salmonids, providing increased predation opportunities for predators in this small portion of the reservoir. Mid-reservoir locations in the mid-Columbia River were selected based on approximately equal distance between hydroelectric projects, launch site accessibility and fisheries information provided by Public Utility District (PUD) and WDW biologists. Mid-reservoir sites were located at Buckshot Ranch-Road Fishing Access (north of Priest Rapids Dam), Crescent Bar, Wenatchee, Daroga Park and Pateros (Figure 1). Transects were distributed equally and continuously along each side of the river at each sample location. Two or four transects, depending on the size of the project, were established in each forebay and tailrace boat restricted zone (BRZ).

Consumption Index (CI) sampling was conducted by NBS using two electroshocking boats. Sampling was scheduled to coincide with spring and summer outmigration of juvenile salmonids, based on planned hatchery release dates and historical passage patterns. Spring sampling began concurrently at Chief Joseph Dam tailrace and Wells mid-reservoir (Pateros, WA) on April 20, 1993 (Table 1). A minimum of two sampling days were spent at each location. Locations where catches were low during the early spring were supplemented with a third day of sampling at the end of the spring season. Supplemental sampling occurred at four upper river locations: Chief Joseph Dam tailrace, Wells mid-reservoir, Wells Dam forebay and Rocky Reach mid-reservoir. Spring sampling at Rock Island forebay was out of sequence with the rest of the sampling season to accommodate Canadian goose research by Chelan County PUD biologists in Rock Island forebay (Table 1).

Spill closures, coordinated by the PUDS, were arranged for a one hour period from 4 am to 5 am each day to allow sampling in the restricted tailrace and forebay areas. Sampling began approximately 90 minutes before sunrise each morning. Each transect was sampled for 15 minutes with an electroshocking boat. The first six transects were chosen randomly each day; additional transects were sampled to maximize the catch of northern squawfish. As in previous sampling years, a target catch of 15 northern squawfish per day from each location was established. Effort was targeted to catch a minimum of 15 northern squawfish from the restricted area and 15 from outside the restricted area at dam locations. Spring sampling was completed on May 21, 1993.

Summer sampling was accomplished over a six and a half week period between late June and early August, with a break in sampling during mid-July to allow for slow movement of summer outmigrants (Table 1). No supplemental summer sampling was necessary. Sampling was completed for the season on August 4, 1993.

Sampling of John Day Reservoir in the lower Columbia River was included in our spring and summer field seasons. This reservoir serves as the reference reservoir for our consumption indexing research between years and locations. Spring and summer sampling of John Day Reservoir occurred at approximately the same time in 1993 as in previous years (Table 1).

In addition to northern squawfish, predation data were collected from smallmouth bass and walleye (see below). Bass and walleye were released alive after data collection. Juvenile and adult salmonids (Oncorhynchus spp.) were occasionally encountered in the course of sampling. When this occurred, electroshocking operations were discontinued until these fish moved out of the sampling area.

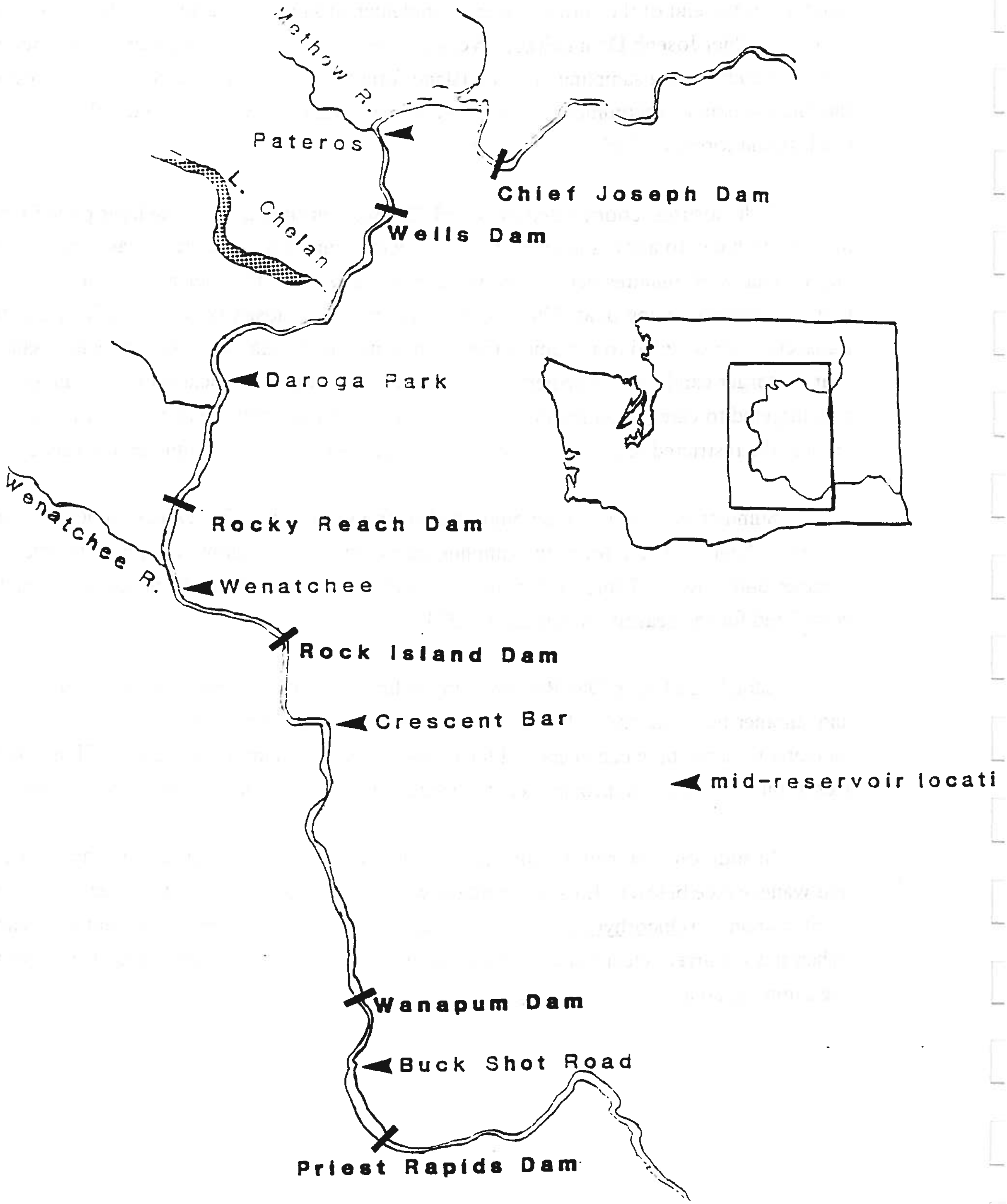

Figure 1. Mid-Columbia River sampling locations for Consumption Indexing during 1993. See Table 1 for sampling information.

Table 1. Spring and summer field samplong locations and dates for 1993 Consumption Indexing in the mid-Columbia River and John Dav Reservoirs.

RESERVOIR	LOCATION	SPRING DATES	SUMMER DATES	SUPPLEMENTAL SAMPLING
Wells	Chief Joseph Tailrace	4/20 + 4/21	6/22 + 6/23	5/18
	Wells Mid-Reservoir	4/20 + 4/21	6/22 + 6/23	5/19
	Wells Forebay	4/22 + 4/23	6/24 + 6/25	5/20
Rocky Reach	Wells Tailrace	4/22 + 4/24	6/24 + 6/25	---
	Rocky Reach Mid-Reservoir	4/27 + 4/28	6/29 + 6/30	5/21
	Rocky Reach Forebay	4/27 + 4/28	6/29 + 6/30	---
Rock Island	Rocky Reach Tailrace	4/29 + 4/30	7/01 + 7/02	---
	Rock Island Mid-Reservoir	4/29 + 4/30	7/01 + 7/02	---
	Rock Island Forebay	5/11 + 5/12	7/13 + 7/14	---
Wanapum	Rock Island Tailrace	5/04 + 5/05	7/14 + 7/15	---
	Wanapum Mid-Reservoir	5/04 + 5/05	7/27 + 7/28	---
	Wanapum Forebay	5/06 + 5/07	7/27 + 7/28	---
Priest Rapids	Wanapum Tailrace	5/06 + 5/07	7/29 + 7/30	---
	Priest Rapids Mid-Reservoir	5/11 + 5/12	7/29 + 7/30	---
	Priest Rapids Forebay	5/13 + 5/14	8/03 + 8/04	---
McNary	Priest Rapids Tailrace	5/13 + 5/14	8/03 + 8/04	---
John Day	McNary Tailrace	5/18 + 5/19	7/07 + 7/08	---
	John Day Mid-Reservoir	5/18 + 5/19	7/07 + 7/08	7/21
	John Day Forebay	5/20 + 5/21	7/07 + 7/08	7/22

Data collection on northern squawfish included fork length measurement (FL. nearest mm), weight (nearest 5 or 10 grams depending on fish size), sex and stage of maturity. Northern squawfish were killed soon after capture with a lethal dose of tricaine methanesulfonate (MS-222) to prevent regurgitation of digestive tract contents. The entire digestive tract was removed after clamping near the esophagus and anus to prevent loss of any gut contents. Digestive tract samples were placed in plastic bags and held on ice until they could be frozen. Northern squawfish less than 200 mm in fork length were retained whole. Smallmouth bass and walleye were anesthetized with MS-222; fork length (FL. nearest mm) and weight (nearest 5 or 10 grams) were recorded. Occasionally we were able to determine sex and maturity on these fish from spawning products. Digestive tract contents were collected from smallmouth bass and walleye by flushing the stomach contents back out the mouth with low water pressure using a Seaburg stomach sampler (Seaburg 1957). Samples were placed in plastic bags and preserved on ice until they could be frozen.

LABORATORY METHODS

Diet Analysis - Northern Squawfish

Frozen digestive tract samples were checked for coded wire tags (CWTs) with a sensor, and thawed for analysis. The sample guts were stripped of their contents, which were divided into major prey taxa groups (fish, crustacean, mollusk, insect, plant, or other). Each group was blotted on tissue paper, weighed to the nearest 0.01 g and returned along with the gut to its original bag.

Hard parts (bones, exoskeletons, shells) were isolated by digesting the soft tissue in the sample bags and pouring the resulting slurry through a 425 micron (#40) sieve. Samples were digested enzymatically (Petersen et al. 1990) using a solution of porcine pancreatin (8x U.S.P.) and sodium sulfide nonahydrate mixed 2% w/w and 1% w/w, respectively, in warm tap water. The enzyme solution was poured into the sample bags and the bags were shaken to ensure contact of all the contents with the enzyme mixture. The samples were incubated at 45 - 50°C for 24 hrs. After digestion a solution of approximately 1.5 molar NaOH was poured into the sample bags and allowed to soak for 10 to 30 minutes to dissolve remaining fat. Samples without CWTs were poured directly through sieves to separate bones from slurried tissue. CWTs were removed from samples with magnets before sieving.

Characterization and enumeration of ingested prey fish was accomplished by identifying diagnostic bones (dentaries, cleithra and opercula; Hansel et al. 1988) using a dissecting microscope and forceps. Using this technique, salmon smolts can be differentiated from steelhead smolts. The similarity of chinook, coho and sockeye bones precludes separation of these species using the diagnostic bone technique, although species identification is possible for many prey fish in the Columbia River system using this method. Diagnostic bones and other hard parts were preserved in labeled vials in 95% ethanol.

Diet Analysis - Smallmouth Bass/Walleye

Smallmouth bass and walleye samples often contained relatively undigested fish which were measured as soon as the samples were thawed. Fork lengths were obtained if possible; if not, then standard or nape lengths were taken. The species of prey fish was determined at that time, by teasing out and identifying diagnostic bones whenever enough of the prey fish remained to do so. Diagnostic bones were cleared of flesh by rinsing and picking in a solution of lye in a watchglass under a microscope. Prey fish that had been relatively unaffected by digestive acid could be processed in the same manner as northern squawfish gut samples. Diagnostic bones and whole preyfish were preserved in 95% ethanol.

Consumption Index

Detailed methods and index derivation for the northern squawfish CI were presented in Petersen et al. (1990); an abbreviated description of the CI is presented here for clarity.

The estimated number of salmonids consumed per day by an individual predator, p, can be expressed as:

$$C_p = \sum_{i=1}^{n} 1 / (\text{Evacuation time for prey item i})$$

or,

$$C_p = \sum_{i=1}^{n} 1 / D90_i \quad (1)$$

where C_p is consumption rate (number of salmonids • individual northern squawfish^{-1}• day^{-1}), $D90_i$ is number of days to 90% digestion for salmonid prey item i, and n is total number of salmonids found in the digestive tract. Using 90% digestion time, rather than 100%, avoids the problem of non-digestible prey parts that may remain in the digestive tract for extended periods. Equation (1) is equivalent to:

$$C_p = \sum_{i=1}^{n} (24 / T90_i) \quad (2)$$

where $T90_i$ is number of hours to 90% digestion for the ith salmonid prey item. $T90_i$ was calculated by Beyer et al. (1988) and modified by Rieman et al. (1991) to:

$$T90_i = 1147 * M_i^{0.61} * T^{-1.60} * W_p^{-0.27} \quad (3)$$

where M_i is meal size (g) at time of ingestion of salmonid prey item i, T is water temperature (°C), and W_p is predator weight
(g). Substituting equation 3 into 2 and rearranging gives:

$$C_p = 0.0209 * T^{1.60} * W_p^{0.27} * \sum_{i=1}^{n} M_i^{-0.61} \quad (4)$$

Equation 4 provides an estimate of daily salmonid consumption per northern squawfish, but still requires estimation of meal size (M_i) through intensive analysis of gut contents and complicated data analysis. The following formula was chosen as a CI, based upon simplicity of data required and percent variance explained:

$$CI = 0.0209 * T^{1.60} * MW^{0.27} * [MTsal * MGutwgt^{-0.61}] \quad (5)$$

where T is water temperature (°C), MW is mean predator weight (g), MTsal is mean number of salmonids per predator, and MGutwgt is mean weight (g) of gut contents. All variables required to compute a CI are averaged over all predators in a sample; a CI is the consumption index for a collection (sample) of predators.

Distribution characteristics of each northern squawfish CI were computed by a bootstrap resampling technique (Efron and Tibshirani 1986; Petersen et al. 1990). For each sample of N predators, a computer program randomly selected N individual predator records and calculated a new CI. Five hundred CI's were computed for each CI distribution; preliminary studies showed that variances and confidence bounds were stable with 500 samples. The number of predators per bootstrap sample was set to the original sample size (N), or 60 if N was greater than 60. The CI for northern squawfish, as derived above, is not meant to be a rigorous method for estimating the number of juvenile salmonids eaten per day by an average predator. The CI is based upon the simple idea of meal turnover times and does not consider such aspects of consumption as diel feeding pattern and evacuation rate of prey. In an analysis of data from John Day Reservoir (Petersen et al. 1990), the consumption rate of northern squawfish (CR - juvenile salmonids•predator^{-1}•day^{-1}) was related to CI by:

$$\log_{10}(CR) = 1.17 * \log_{10}(CI) - 0.41 \quad N = 86 \quad r^2 = 0.89 .$$

RESULTS

Catch Data

The NBS collected 1566 northern squawfish, 374 smallmouth bass, and 54 walleye during spring and summer sampling in the mid-Columbia River and John Day Reservoir. Percent of overall catch of northern squawfish, smallmouth bass, and walleye by reservoir is shown in Figure 2.

Northern squawfish catch was considerably higher during summer sampling than during spring (spring N =527; summer N =1039). Over 95% of the northern squawfish caught in 1993 were taken from the 5 mid-Columbia River reservoirs and Priest Rapids tailrace in the mid-Columbia River. Less than 5% of the catch was from John Day Reservoir.

A major portion of the northern squawfish were collected from dam tailrace locations, accounting for about 48% of the catch, while dam forebay locations accounted for 18% and mid-reservoir sites 34%. High numbers of northern squawfish were taken at mid-reservoir sites in the mid-Columbia River compared to John Day mid-reservoir locations (Table 2).

Sex determinations on northern squawfish were based on identification of gonadal tissue. Northern squawfish sampled in the mid-Columbia River were 60% female and 23% male (Table 2). We were unable to determine the sex on 17% of the catch, due to gonadal immaturity. The ratio of female to male northern squawfish in the mid-Columbia River was consistent with other areas sampled in the Columbia River system. The average forklength of northern squawfish in the mid-Columbia River was 378 mm for females and 315 mm for males (Table 3).

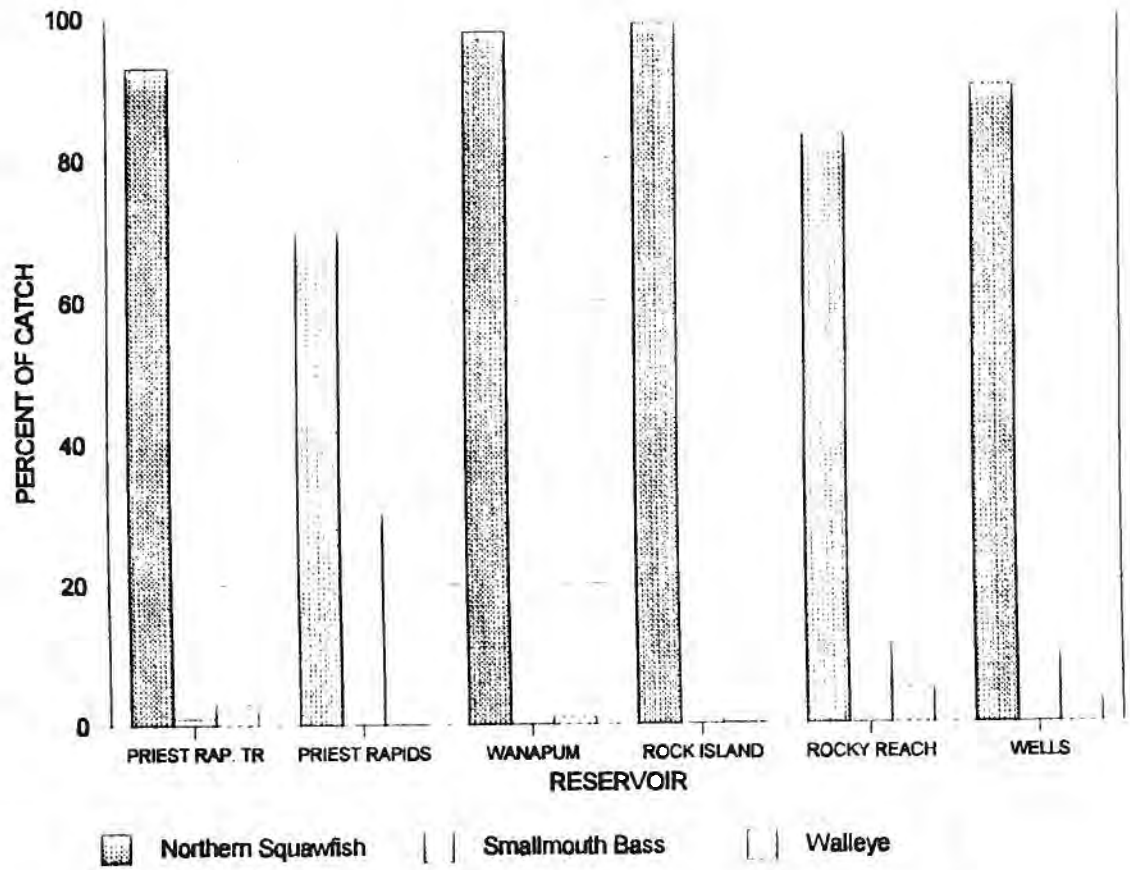

Figure 2. Preliminary predator catch percentages per reservoir during the 1993 consumption indexing. Reservoirs are from dam to dam including BRZ's. Priest Rapids Dam tailrace is included but is not considered a reservoir

Table 2. Number of major predators collected during the 1993 northern squawfish consumption index sampling. N=Sample size. SMB=Smallmouth bass. WAL=Walleye

SPRING	NORTHERN SQUAWFISH						
LOCATION	UNDET.	MALE	FEMALE	N	SMB	WAL	TOTAL
PRIEST RAPIDS TR	0	20	45	65	3	5	73
PRIEST RAPIDS FB	2	0	9	11	42	0	53
PRIEST RAPIDS MR	3	15	42	60	3	0	63
WANAPUM TR	0	0	61	61	0	1	62
WANAPUM FB	0	5	29	34	0	0	34
WANAPUM MR	2	1	20	23	0	0	23
ROCK ISLAND TR	0	1	39	40	0	4	44
ROCK ISLAND FB	0	0	29	29	0	0	29
ROCK ISLAND MR	3	17	11	31	0	0	31
ROCKY REACH TR	1	4	4	9	0	2	11
ROCKY REACH FB	1	0	8	9	1	0	10
ROCKY REACH MR	3	8	14	25	0	1	27
WELLS TR	0	7	33	40	0	8	48
WELLS FB	1	0	17	18	0	0	18
WELLS MR	3	5	13	21	3	0	24
CHIEF JOSEPH TR	1	3	9	13	0	5	18
TOTAL	20	86	383	489	52	26	568

SUMMER	NORTHERN SQUAWFISH						
LOCATION	UNDET.	MALE	FEMALE	N	SMB	WAL	TOTAL
PRIEST RAPIDS TR	0	40	60	100	0	3	103
PRIEST RAPIDS FB	2	4	7	13	28	0	41
PRIEST RAPIDS MR	2	5	12	19	17	0	36
WANAPUM TR	1	21	25	47	0	0	47
WANAPUM FB	3	12	40	55	4	0	59
WANAPUM MR	21	23	32	76	0	1	77
ROCK ISLAND TR	5	36	75	116	0	2	118
ROCK ISLAND FB	2	7	9	18	1	0	19
ROCK ISLAND MR	75	16	47	138	1	0	139
ROCKY REACH TR	20	31	32	83	2	0	85
ROCKY REACH FB	9	5	22	36	14	1	51
ROCKY REACH MR	64	15	24	103	0	5	107
WELLS TR	11	6	39	56	21	1	79
WELLS FB	5	5	33	43	2	0	45
WELLS MR	9	1	14	24	13	0	37
CHIEF JOSEPH TR	5	36	38	79	0	2	81
TOTAL	234	263	509	1006	103	15	1124

SPRING	NORTHERN SQUAWFISH						
LOCATION	UNDET.	MALE	FEMALE	N	SMB	WAL	TOTAL
JOHN DAY FB	0	2	9	11	53	0	64
JOHN DAY MR	0	1	1	2	42	2	46
MCNARY	7	2	16	25	8	7	40
TOTAL	7	5	26	38	103	9	150

SUMMER	NORTHERN SQUAWFISH						
LOCATION	UNDET.	MALE	FEMALE	N	SMB	WAL	TOTAL
JOHN DAY FB	1	2	13	16	31	0	47
JOHN DAY MR	0	2	4	6	67	0	73
MCNARY TR	5	0	6	11	18	4	33
TOTAL	6	4	23	33	116	4	153

Table 3. Average fork lengths (mm) of northern squawfish collected in the mid-Columbia River during the 1993 consumption index study.

SPRING LOCATION	N	UNDET.	MALE	FEMALE	TOTAL
PRIEST RAPIDS TR	65	--	380	436	419
PRIEST RAPIDS FB	11	137	--	392	346
PRIEST RAPIDS MR	60	186	312	373	348
WANAPUM TR	61	--	--	436	436
WANAPUM FB	34	--	315	411	397
WANAPUM MR	23	144	288	332	313
ROCK ISLAND TR	40	--	385	422	421
ROCK ISLAND FB	29	--	--	380	380
ROCK ISLAND MR	31	230	283	327	293
ROCKY REACH TR	9	141	308	366	315
ROCK REACH FB	9	256	--	370	357
ROCKY REACH MR	25	226	288	368	325
WELLS TR	40	--	369	396	392
WELLS FB	18	244	--	387	379
WELLS MR	21	301	310	373	348
CHIEF JOSEPH TR	13	181	341	378	354
SUMMER LOCATION	**N**	**UNDET.**	**MALE**	**FEMALE**	**TOTAL**
PRIEST RAPIDS TR	100	--	360	429	402
PRIEST RAPIDS FB	13	216	290	337	304
PRIEST RAPIDS MR	19	203	314	375	341
WANAPUM TR	47	209	345	409	376
WANAPUM FB	55	221	311	368	347
WANAPUM MR	76	196	287	354	290
ROCK ISLAND TR	116	203	327	391	363
ROCK ISLAND FB	18	174	266	367	307
ROCK ISLAND MR	138	224	279	307	259
ROCKY REACH TR	83	211	293	329	287
ROCK REACH FB	36	169	283	347	293
ROCKY REACH MR	103	182	261	309	223
WELLS TR	56	213	304	351	319
WELLS FB	43	162	287	355	324
WELLS MR	24	186	277	323	270
CHIEF JOSEPH TR	79	263	296	331	311
SPRING LOCATION					
JOHN DAY FB	11	--	375	445	432
JOHN DAY MR	2	--	413	378	395
MCNARY TR	25	159	348	384	318
SUMMER LOCATION					
JOHN DAY FB	16	390	348	414	404
JOHN DAY MR	6	--	312	421	384
MCNARY TR	11	183	--	404	304

Smallmouth bass made up 19% (8% mid-Columbia River; 11% John Day Reservoir) of the total predator catch. Of the 374 smallmouth bass captured, were collected in spring, of which 103 came from John Day pool. During the summer sampling, 219 smallmouth bass were collected, 116 from the John Day pool. The highest catch of smallmouth bass during the 1993 field season was in John Day Reservoir (N =219); in the mid-Columbia River, Priest Rapids

Reservoir produced the highest catch of smallmouth bass (N =90) (Figure 2). Walleye accounted for 3% of the overall catch (2% mid-Columbia River; 1% John Day Reservoir). The majority of walleye were caught in Chief Joseph and Priest Rapids tailraces and in Rocky Reach Reservoir (Figure 2).

Identification and qualitative estimates of abundance were recorded for non-target fish species encountered during electroshocking. Most common species in the incidental catch were adult bridgelip suckers (Catostomus columbianus), chiselmouth (Acrocheilus alutaceus), and peamouth (Mylocheilus caurinus). The mid-Columbia River appeared to have a greater abundance and diversity of resident salmonids, including lake trout (Salvelinus namaycush), brown trout (Salmo trutta) and whitefish (Prosopium williamsoni), than has been observed in the lower Columbia and Snake rivers in previous years. The mid-Columbia River also appeared to have a rich preyfish base. Large numbers of red-sided shiners (Richardsonius balteatus), three-spined sticklebacks (Gasterosteus aculeatus) and prickly sculpin (Cottus asper), as well as juvenile stages of bridgelip suckers, northern squawfish, yellow perch (Perca flavescens) and chiselmouth were observed. Several burbot (Lota lota) and tench (Tinca tinca) were collected in Wells Reservoir. During summer sampling in the lower reservoirs, we frequently saw juvenile smallmouth bass, bluegill (Lepomis macrochirus) and pumpkinseed (Lepomis gibbosus). Carp (Cyprinus carpio) and shad (Alosa sapidissima) were also observed in Priest Rapids tailrace.

Diet of Northern Squawfish

Samples of digestive tract contents of 1535 squawfish (Spring N = 524, Summer N = 1011) were examined in the laboratory. Measurable amounts of dietary items were contained in 399 of the spring gut samples, and 575 of the summer gut samples (Table 4). Percentages of empty guts ranged from 7.7% for samples collected during spring at Chief Joseph Tailrace, to 83.3% for samples collected at Wells mid-reservoir in summer. Fractions of empty digestive tracts in most sample collections ranged from about 25 to 50% (Table 4). The low proportion of empty guts from Chief Joseph tailrace during spring may have been an artifact of a small sample (N = 13) at that site and time.

Northern squawfish diet varied seasonally in the mid-Columbia River, with fish accounting for a larger proportion of the diet in spring (average of 63.6%) than in summer (average of 37.5%)(Table 4). Similarly in the John Day pool, fish were 51.7% of northern squawfish diets in spring, and 20.1% for summer. The fraction of fish consumed decreased from spring to summer, while the proportion of crustaceans consumed changed very little seasonally. The largest proportion of crustaceans (73.2%) was in the summer samples from Priest Rapids mid-reservoir. Amounts of insect and plant matter in the diet increased over the season. Plant matter made up almost half the diet of northern squawfish from Rock Island tailrace in the summer (Table 4). Many samples contained honey bees, perhaps a result of the orchards along that area of the river.

Gut contents of northern squawfish collected from within the BRZs of the dams (Table 5) were generally similar to those from northern squawfish collected from all other areas (Table 4). The only discernable difference is that the squawfish in the BRZs appear to have higher percentages of fish than other diet items in their gut contents than squawfish collected outside of the BRZs.

The mid-Columbia River digestive tract samples contained 582 smolts , 406 in spring samples and 176 in summer (Table 6). John Day reservoir samples contained 33 smolts, 27 in spring and 6 in summer samples.

There were 187 smolts recovered from squawfish guts taken within the boat restricted zones (BRZs) in the mid-Columbia River and John Day locations during both seasons (Table 7). In the spring, 105 smolts came from mid-Columbia River BRZ locations and none from John Day Reservoir BRZs. Summer samples included 79 smolts from mid-Columbia River BRZs and 3 smolts from McNary tailrace BRZ of John Day Reservoir. The greatest number of ingested smolts recovered within a BRZ (N = 54) was from Rock Island tailrace in the spring. In mid-Columbia River dam BRZs, the average percentage of northern squawfish gut contents that were fish was 67% in spring and 43% in summer (Table 5).

Table 4. Gut content of northern squawfish collected at locations in the mid-Columbia River during 1993. Gut contents (%) are the mean percentages of individual northern squawfish. Crust = curstacean. Moll = mollusk.

LOCATION	N	Mean gut wt (g)	% empty guts	GUT CONTENTS (%) Fish	Crust	Moll	Insect	Plant	Other
PRIEST RAPIDS TR	65	19.74	12.3	86.5	10.2	0.0	1.3	0.0	2.0
PRIEST RAPIDS FB	11	2.87	63.6	34.9	50.0	0.0	15.1	0.0	0.0
PRIEST RAPIDS MR	60	5.81	13.3	64.3	28.2	0.6	2.0	2.6	2.3
WANAPUM TR	61	25.53	13.1	95.9	3.9	0.0	0.0	0.2	0.0
WANAPUM FB	32	10.61	21.9	48.9	25.5	4.0	1.9	8.0	11.8
WANAPUM MR	23	1.59	47.8	34.4	36.0	0.0	2.6	11.1	15.8
ROCK ISLAND TR	40	20.52	10.0	94.0	5.6	0.0	0.5	0.0	0.0
ROCK ISLAND FB	29	12.51	41.4	90.8	9.2	0.0	0.0	0.0	0.0
ROCK ISLAND MR	31	2.02	51.6	34.7	45.3	0.0	11.5	1.9	6.7
ROCKY REACH TR	9	5.68	33.3	47.7	35.6	0.0	8.3	8.3	0.0
ROCKY REACH FB	9	5.98	33.3	66.7	16.7	0.0	16.7	0.0	0.0
ROCKY REACH MR	25	2.30	24.0	42.4	22.6	6.6	16.3	5.3	6.7
WELLS TR	40	18.85	12.5	99.9	0.0	0.0	0.0	0.0	0.0
WELLS FB	18	2.55	38.9	87.9	0.0	0.0	9.1	3.0	0.0
WELLS MR	21	2.98	28.6	60.1	20.0	0.0	12.3	6.7	0.9
CHIEF JOSEPH TR	13	7.81	7.7	28.6	59.7	0.0	1.6	0.0	10.1
SUMMER									
PRIEST RAPIDS TR	100	3.7	56.0	66.1	14.2	0.0	9.1	4.8	5.7
PRIEST RAPIDS FB	13	1.62	30.8	0.0	31.3	11.1	38.9	13.0	5.7
PRIEST RAPIDS MR	19	5.38	42.1	17.7	73.2	0.0	4.2	4.9	0.0
WANAPUM TR	46	2.80	52.2	45.4	30.7	0.0	18.2	4.6	1.1
WANAPUM FB	55	2.69	40.0	35.1	17.1	0.0	38.5	6.3	3.0
WANAPUM MR	75	1.16	54.7	42.1	24.5	5.9	20.6	6.4	0.6
ROCK ISLAND TR	115	1.04	66.1	37.8	1.4	2.6	4.4	47.8	6.0
ROCK ISLAND FB	18	0.15	77.8	25.0	25.0	0.0	25.0	25.0	0.0
ROCK ISLAND MR	133	2.89	28.6	13.8	40.9	0.8	2.9	41.4	0.3
ROCKY REACH TR	82	6.49	26.8	50.0	27.7	0.8	1.7	17.3	2.6
ROCKY REACH FB	36	3.02	47.2	47.4	35.3	6.8	8.9	0.0	1.5
ROCKY REACH MR	94	2.32	26.6	37.3	8.6	6.1	13.1	26.9	7.9
WELLS TR	55	2.67	32.7	35.8	27.5	2.7	8.1	18.8	7.1
WELLS FB	41	3.26	36.6	36.8	32.3	1.0	16.0	6.2	7.7
WELLS MR	18	0.28	83.3	33.3	6.1	0.0	0.0	60.6	0.0
CHIEF JOSEPH TR	79	1.91	36.7	76.7	15.2	0.1	0.0	0.0	8.0
JOHN DAY RESERVOIR									
SPRING									
JOHN DAY FB	11	26.60	9.1	80.0	10.0	0.0	0.0	10.0	0.0
JOHN DAY MR	2	18.45	0.0	0.0	100.0	0.0	0.0	0.0	0.0
MCNARY TR	24	5.60	50.0	75.0	25.0	0.0	0.0	0.0	0.0
SUMMER									
JOHN DAY FB	16	1.80	0.0	28.6	0.0	0.0	71.2	0.0	0.2
JOHN DAY MR	6	2.96	33.3	0.0	16.7	16.7	33.4	27.8	5.4
MCNARY TR	10	3.81	10.0	31.7	54.1	7.1	0.0	7.1	0.0

Table 5. Diet summary of northern squawfish collected witin dam BRZ's in the mid-Columbia River during 1993. See Table 4 for an explanation of columns. John Day Reservoir BRZ's were not sampled in spring because spill closures could not be obtained (unusually high spring flow).

LOCATION	N	Mean gut wt (g)	% empty guts	GUT CONTENTS (%) Fish	Crust	Moll	Insect	Plant	Other
SPR									
PRIEST RAPIDS TR	5	19.18	20.0	100.0	0.0	0.0	0.0	0.0	0.0
PRIEST RAPIDS FB	8	2.27	75.0	0.0	100.0	0.0	0.0	0.0	0.0
WANAPUM TR	9	13.48	11.1	98.4	0.0	0.0	0.0	1.6	0.0
WANAPUM FB	18	6.28	22.2	35.7	32.7	7.1	3.3	0.0	21.2
ROCK ISLAND TR	28	13.07	10.7	95.3	4.0	0.0	0.7	0.0	0.0
ROCK ISLAND FB	18	11.64	61.1	100.0	0.0	0.0	0.0	0.0	0.0
ROCKY REACH TR	6	6.07	33.3	71.5	28.5	0.0	0.0	0.0	0.0
ROCKY REACH FB	8	6.73	25.0	66.7	16.7	0.0	16.7	0.0	0.0
WELLS TR	0	--	--	--	--	--	--	--	--
WELLS FB	12	2.36	50.0	77.8	16.7	0.0	16.7	5.6	0.0
CHIEF JOSEPH TR	1	10.42	0.0	24.8	0.0	0.0	0.0	0.0	0.0
SUMMER									
PRIEST RAPIDS TR	75	1.8	58.7	80.2	0.0	0.0	9.7	6.8	3.2
PRIEST RAPIDS FB	5	1.87	40.0	0.0	0.0	0.0	66.7	33.3	0.0
WANAPUM TR	33	1.94	57.6	57.0	7.1	0.0	28.6	7.3	0.0
WANAPUM FB	17	3.44	35.3	6.1	27.3	0.0	52.8	13.8	0.0
ROCK ISLAND TR	94	0.94	67.0	36.4	0.0	3.2	5.6	47.2	7.5
ROCK ISLAND FB	5	0.09	60.0	0.0	0.0	0.0	50.0	50.0	0.0
ROCKY REACH TR	27	6.12	37.0	62.0	18.1	0.0	0.0	14.0	5.9
ROCKY REACH FB	21	3.50	42.9	58.3	32.5	0.0	8.3	0.0	0.9
WELLS TR	18	2.48	38.9	50.0	20.1	0.0	9.1	20.9	0.0
WELLS FB	18	4.12	27.8	37.1	17.8	2.0	15.9	11.9	5.4
CHIEF JOSEPH TR	69	1.81	36.2	80.0	10.9	0.0	0.0	0.0	9.1
JOHN DAY RESERVOIR									
SPRING									
JOHN DAY FB	--	--	--	--	--	--	--	--	--
MCNARY TR	--	--	--	--	--	--	--	--	--
SUMMER									
JOHN DAY FB	7	0.69	57.1	0.0	0.0	0.0	100.0	0.0	0.0
MCNARY TR	2	3.23	50.0	100.0	0.0	0.0	0.0	0.0	0.0

Table 6. Prey fish consumed by northern squawfish (SQF) collected at locations in the mid-Columbia River during 1993. FL=forklength; Mean Fish Wt.=mean prey fish mass (g) per predator; % Smolts = percent of the total number of fish consumed that were smolts.

PREDATORS				PREY FISH CONSUMED				
LOCATION	N	Mean FL (mm)	Mean Fish Wt. (g)	Total # Smolts	# Smolts Per SQF	% Smolts	Total # Other Fish	% Other Fish
SPRING								
PRIEST RAPIDS TR	65	419	18.26	97	1.5	88.2	13	11.8
PRIEST RAPIDS FB	11	346	1.04	1	0.1	50.0	1	50.0
PRIEST REPIDS MR	60	348	3.81	2	0.0	2.4	81	97.6
WANAPUM TR	61	436	25.19	97	1.6	98.0	2	2.0
WANAPUM FB	32	397	9.39	16	0.3	10.1	7	89.9
WANAPUM MR	23	313	0.78	0	0.0	0.0	5	100.0
ROCK ISLAND TR	40	421	20.10	85	2.1	96.6	3	3.4
ROCK ISLAND FB	29	380	12.11	19	0.7	70.4	8	29.6
ROCK ISLAND MR	31	293	0.94	4	0.1	66.7	2	33.3
ROCKY REACH TR	9	315	3.02	3	0.3	75.0	1	25.0
ROCKY REACH FB	9	357	5.65	2	0.2	33.3	4	66.7
ROCKY REACH MR	25	325	1.07	0	0.0	0.0	49	100.0
WELLS TR	40	392	18.83	73	1.8	100.0	0	0.0
WELLS FB	18	379	2.52	4	0.2	30.8	9	69.2
WELLS MR	21	348	2.65	3	0.1	30.0	7	70.0
CHIEF JOSEPH TR	13	354	3.63	0	0.0	0.0	10	100.0
SUMMER								
PRIEST RAPIDS TR	100	408	2.11	28	0.3	66.7	14	33.3
PRIEST RAPIDS FB	13	323	0.00	0	0.0	--	0	--
PRIEST REPIDS MR	19	346	1.61	0	0.0	0.0	4	100.0
WANAPUM TR	46	410	1.40	11	0.2	91.7	1	8.3
WANAPUM FB	55	366	1.18	0	0.0	0.0	22	100.0
WANAPUM MR	75	295	0.55	0	0.0	0.0	38	100.0
ROCK ISLAND TR	115	378	0.65	1	0.0	6.7	14	93.3
ROCK ISLAND FB	18	352	0.12	0	0.0	0.0	2	100.0
ROCK ISLAND MR	133	265	0.31	13	0.1	61.9	8	38.1
ROCKY REACH TR	82	290	5.45	110	1.3	90.2	12	9.8
ROCKY REACH FB	36	306	2.00	6	0.2	20.0	24	80.0
ROCKY REACH MR	94	243	1.13	0	0.0	0.0	71	100.0
WELLS TR	55	349	1.04	6	0.1	33.3	12	66.7
WELLS FB	41	340	1.29	1	0.0	9.1	10	90.9
WELLS MR	18	306	0.19	0	0.0	0.0	1	100.0
CHIEF JOSEPH TR	79	317	1.50	0	0.0	0.0	68	100.0
JOHN DAY RESERVOIR								
SPRING								
JOHN DAY FB	11	432	20.64	12	1.1	85.7	2	14.3
JOHN DAY MR	2	395	0.00	0	0.0	--	0	--
MCNARY TR	24	318	4.71	15	0.6	93.8	1	6.3
SUMMER								
JOHN DAY FB	16	415	1.27	3	0.2	100.0	0	0.0
JOHN DAY MR	6	387	0.00	0	0.0	--	0	--
MCNARY TR	10	314	1.21	3	0.3	75.0	1	25.0

Table 7. Prey fish consumed by northern squawfish (SQF) collected within dam BRZ's in the mid-Columbia River during 1993. See table 5 for an explanation of columns. John Day res. BRZ's were not sampled in spring because spill colsures could not be obtained (unusually high spring flow)

PREDATORS				PREY FISH CONSUMED				
RESERVOIR / LOCATION	N	Mean FL (mm)	Mean Fish Wt. (g)	Total # Smolts	# Smolts Per SQF	% Smolts	Total # Other Fish	% Other Fish
SPRING								
PRIEST RAPIDS TR	5	416	19.18	13	2.6	100.0	0	0.0
PRIEST RAPIDS FB	8	366	1.00	0	0.0	--	0	--
WANAPUM TR	9	386	12.68	15	1.7	88.2	2	11.8
WANAPUM FB	18	372	4.70	6	0.3	--	3	--
ROCK ISLAND TR	28	408	12.95	54	1.9	96.4	2	3.6
ROCK ISLAND FB	18	376	11.64	10	0.6	100.0	0	0.0
ROCKY REACH TR	6	335	4.53	3	0.5	75.0	1	25.0
ROCKY REACH FB	8	348	6.36	2	0.3	33.3	4	66.7
WELLS TR	0	--	--	0	--	--	0	--
WELLS FB	12	371	2.32	2	0.2	40.0	3	60.0
CHIEF JOSEPH TR	1	341	2.58	0	0.0	0.0	2	100.0
SUMMER								
PRIEST RAPIDS TR	75	402	1.72	28	0.4	82.4	6	17.6
PRIEST RAPIDS FB	5	349	0.00	0	0.0	--	0	--
WANAPUM TR	33	377	1.73	10	0.3	100.0	0	0.0
WANAPUM FB	17	354	0.49	0	0.0	0.0	2	100.0
ROCK ISLAND TR	94	374	0.57	0	0.0	0.0	7	100.0
ROCK ISLAND FB	5	368	0.00	0	0.0	--	0	
ROCKY REACH TR	27	314	5.64	29	1.1	85.3	5	14.7
ROCKY REACH FB	21	318	2.96	6	0.3	26.1	17	73.9
WELLS TR	18	319	1.95	6	0.3	60.0	4	40.0
WELLS FB	18	346	1.05	0	0.0	0.0	6	100.0
CHIEF JOSEPH TR	69	308	1.53	0	0.0	0.0	60	100.0
JOHN DAY RESERVOIR								
SPRING								
JOHN DAY FB	--	--	--	--	--	--	--	--
MCNARY TR	--	--	--	--	--	--	--	--
SUMMER								
JOHN DAY FB	7	398	0.00	0	0.0	--	0	--
MCNARY TR	2	444	3.23	3	1.5	100.0	0	0.0

Diet of Smallmouth Bass

Of the 374 smallmouth bass collected from the mid-Columbia River (N =155) and John Day Reservoir (N =219) in 1993, 260 smallmouth bass had measurable quantities of food in their stomachs. Smallmouth bass stomachs containing food made up 37% of the spring and 63% of the summer samples. The diet of mid-Columbia River smallmouth bass consisted of 87% fish, 12% crustaceans and 1% other catagories (mollusk, insect, plant, etc.). Dietary totals for John Day Reservoir in 1993 were 57% fish, 42% crustaceans, and 1% other catagories. Cyprinids and cottids were the most common preyfish, while salmonids were 11% of all preyfish recovered from smallmouth bass. Most smolts (91%) recovered from smallmouth bass were from summer samples.

Northern Squawfish Consumption Indexing

Minimum sample sizes were achieved at 6 of 16 locations during spring sampling. Minimum catch was achieved at all but 3 locations during summer sampling. Consumption Index (CI) values ranged from 0 to 1.1 in spring and from 0 to 3.9 in summer at mid-Columbia River sampling sites (Table 8). As in previous studies, consumption indices were generally highest in the tailrace and lowest in mid-reservoir locations. CI values rose from spring to summer at all tailrace locations except Rock Island (decreased from 0.9 to 0.1) and Wells (0.5 for both seasons). The summer CI in Rocky Reach tailrace was exceptionally high (CI=3.9). Most tailrace BRZ CI values (Table 9) were higher than combined BRZ/non-BRZ values (Table 8).

John Day Reservoir followed a similar pattern; highest CI values in McNary tailrace and lowest values in mid-reservoir as in previous years (Table 8). The greatest CI value (2.1) for this reservoir occurred in McNary tailrace during spring (Table 8).

DISCUSSION

Catch

Fewer total northern squawfish were caught in the mid-Columbia River (N =1566) in 1993 than during CI sampling in the lower Snake River (N =2118, 1991), in the lower Columbia River reservoirs (N =2017, 1990), or at locations below Bonneville Dam (N =1689, 1992) (Petersen et al. 1991; Shively et al. 1992; Petersen et al. 1993). The number of smallmouth bass collected in the mid-Columbia River was similar to the number collected in lower Columbia River reservoirs sampled in 1990 but fewer than the Snake River index study in 1991. More walleye were sampled in the mid-Columbia River than in the previous lower Columbia and Snake River studies.

Water temperature, conductivity, and turbidity may have influenced squawfish catches during 1993. Water temperatures were well below average when CI sampling began on Wells Reservoir in the spring. The average temperature recorded at Wells Dam for the first week of sampling, April 19 - 25, 1993 was 5.5°C. The 7-year average river temperature recorded at Wells Dam for those dates in previous years (1985 - 1990 and 1992) was 8.1°C. Water temperature effects the catch efficiency of the electroshocking gear in several ways. The very low water temperatures (5°C) in the mid-Columbia River at the beginning of the season likely depressed movement and feeding activity of northern squawfish and increased the tendency of northern squawfish to remain in deeper water, out of the effective range of the electroshocking gear. Stunned northern squawfish float up toward the water surface at water temperatures above about 8°C (NBS, unpublished data), while at lower water temperatures, stunned fish tended to sink, making recovery more difficult. Water temperatures also influence the conductivity of water. Conductivity is also lower with lower water temperatures (Reynolds 1983), possibly reducing the effective range of the electroshocking gear. On the other hand, water clarity was high in the mid-Columbia River, compared to the lower Columbia and Snake rivers, which likely permitted capture of stunned northern squawfish from deeper in the water column. Water temperature and turbidity were generally higher during CI studies in the Snake and lower Columbia rivers.

Table 8 Northern squawfish consumption indices (CI) at locations in the mid-Columbia River and John Day Reservoir during 1993. Note that a CI of 0 means no juvenile salmon were found in the predator disgestive tracts. CI is the consumption index for the original sample (N). Mean CI, standard deviation (SD), coefficient of variation (CV%) and quartiles are given for the 500 bootstrap samples. Summer John Day Reservoir data were pooled between ODFW and USFWS.

			Bootstrap Summary				
						Quarterlies	
LOCATION	N	CI	Mean	SD	CV (%)	25th	75th
SPRING							
PRIEST RAPIDS TR	65	1.1	1.1	0.1	13.1	1.0	1.2
PRIEST RAPIDS FB	8	0.2	0.2	0.2	85.4	0.0	0.4
PRIEST RAPIDS MR	57	0.0	0.0	0.0	68.3	0.0	0.1
WANAPUM TR	61	0.8	0.8	0.1	12.5	0.7	0.8
WANAPUM FB	32	0.3	0.3	0.1	28.2	0.3	0.4
WANAPUM MR	19	0	0	0	–	0	0
ROCK ISLAND TR	40	0.9	0.9	0.2	17.5	0.8	1.0
ROCK ISLAND FB	29	0.4	0.4	0.1	17.4	0.4	0.5
ROCK ISLAND MR	26	0.2	0.2	0.1	45.5	0.1	0.2
ROCKY REACH TR	8	0.3	0.3	0.2	60.6	0.1	0.4
ROCKY REACH FB	9	0.1	0.1	0.1	80.5	0.0	0.2
ROCKY REACH MR	22	0	0	0	--	0	0
WELLS TR	40	0.5	0.5	0.1	11.7	0.5	0.6
WELLS FB	17	0.5	0.5	0.2	48.7	0.3	0.7
WELLS MR	20	0.3	0.3	0.1	50.4	0.2	0.4
CHIEF JOESPH TR	12	0	0	0	–	0	0
SUMMER							
PRIEST RAPIDS TR	100	1.7	1.8	0.6	34.0	1.4	2.3
PRIEST RAPIDS FB	11	0	0	0	–	0	0
PRIEST RAPIDS MR	17	0	0	0	–	0	0
WANAPUM TR	44	1.7	1.7	0.6	35.9	1.3	2.1
WANAPUM FB	52	0	0	0	–	0	0
WANAPUM MR	52	0	0	0	–	0	0
ROCK ISLAND TR	111	0.1	0.1	0.1	127.9	0.0	0.2
ROCK ISLAND FB	16	0	0	0	–	0	0
ROCK ISLAND MR	76	0.3	0.3	0.2	48.7	0.2	0.4
ROCKY REACH TR	63	3.9	3.9	0.6	14.5	3.5	4.3
ROCKY REACH FB	27	0.8	0.7	0.4	53.4	0.4	0.9
ROCKY REACH MR	33	0	0	0	–	0	0
WELLS TR	45	0.5	0.5	0.3	57.7	0.3	0.7
WELLS FB	34	0.1	0.1	0.1	99.0	0.0	0.2
WELLS MR	11	0	0	0	–	0	0
CHIEF JOESPH TR	77	0	0	0	–	0	0
JOHN DAY RESERVOIR							
SPRING							
JOHN DAY FB	11	1.5	1.5	0.3	22.2	1.3	1.7
JOHN DAY MR	2	0	0	0	–	0	0
MCNARY TR	15	2.1	2.1	0.5	26.8	1.7	2.4
SUMMER							
JOHN DAY FB	39	0.6	0.6	0.5	72.3	0.3	0.9
JOHN DAY MR	10	0.6	0.6	0.6	100.5	0.0	0.8
MCNARY TR	128	0.5	0.5	0.3	65.8	0.3	0.7

Table 9 Consumption indices (CI) of northern squawfish within dam BRZ's in the mid-Columbia River and John Day Reservoir during 1993. See table 8 for explanation of columns. John Day Reservoir BRZ's were not sampled in spring because spill closures could not be obtained (unusually high spring flow). Summer John Day Reservoir data were pooled between ODFW and USFWS.

			Bootstrap Summary				
						Quartercles	
LOCATION	N	CI	Mean	SD	CV (%)	25th	75th
SPRING							
PRIEST RAPIDS TR	5	2.0	2.0	0.6	28.2	1.6	2.4
PRIEST RAPIDS FB	6	0	0	0	--	0	0
WANAPUM TR	9	1.1	1.2	0.3	27.1	0.9	1.3
WANAPUM FB	18	0.3	0.3	0.2	60.2	0.2	0.4
ROCK ISLAND TR	28	1.0	1.0	0.1	14.3	0.9	1.1
ROCK ISLAND FB	18	0.4	0.4	0.1	23.5	0.3	0.4
ROCKY REACH TR	6	0.4	0.4	0.2	48.4	0.2	0.5
ROCKY REACH FB	8	0.1	0.1	0.1	76.9	0.0	0.2
WELLS TR	0	--	--	--	--	--	--
WELLS FB	11	0.4	0.4	0.3	89.3	0.0	0.6
CHIEF JOESPH TR	1	0	0	0	--	0	0
SUMMER							
PRIEST RAPIDS TR	75	3.6	3.6	0.6	16.7	3.2	4.0
PRIEST RAPIDS FB	4	0	--	--	--	--	--
WANAPUM TR	31	2.7	2.8	0.7	25.1	2.3	3.2
WANAPUM FB	14	0	0	0	--	0	0
ROCK ISLAND TR	93	0	0	0	--	0	0
ROCK ISLAND FB	4	0	0	0	--	0	0
ROCKY REACH TR	24	3.2	3.1	0.5	17.1	2.8	3.5
ROCKY REACH FB	18	1.1	1.0	0.5	47.2	0.7	1.4
WELLS TR	15	1.5	1.4	0.7	48.9	0.9	1.8
WELLS FB	17	0	0	0	--	0	0
CHIEF JOESPH TR	68	0	0	0	--	0	0
JOHN DAY RESERVOIR							
SPRING							
JOHN DAY FB	--	--	--	--	--	--	--
MCNARY TR	--	--	--	--	--	--	--
SUMMER							
JOHN DAY FB	20	0	0	0	--	0	0
MCNARY TR	119	0.5	0.6	0.4	67.7	0.3	0.8

An apparent response by northern squawfish to the onset of daylight was observed during electroshocking at several locations during spring 1993 sampling. A sharp decline in northern squawfish catch was noted at approximately 0530 hrs. The decrease in catch was abrupt and may reflect a behavioral response to light intensity by predators or prey. This pattern was most apparent during spring sampling at Rock Island mid-reservoir, but it was also observed at Rock

Island forebay and tailrace, Wanapum mid-reservoir and during the supplemental spring sampling at Wells mid-reservoir.

Movement out of littoral areas with onset of daylight by northern squawfish may be related to movement of prey fish or prey fish vulnerability to predation with increasing light intensity (Cerri 1983; Petersen and Gadomski 1992). Laboratory studies by Petersen and Gadomski (1992) found feeding rates of northern squawfish on juvenile salmonids decreased in response to increasing light intensity. Decreased predation rates with increased light intensity may result from light-dependent schooling behavior which visually confuses predators and increases prey reaction distance (Moyle and Cech 1988). As in many teleost fish (Arnott et al. 1970; Braekevelt et al. 1975; Braekevelt et al. 1989), visual acuity in northern squawfish may also be optimal at low light levels. The high degree of water clarity observed in the mid-Columbia River and low densities of vegetation during spring may also have contributed to northern squawfish movement patterns in response to light.

Spring sampling at Wells Dam tailrace followed a hatchery release from Wells Hatchery which may have influenced northern squawfish catch. Summer chinook were flushed out of Wells Hatchery ponds and into a small spawning channel below the dam on April 16, a week prior to our sampling. The relatively large numbers of northern squawfish caught in the spawning channel (N = 37; 93% of total catch in this area) may reflect a feeding response by northern squawfish to the hatchery release. However, the CI at this tailrace was lower than several other tailraces (Table 8) and diet was similar to other tailrace locations (Tables 4 and 6). A strong current flows from Wells Dam along the west shore past the spawning channel and outmigrating juvenile salmonids may be attracted to the quiet water in the channel. In addition, the sheltered spawning channel may attract other prey species, providing feeding opportunities for northern squawfish.

We identified 73 ingested salmonids from the stomachs of 37 northern squawfish collected from the Wells Hatchery spawning channel on April 22 and 24. A total of 7 coded wire tags (CWTs) were recovered from these stomach samples. From the April 22 sample, all (N = 3) recovered CWTs were from the Wells Hatchery release of summer chinook salmon on April 16, 1993. The spawning channel was sampled again on April 24, and one of four recovered CWTs was from the Wells Hatchery release while the other three CWTs were from a release of spring chinook salmon at Winthrop National Fish Hatchery on April 15, 1993. Although these data are far from conclusive, the CWTs recovered from squawfish guts support hatchery personnel observations that some of the juvenile salmonids released from Wells Hatchery hold at the release site where they are subject to predation. CWT recovery data also provides some evidence that the spawning channel may attract outmigrating salmon that have come through Wells Dam.

Average fork length differences between male and female northern squawfish were noted on the mid-Columbia River catch in 1993 and also in previous CI sampling years on the Snake and lower Columbia Rivers. Age and growth studies on northern squawfish indicate sexual maturation occurs 1 to 3 years later in females than males (Olney 1975; Beamesderfer 1992). Earlier diversion of energy resources by male northern squawfish away from growth and into reproductive processes may partially account for size differences between males and females. Size differences between sexes is a common pattern in fish, associated with reproductive strategy and degree of parental care afforded young (Bond 1979). Adult northern squawfish gather in large aggregates to broadcast spawn in June and July in the Columbia River system when water temperatures reach about 15.5°C (Jeppson 1957; Jeppson and Platts 1959). Female northern squawfish display high fecundity. Jeppson and Platts (1959) estimate that a large female northern squawfish may carry 100,000 eggs or more; once fertilized, eggs adhere to the bottom substrate and no parental care is provided. The tendency for northern squawfish males to mature earlier than females as well as the reproductive strategy of the species probably accounts for the size variation between the sexes.

Diet and Consumption Indexing

The diet of northern squawfish sampled in the mid-Columbia River was similar in the proportion of major taxonomic groups (fish, crustaceans, insects, plant, etc.) to the diet of northern squawfish sampled in previous years from the Snake and lower Columbia River (Petersen et al. 1991; Shively et al. 1992; Petersen et al. 1993). In particular, the proportion of fish versus crustaceans (primarily crayfish in the mid-Columbia River) consumed did not differ from other locations sampled in previous years. Corophium spp., a small crustacean, was, however, quite scarce in the guts of northern squawfish collected in the mid-Columbia River compared to squawfish from the lower Columbia River. Northern squawfish collected in the mid-Columbia River also contained a higher proportion of prey fish other than Oncorhynchus spp. and Cottus spp., compared to the lower Columbia river (34.3% versus 6.9%, respectively).

Consumption indexing results for the mid-Columbia River share certain patterns with data collected in previous years in the lower Snake and lower Columbia River reservoirs (Petersen et al. 1991; Shively et al. 1992). Throughout the Snake and Columbia rivers, CI values were highest near hydroelectric projects (especially in tailrace areas), summer CI's were higher than spring CI's, and mid-reservoir CI values were very low or zero for both seasons (Petersen et al. 1991; Shively et al. 1992; Petersen et al. 1993).

A cluster of relatively high CI values were obtained from Rocky Reach forebay (CI= 0.8), Rocky Reach tailrace (CI= 3.9) and Rock Island mid-reservoir (CI= 0.3) during summer sampling. The summer Rocky Reach tailrace value is the highest CI obtained during the 1993 field season. The Rocky Reach forebay and Rock Island mid-reservoir values are both high relative to other forebay and mid-reservoir locations in the mid-Columbia River. Although juvenile salmonid passage indices are available only at Rock Island Dam in the mid-Columbia River, our results suggested that a large pulse of outmigrants may have passed through the Rocky Reach - Rock Island portion of the system while we were sampling. Investigation of hatchery release dates revealed that the Washington Department of Fisheries released 1.5 million subyearling chinook salmon (71,000 of these fish were CWTed) on June 29, 1993 from Turtle Rock in the Rocky Reach forebay sampling area. Sampling for consumption indexing was done on June 29 - 30, 1993 in Rocky Reach forebay and on July 1 - 2, 1993 in Rocky Reach tailrace and Rock Island mid-reservoir. All of the northern squawfish with salmonids in their digestive tracts from Rocky Reach forebay were collected on June 30, 1993, whereas no salmonids were recovered from northern squawfish collected the morning of June 29th -- the day of the hatchery release. Only 3 CWTs were recovered from northern squawfish with ingested smolts sampled from Rocky Reach tailrace on July 1 - 2, 1993, but all of these CWTs were from the June 29th Turtle Rock release.

The proximity of the Turtle Rock release site to Rocky Reach Dam likely increased local smolt densities and the incidence of northern squawfish predation at this location. Rock Island reservoir is small and may tend to keep migrating salmonids (whether released locally or amassed by Rocky Reach Dam) concentrated in the length of the reservoir. This may explain the higher consumption indices for Rock Island mid-reservoir relative to other mid-reservoir sites sampled. Differential size and behavior patterns between spring and subyearling chinook salmon, as well as absolute prey fish density may partially account for the relatively high CI values. Subyearling chinook salmon tend to migrate more slowly and use nearshore, shallow habitat while yearling chinook salmon migrate in mid-channel (Ledgerwood et al. 1991). Radiotelemetry studies indicated that northern squawfish preferentially utilize nearshore areas, possibly overlapping with subyearling chinook salmon (Poe et al. In Press).

Sample timing and size are important considerations when making spatial or temporal comparisons between consumption indices. Passage indices on outmigrating juvenile salmonids is available only at Rock Island Dam in the mid-Columbia River. Sample timing coincided with the initial upswing of passage in the spring although the peak of passage in the summer was missed at Rock Island Dam (Figure 3). The short peak in outmigrants over Rock Island Dam beginning June 30, 1993 was intercepted at Rocky Reach Dam during the same period of time (Figure 3). Spring sampling at McNary Dam tailrace and John Day mid-reservoir coincided with major outmigrant passage, summer sampling occurred just following peak passage. Sampling at John Day forebay occurred while passage of juvenile salmonids was still relatively high, but after the peak passage had passed (Figure 4). In the spring, 10 out of 16 mid-Columbia locations produced sample sizes smaller than the target catch of 30 northern squawfish (15 per sampling day), even with supplemental sampling at 4 locations. Target catch was achieved at all but 4 locations during the summer sampling period. Difficulty in reaching target catch occurred most frequently at forebay and mid-reservoir locations. The variability of small-sample CI estimates were narrow enough that rough CI comparisons could be made (e.g., CI/2 vs. CI vs. 2*CI) with high statistical power (>90%). Comparison of CI estimates from tailrace locations could be made with even greater confidence because of the larger samples and reduced variability about the mean CI's.

Results of consumption indexing in the mid-Columbia River emphasizes the need for companion research to increase our understanding of northern squawfish predation patterns on juvenile salmonids during river passage. Northern squawfish habitat use and the degree of plasticity in predatory behavior, including size selectivity, are important components of northern squawfish predation that need study. Data on the onshore-offshore patterns of smolt movements would also be helpful. Further research may be needed to determine the extent of northern squawfish predation on different juvenile salmonid stocks (e.g. spring or summer chinook), the effect of local hatchery releases on predation rates, and the effect of various management options with modeling studies.

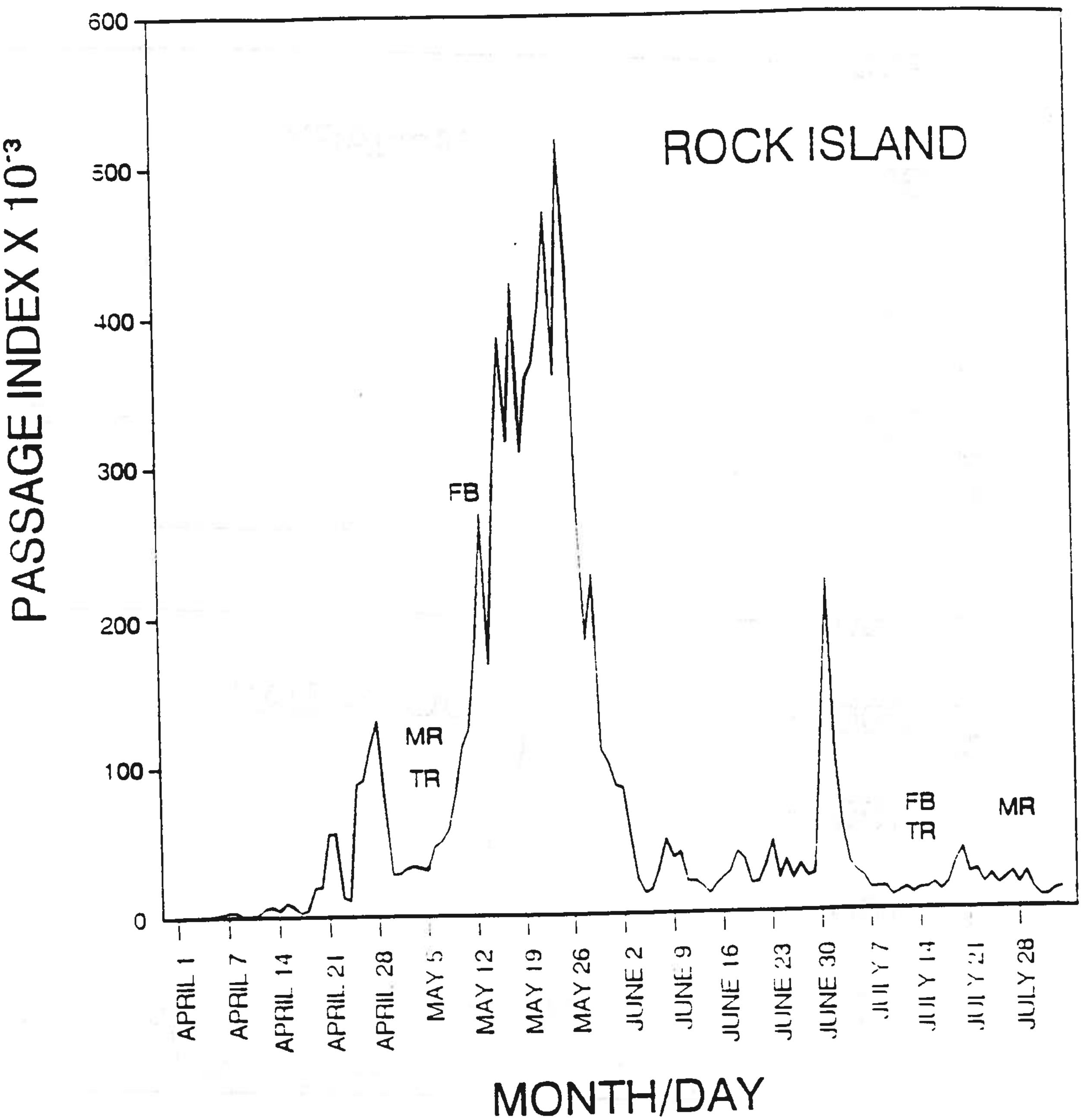

Figure 3. Timing of Consumption index sampling during 1993 with respect to juvenile salmonid passage indices at Rock Island Dam. Approximate sample times for tailrace (TR), and immediate downstream mid-reservoir (MR), and forebay (FB) locations are shown in panal. The MR locator represents sampling at Crescent Bar, downstream of Rock Island Dam. Passage data from the Fish Passage Center.

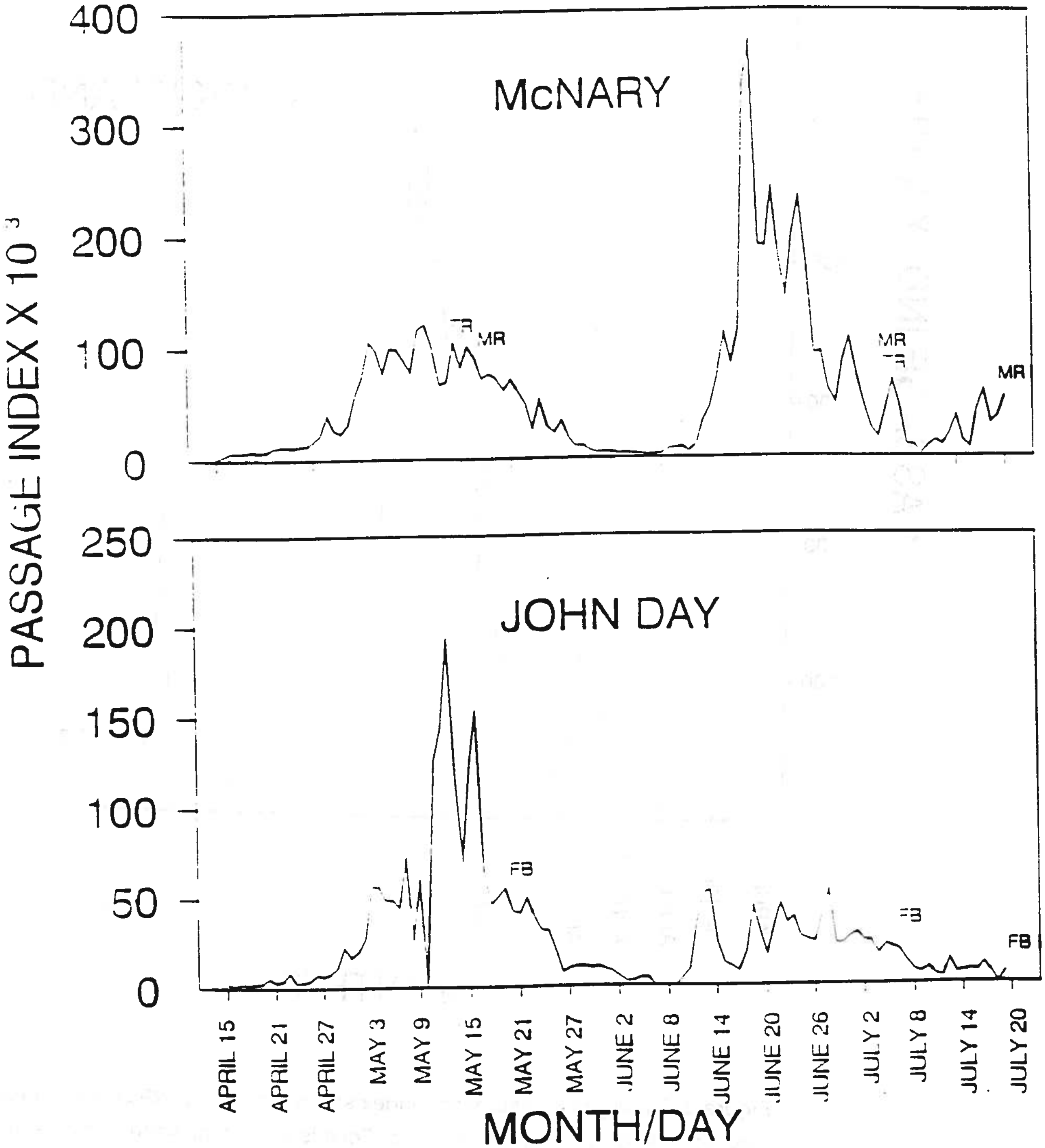

Figure 4. Timing of Consumption Index sampling for 1993 with respect to juvenile salmonid passage indices at McNary and John Day Dams. Approximate sample times for tailrace (TR), and immediate downstream mid-reservoir (MR), and forebay (FB) locations are shown in panals. The mid-reservoir locator in the McNary panal represents sampling within the John Day mid-reservoir. Passage data from the Fish Passage Center.

Arnott, H.J., N.J. Maciolek, and J.A.C. Nicol. 1970. Retinal tapetum lucidum: a novel reflecting system in the eye of teleosts. Science 169:478-480.

Beamesderfer, R.C., 1992. Reproduction and early life history of northern squawfish (Ptychocheilus oregonensis) in Idaho's St. Joe River. Environmental Biology of Fishes 35:231-241.

Beyer, J.M., G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish (Ptychocheilus oregonensis). Canadian Journal of Fisheries and Aquatic Science 45:548-553.

Bledsoe, L.J., S. Vigg, and J.H. Petersen. 1990. Simulation estimates of salmonid predation loss to northern squawfish in a Columbia River reservoir. Pages 206-220. In: A.A. Nigro (ed.), 1990. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. 1989 Annual Progress Report. Bonneville Power Administration, Portland, OR.

Bond, C.E. 1979. Reproduction In: Biology of Fishes. Philadelphia, Saunders College Publishing, pp. 406 - 424.

Braekevelt, C.R. 1975. Photoreceptor fine structure in the northern pike. Journal of Fisheries Research Board of Canada 32:1711-1721.

Braekevelt, C.R., D.B. McIntyre, and F.J. Ward. 1989. Development of the retinal tapetum lucidum of the Walleye (Stizostedion vitreum vitreum). Histology and Histopathology 4:63-70.

Cerri, R. 1983. The effect of light intensity on predator and prey behaviour in cyprinid fish: Factors that influence prey risk. Animal Behavior 31:736-742.

CQS (Center for Quantitative Science, University of Washington). 1991. Columbia River Passage Model, Documentation for CRiSP.1, DRAFT (August 16, 1991). Bonneville Power Administration, Portland, OR.

Effron, B. and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1:54-77.

Foerster, R. E., and W.E. Ricker. 1941. The effect of reduction of predaceous fish on survival of young sockeye salmon at Cultus Lake. Journal of the Fisheries Research Board of Canada 5:315-336.

Hansel, H.C., S.D. Duke, P.T. Lofy, and G. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Jeppson, P.W. 1957. The Control of Squawfish by use of Dynamite, Spot Treatment, and Reduction of Lake Levels. Progressive Fish Culturist 19:168-171.

Jeppson, P.W. and W.S. Platts. 1959. Ecology and control of Columbia squawfish in northern Idaho lakes. Transactions of the American Fisheries Society 88:197-202.

Lee, D.C. 1991. A stochastic, compartmental model of the migration of juvenile anadromous salmonids in the Columbia River Basin. Ecological Modelling 54:227-245.

Ledgerwood, R.D., F.P. Thrower, and E.M. Dawley. 1991. Diel sampling of migratory juvenile salmonids in the Columbia River estuary. Fishery Bulletin 89:599-609.

MEG (Monitoring and Evaluation Group). 1989. System planning model documentation. Northwest Power Planning Council, Portland, OR.

Mesa, M.G. and T.M. Olson. 1993. Prolonged Swimming Performance of Northern Squawfish. Transactions of the American Fisheries Society 122:1104-1110.

Moyle, P.B. and J.J. Cech. 1988. Fishes: An Introduction to Ichthyology pp. 152-155. Prentice Hall, New Jersey.

Olney, F.E. 1975. Life History and Ecology of the Northern Squawfish Ptychocheilus oregonensis (Richardson) in Lake Washington. Master's thesis. University of Washington, Seattle.

Petersen, J.H., M.G. Mesa, J. Hall-Griswold, W.C. Schrader, G. Short, and T.P. Poe. 1990. Magnitude and dynamics of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1989-1990. Bonneville Power Administration, Portland, OR.

Petersen, J.H., D.B. Jepsen, R.D. Nelle, R.S. Shively, R.A. Tabor, and T.P. Poe. 1991. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1990. Bonneville Power Administration, Portland, OR.

Petersen J.H. and T.P. Poe, editors. 1993. System-wide significance of predation on juvenile salmonids in Columbia and Snake River Reservoirs. Annual Report of Research, 1992. Bonneville Power Administration, Portland, OR.

Petersen, J.H. and D.M. Gadomski. 1992. Report 7 - Effects of light intensity on northern squawfish capture of juvenile salmonids in the laboratory. In: T.P. Poe (ed.), 1992. Significance of Selective Predation and Development of Prey Protection Measures for Juvenile Salmonids in Columbia and Snake River Reservoirs. 1991 Annual Progress Report. Bonneville Power Administration, Portland, OR.

Poe, T.P., and B.E. Rieman, editors. 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983 - 86. Final Report. Bonneville Power Administration, Portland, OR.

Poe, T.P., M.G. Mesa and R.S. Shively. In Press. Development of Biological Criteria for Siting and Operation of Juvenile Fish Bypass Systems: Implications for Protecting Juvenile Salmonids from Predation. Proceedings of a Bioengineering Section Symposium at the 1993 American Fisheries Society Annual Meeting. Portland, OR.

Reynolds, J.B. 1983. Electrofishing. In: L.A. Nielsen and D.L. Johnson (eds.). Fisheries Techniques. Southern Printing Company, Inc., Blacksburg, VI.

Ricker, W.E. 1941 The consumption of young sockeye salmon by predaceous fishes. Journal of the Fisheries Research Board of Canada 5:293-313.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society. 120(4):448-458.

Seaburg, K.G. 1957. A stomach sampler for live fish. Progressive Fish Culturist 19:137-139.

Shively, R.S., R.A. Tabor, R.D. Nelle, D.B. Jepsen, J.H. Petersen, S.T. Sauter, T.P. Poe. 1992. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1991. Bonneville Power Administration, Portland, OR.

Thompson, R.B. 1959. Food of the Squawfish Ptychocheilus oregonensis (Richardson) of the lower Columbia River. U.S. Department of the Interior Fish and Wildlife Service Bulletin No. 158:43-58.

Thompson, R.B. and D.R. Tufts. 1967. Predation by Dolly Varden and northern squawfish on hatchery-reared sockeye salmon in Lake Wenatchee, Washington. Transactions of the American Fisheries Society 96:424-427.

Vigg, S. and C.C. Burley. 1990. Report A - Developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River. In: A.A. Nigro (ed.), 1990. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. 1989 Annual Progress Report. Bonneville Power Administration, Portland, OR.

REPORT B

Significance of predation in the Columbia River from
Priest Rapids Dam to Chief Joseph Dam:
Abundance and Predation Indexing

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INTRODUCTION

The mortality of juvenile salmonids emigrating through the Columbia River Basin is a major concern of the Columbia Basin Fish and Wildlife Program (NPPC 1987). Predation is an important component of juvenile salmonid mortality and northern squawfish (*Ptychocheilus oregonensis*) is a major predator (NPPC 1987). The Northwest Power Planning council (NPPC, 1987) has directed the Bonneville Power Administration and other relevant parties to carry out, monitor and evaluate long-term contributions of an expanded northern squawfish demonstration project.

In 1993, the Washington Department of Fish and Wildlife (WDFW; formerly the Washington Department of Wildlife), in cooperation with the National Biological Survey (NBS; formerly the U.S. Fish and Wildlife Service), conducted a study to assess the significance of predation in the mid-Columbia River. Objectives of this report were: To determine reservoir specific predator abundance values, combine the abundance and consumption index values (determined by NBS) to calculate predation index values and report baseline biological data collected for predator fish species. We report abundance and predation indices for mid-Columbia reservoirs relative to John Day Reservoir.

METHODS

Study Area

The study area encompassed five reservoirs and one tailrace (Priest Rapids tailrace) within the mid-Columbia River. The five reservoirs were: Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells (Figure 1). The sampling area encompassed about 208 km (130 mi.) of the Columbia River.

Field Sampling

We electrofished from Priest Rapids Dam tailrace upriver to Chief Joseph Dam tailrace (Appendix A). Field data collection and methods for determining abundance were similar to Vigg and Burley (1990). Each reservoir was divided into forebay, mid-reservoir, and tailrace areas. Sampling areas were about six kilometers long. Within each area, 24 transects were established (each about 500 m long; Appendix B). Forebay and tailrace areas were further subdivided into boat restricted zones (BRZ) and non-boat restricted zones. Sampling effort was stratified by time and location to achieve a representative sample while maximizing the total number of samples. Each electrofishing crew sampled for two days in an area per reservoir. Sampling occurred during two segments of the juvenile salmonid emigration: spring (April-June) and summer (June-August). The WDFW started sampling each period at Priest Rapids Dam tailrace and worked upriver to Chief Joseph Dam tailrace (Table 1) whereas NBS sampling started at Chief Joseph Dam tailrace and worked down river toward Priest Rapids tailrace (Report A). Two days of supplemental sampling were conducted with the electrofishing boat at Priest Rapids Tailrace, Priest Rapids Forebay, Wanapum Tailrace and Rock Island Tailrace (Appendix A).

Sampling was conducted 90 minutes before sunrise at all locations. A minimum of six randomly assigned transects were sampled each day by each crew. The target predators were northern squawfish, smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum*), and channel catfish (*Ictalurus punctatus*).

Density Index

We summarized WDFW and NBS catch data for northern squawfish (fork length ≥250 mm) captured in each reservoir for five areas: forebay BRZ, forebay, mid-reservoir, tailrace, and tailrace BRZ. We calculated the density index (DI) value (Vigg and Burley, 1990) for each of the five reservoir areas as follows:

DI = [1/sqrt of the proportion of 0-catches of northern squawfish]

Abundance Index

The abundance index (AI) in each sampling area was calculated as the product of the density index and surface area:

$$AI_i = DI_i * S_i$$

where,

AI_i = Index of northern squawfish abundance in sampling area i;

DI_i = Index of northern squawfish density in sampling area i; defined as 1/square root of the proportion of 0-catches;and

S_i = Surface area (hectares) for area i (adjusted to include only littoral areas).

Northern squawfish are seldom captured in areas with mid-channels or depths greater than 40 feet (12.2 m; Nigro et al. 1985). Mid-reservoirs account for most of the surface area in a reservoir. Therefore, a correction factor for surface area for each mid-reservoir area was needed before mid-reservoir AI values could be calculated. Mid-Columbia reservoirs lacked maps defining areas with mid-channels and depths greater than 12.2 m. Oregon Department of Fish and Wildlife (ODFW) provided littoral area data for mid-reservoir areas of eight Columbia River reservoirs (Table 2). We averaged the littoral area of the eight reservoirs to calculate a correction factor. Mid-reservoir areas were adjusted by the correction factor for a corrected mid-reservoir surface area. To be consistent with previous researchers (i.e., ODFW, NBS), the surface area was divided by 1000 before multiplying by DI to calculate AI to enable direct comparison with other work in the Columbia River Basin (This intermediate step allows researchers a smaller more workable number for constructing graphs of the final PI values in later comparisons). We assumed that littoral area for mid-Columbia reservoirs were similar to reservoirs reported in Table 2. Although we divided surface area by 1000, no surface area adjustment was used for tailrace or forebay areas to calculate AI values. Oregon Department of Fish and Wildlife provided AI values for John Day Reservoir (personal communication, Mark Zimmerman, ODFW).

The index value for a reservoir was determined by summing index values across areas. For example, the sum of forebay BRZ, forebay, mid-reservoir, tailrace, and tailrace BRZ indices would yield an estimated reservoir-wide index value.

Predation Index

The predation index for each sample area was calculated as the product of abundance and consumption indices (see Report A):

$$PI_{ij} = AI_{ij} * CI_{ij}$$

where,

PI_{ij} = Predation index in sampling area i in time j;
AI_{ij} = Abundance index in sampling area i in time j; CI_{ij} = Consumption index in sampling area i in time j.

We calculated predation index values for spring and summer for mid-Columbia River reservoirs. Reservoir-wide predation indices were calculated by summing predation indices across areas. Physical characteristics of mid-Columbia River reservoirs are given in Table 3.

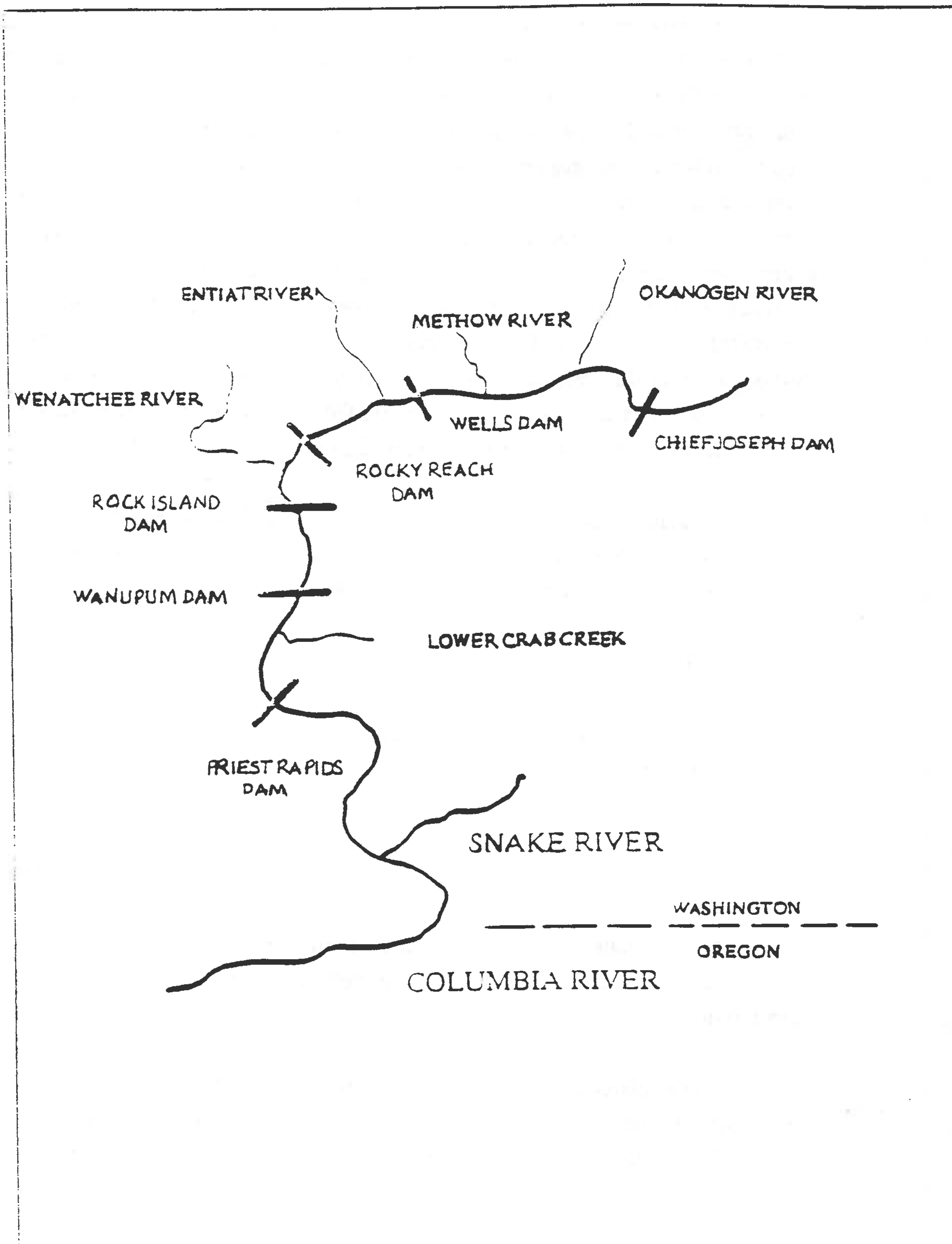


Figure 1. Mid-Columbia predator abundance indexing study are
April - August, 1993.

Table 1 Sampling schedule for Washington Department of Wildlife, mid-Columbia River, 1993.

Dam	Location	Early Season	Late Season	Supplemental[a]
Priest Rapids	Tailrace	4/13-4/14	6/21-6/22	6/17
	Forebay	4/15-4/16	6/23-6/27	6/17
	Mid-reservoir	4/19-4/20	6/28-6/29	—
Wanapum	Tailrace	4/21-4/22	6/30-7/1	—
	Forebay	4/26-4/27	7/6-7/7	6/18
	Mid-reservoir	4/28-4/29	7/8-7/9	—
Rock Island	Tailrace	5/3 + 5/6	7/19-7/20	6/18
	Forebay	5/10 + 5/13	7/21-7/22	—
	Mid-reservoir	5/4-5/5	7/12-7/13	—
Rocky Reach	Tailrace	5/11-5/12	7/14-7/15	—
	Forebay	5/17-5/18	7/26-7/27	—
	Mid-reservoir	5/19-5/20	7/28-7/29	—
Wells	Tailrace	5/24-5/25	8/2-8/3	—
	Forebay	5/26-5/27	8/4-8/5	—
	Mid-reservoir	6/1-6/2	8/9-8/10	—
Chief Joseph	Tailrace	6/3-6/4	8/11-8/12	—

Table 2 Estimated areas for mid-reservoirs with (w/) and without (w/o) mid-channel areas and percentage of littoral area for eight Columbia River and Snake River reservoirs, 1993 (Oregon Department of Fish and Wildlife Makr Zimmerman, personal communication).

	Mid-reservoir (hectares)[a]		
Reservoir	w/mid-channel	w/o mid-channel	Percentage litteral area
Bonneville	19.968	7.212	42.5
The Dalles	6.509	3.964	60.9
John Day	44.921	19.602	43.6
McNary	25.968	13.786	53.1
Ice Harbor	5.980	3.588	60.0
Lower Monumental	4.053	1.532	37.8
Little Goose	7.624	3.686	48.3
Lower Granite	5.696	3.055	53.6
Average			50.0

[a] Using Columbia River maps having depth contours for each reservoir, ODFW calculated littoral area as the proportion of the total reservoir size less those areas (i.e., mid-channels) identified ≥ 12.2 m in depth.

RESULTS

Density Index

Density index values for northern squawfish were estimated for site-specific areas within mid-Columbia Reservoirs. Density of northern squawfish with fork length ≥250 mm was highest in the tailrace BRZ areas of Wanapum (DI = 3.74) Reservoir (Table 4). Densities were higher in mid-reservoir locations than observed for forebay areas (Figure 3). Densities ranged from a DI equal to 1.06 in Priest Rapids forebay to a DI equal to 3.74 in the Wanapum tailrace boat restricted zone. Density index values were used to calculate AI.

Table 3 Physical characteristics of mid-Columbia River reservoirs[a].

Reservoir	Length (km)	Mean width (km)	Surface Area (hectares)	Mean depth (m)
John Day	122.9	1.79	20,235	14.5
McNary	98.2	1.58	15,419	10.8
Priest Rapids	29.0	0.87[b]	2,833	8.7
Wanapum	61.1	0.96[b]	5,585	13.0
Rock Island	33.8	0.46[b]	1,012	13.9
Rocky Reach	67.3	0.55[b]	3,723	14.2
Wells	47.0	0.56[b]	4,330	8.5

[a] Values converted from standard values to metric: data from Table A-2, page 16 of Vigg and Burley (1989).

[b] Estimated 1993 by WDFW from maps (scale 1:2400) using a planimeter.

Abundance Index

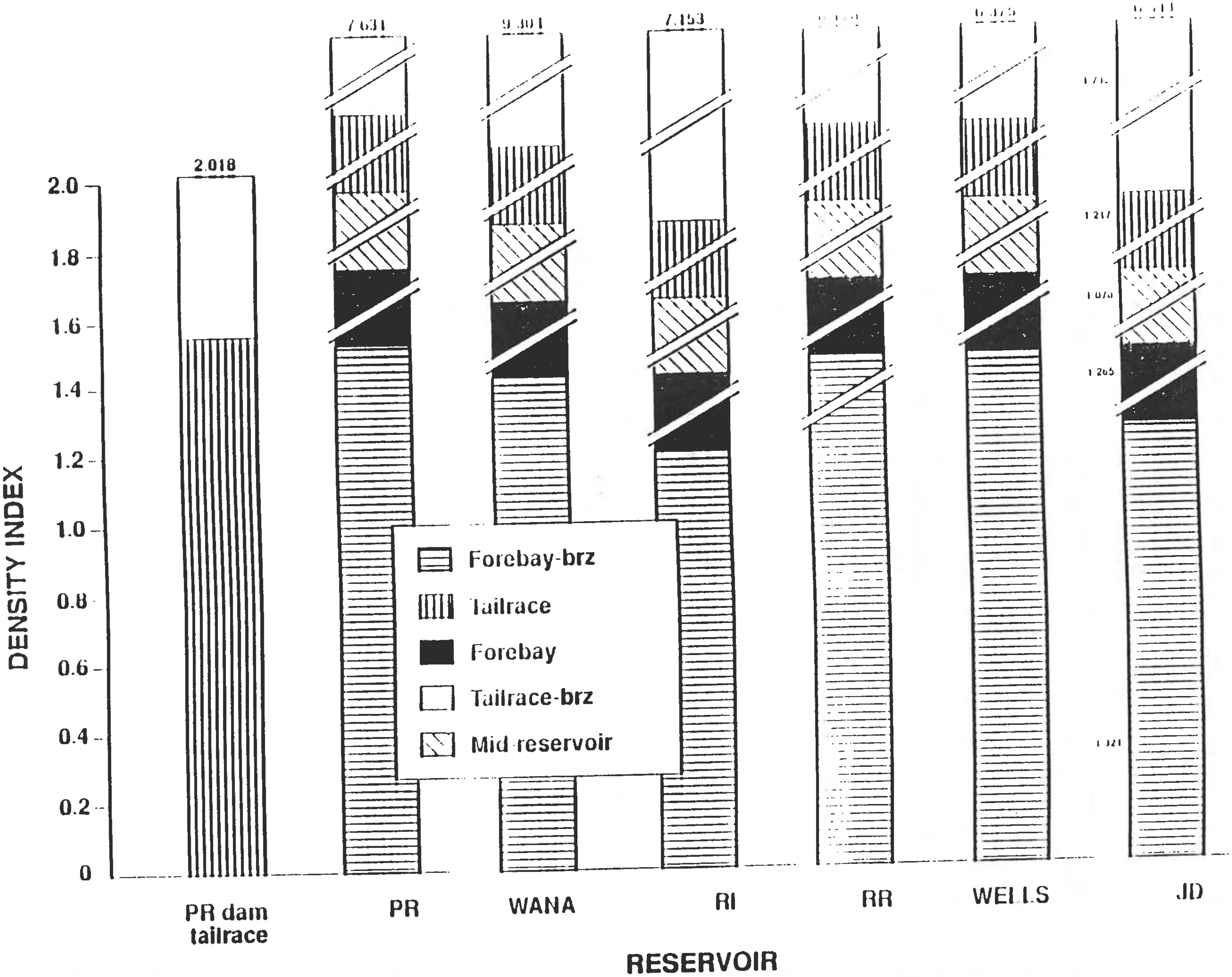
Northern squawfish abundance varied between mid-Columbia reservoirs. Mid-reservoir abundance index values were generally higher than found for tailrace or forebay sampling areas with the exception of Rock Island Reservoir (Figure 4).

Wanapum Reservoir had the highest reservoir-wide abundance value in the mid-Columbia (AI = 4.98), whereas Rock Island had the lowest reservoir-wide abundance value (AI = 1.17; Table 5). Mid-Columbia reservoir-wide abundance index values were lower than the John Day Reservoir-wide abundance index value (Figure 4). The product of the AI and CI were used to determine PI values for mid-Columbia reservoirs.

Table 4 Northern squawfish density indices (1 divided by the square root of the proportion of electrofishing runs in which no northern squawfish were caught), mid-Columbia River reservoirs, 1993.

Reservoir	Location[a]	Denisty Index	Electrofishing Runs
John Day	John Day Forebay BRZ	1.265	8
	John Day Forebay	1.251	36
	John Day Mid-Reservoir	1.078	43
	McNary Tailrace	1.217	37
	McNary Tailrace-BRZ	1.732	9
McNary	Priest Rapids Tailrace	1.470	54
	Pirest Rapids Tailrace BRZ	1.871	14
Priest Rapids	Priest Rapids Forebay BRZ	1.512	16
	Priest Rapids Forebay	1.064	60
	Priest Rapids Mid-Reservoir	1.209	57
	Wanapum Tailrace	1.296	47
	Wanapum Tailrace BRZ	2.550	13
Wanapum	Wanapum Forebay BRZ	1.414	20
	Wanapum Forebay	1.316	45
	Wanapum Mid-Reservoir	1.515	62
	Rock Island Tailrace	1.317	52
	Rock Island Tailrace BRZ	3.742	14
Rock Island	Rock Island Forebay BRZ	1.206	16
	Rock Island Forebay	1.350	51
	Rock Island Mid-Reservoir	1.581	60
	Rocky Reach Tailrace	1.504	52
	Rocky Reach Tailrace BRZ	1.512	6
Rocky Reach	Rocky Reach Forebay BRZ	2.236	15
	Rocky Reach Forebay	1.246	45
	Rocky Reach Mid-Reservoir	1.696	69
	Wells Tailrace	1.528	49
	Wells Tailrace BRZ	1.472	13
Wells	Wells Forebay BRZ	1.472	13
	Wells Forebay	1.194	57
	Wells Mid-Reservoir	1.112	73
	Chief Joseph Tailrace	1.133	59
	Chief Joseph Tailrace BRZ	1.464	15

[a] BRZ = boat restricted zone.



2.018
7.631
9.301
7.153
DENSITY INDEX
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Forebay-brz
Tailrace
Forebay
Tailrace-brz
Mid-reservoir
PR dam tailrace
PR
WANA
RI
RR
WELLS
JD
RESERVOIR

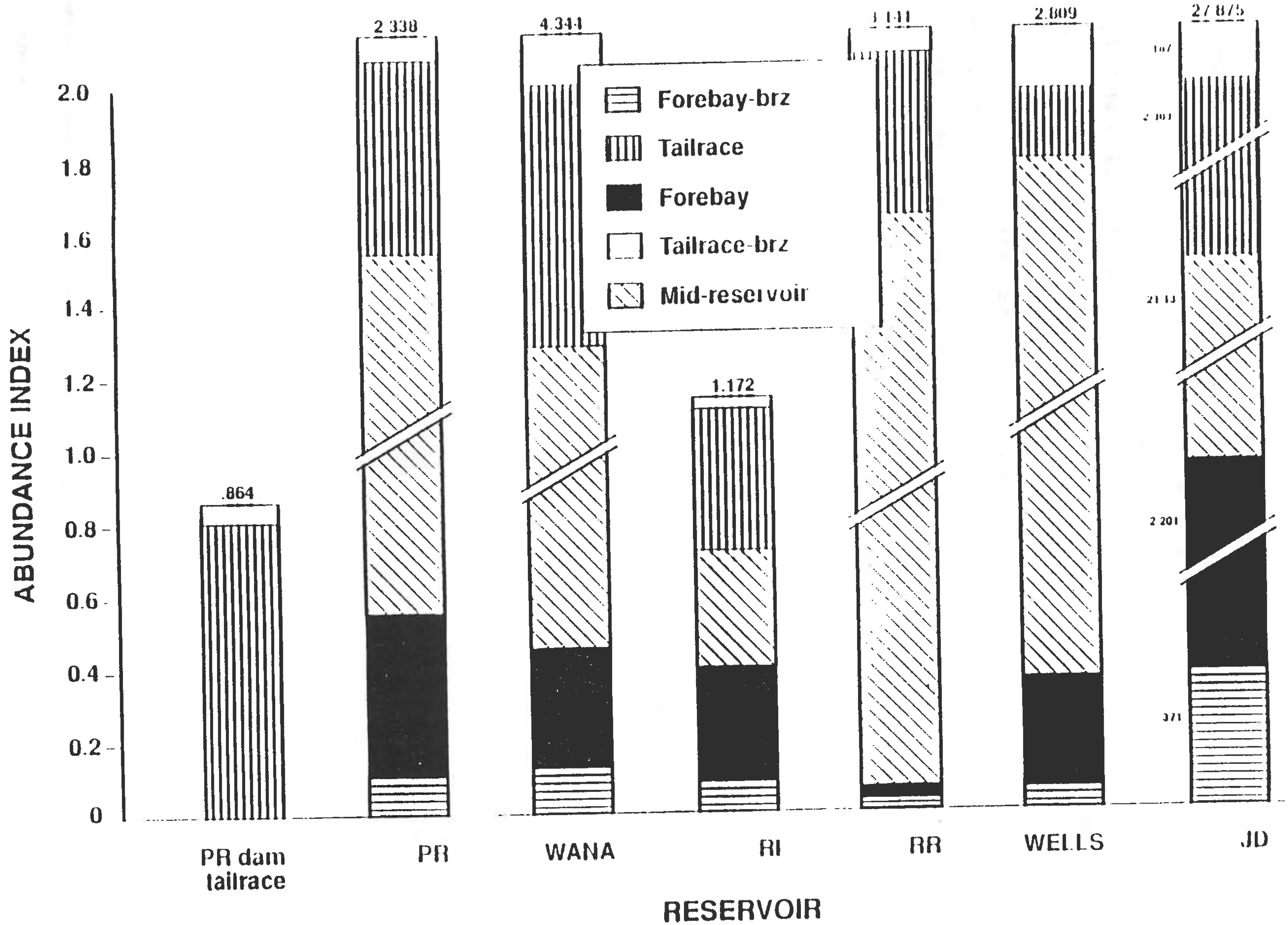


Figure 3. Predator abundance index value on juvenile salmonids by northern squawfish in the mid-Columbia River, 1993. PR=Priest Rapids; Wana=Wanapum; RI=Rock Island; RR=Rocky Reach; JD=John Day *(cummulative total).

Predation Index

Predation index values were calculated for site specific locations within reservoirs and pooled (forebay - tailrace) for reservoir-wide index values. Reservoir-wide predation on juvenile salmonids by northern squawfish was highest in Wanapum (PI = 1.00)(Figure 5). Rock Island (PI = 1.70) had the highest predation on juvenile salmonids in summer (Figure 6). During spring, Rocky Reach Reservoir had the lowest predation index value (PI = 0.28) whereas Wells Reservoir (PI = 0.04) had the lowest predation for summer (Figures 5 and 6).

Predation index values varied by location and time (Table 5). Tailrace boat restricted and non-restricted zones had higher predation than other sampling areas. John Day Reservoir in spring and summer had higher estimated predation index values than mid-Columbia reservoirs (Figures 5 and 6).

Table 5 Reservoir, location, northern squawfish (≥250 mm fl) index values for mid-Columbia River reservoirs, 1993. Washington Department of Wildlife and National Biological Survey data combined.

		Indices[a]				
Reservoir	Location[b]	AI	Spring	Summer	Spring	Summer
John Day	John Day FB-BRZ	0.37	0.0	0.0	0.56[c]	0.00
	John Day FB	2.20	1.5	0.6	3.30	1.32
	John Day MR	21.13	0.0	0.6	0.00	12.68
	McNary TR	2.30	2.1	0.5	4.84	1.15
	McNary TR-BRZ	0.19	0.0	0.5	0.40[c]	0.09
McNary	Priest Rapids TR	0.80	1.1	1.7	0.88	1.36
	Priest Rapids TR-BRZ	0.06	2.0	3.6	0.13	0.23
Priest Rapids	Priest Rapids FB-BRZ	0.11	0.0	0.0	0.00	0.00
	Priest Rapids FB	0.46	0.2	0.0	0.09	0.00
	Priest Rapids Mr	1.12	0.0	0.0	0.00	0.00
	Wanapum TR	0.56	0.8	1.7	0.45	0.96
	Wanapum TR-BRZ	0.07	1.1	2.7	0.08	0.20
Wanapum	Wanapum FB-BRZ	0.15	0.3	0.0	0.04	0.00
	Wanapum FB	0.63	0.3	0.0	0.19	0.00
	Wanapum MR	3.36	0.0	0.0	0.00	0.00
	Rock Island TR	0.70	0.9	0.1	0.63	0.07
	Rock Island TR-BRZ	0.14	1.0	0.0	0.14	0.00
Rock Island	Rock Island FB-BRZ	0.13	0.4	0.0	0.05	0.00
	Rock Island FB	0.31	0.4	0.0	0.12	0.00
	Rock Island MR	0.31	0.2	0.2	0.06	0.09
	Rocky Reach TR	0.38	0.3	3.9	0.11	1.48
	Rocky Reach TR-BRZ	0.04	0.4	3.2	0.02	0.13
Rocky Reach	Rocky Reach FB-	0.11	0.1	1.1	0.01	0.12
	BRZ	0.34	0.1	0.8	0.03	0.27
	Rocky Reach FB	2.61	0.0	0.0	0.00	0.00
	Rocky Reach Mr	0.42	0.5	0.5	0.21	0.21
	Wells TR	0.07	--	1.5	0.03[d]	0.10
	Wells TR-BRZ					
Wells	Wells FB-BRZ	0.02	0.4	0.0	0.01	0.00
	Wells FB	0.37	0.5	0.1	0.18	0.04
	Wells MR	2.05	0.3	0.0	0.61	0.00
	Chief Joseph TR	0.35	0.0	0.0	0.00	0.00
	Chief Joseph TR-BRZ	0.02	0.0	0.0	0.00	0.00

[a] AI = Abundance Index; CI = Consumption Index; PI = Predation Index.

[b] FB-BRZ = Forebay boat restricted zone; FB = Forebay; MR = Mid-Reservoir; TR = Tailrace

[c] Spill conditions prohibited sampling; values estimated from adjacent non-boat restricted area.

[d] Value estimated from adjacent non-boat restricted area.

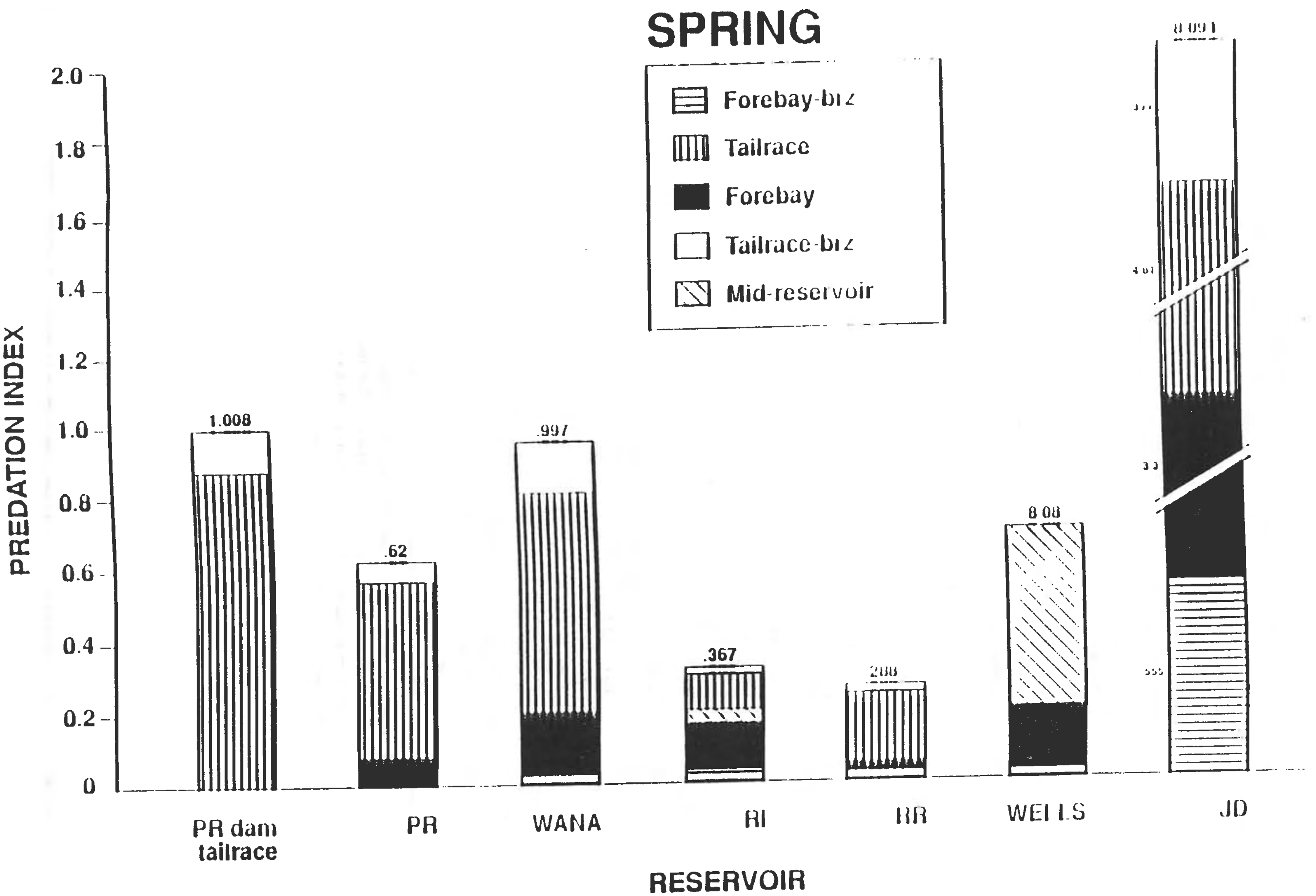


Figure 4. Relative predation on juvenile salmonids by northern squawfish in the mid-Columbia River (spring), 1993. PR Priest Rapids; Wana=Wanapum; RI=Rock Island; RR=Rocky Reach; JD=John Day *(cummulative total).

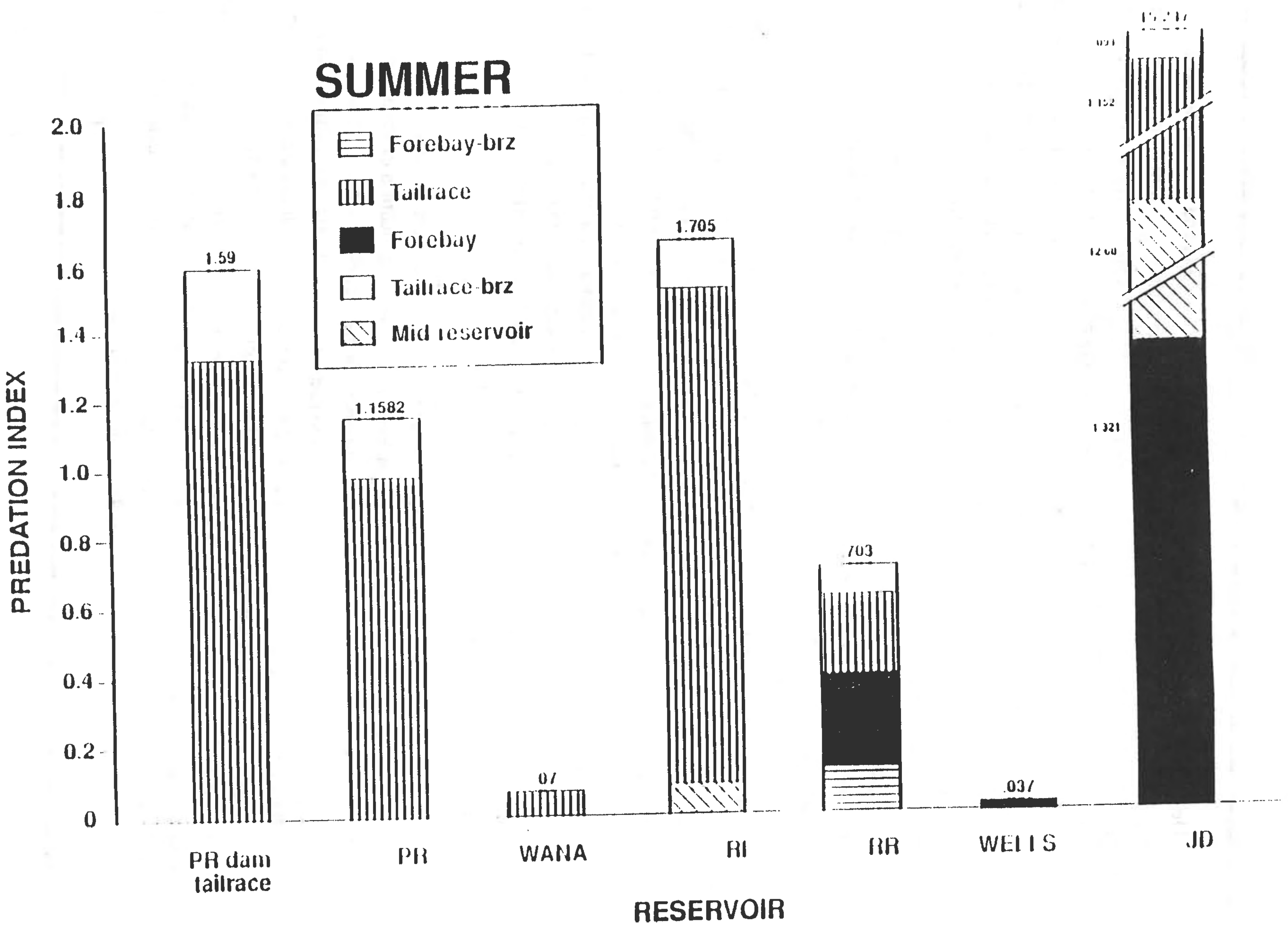


Figure 5. Relative predation on juvenile salmonids by northern squawfish in the mid Columbia River (summer), 1993. PR=Priest Rapids; Wana=Wanapum; RI=Rock Island; RR=Rocky Reach; JD=John Day *(cummulative total).

Density index values for northern squawfish varied by location and season for most reservoirs sampled. We found high densities of northern squawfish (>250 mm fl) in tailrace areas than mid-reservoir or forebay areas. Uremovich et al. (1980) has found that local concentrations of northern squawfish in tailrace and forebay areas of Columbia River Basin dams can be high. Beamesderfer and Rieman (1991) and Sims et al. (1978) found densities of northern squawfish to be higher in tailrace areas of John Day and Little Goose Reservoirs, respectively. We found that non-boat restricted zones of mid-Columbia reservoir tailraces had higher densities of northern squawfish than John Day Reservoir non-boat restricted zone of tailrace areas.

Densities of northern squawfish for mid-Columbia reservoir tailrace BRZs were similar. Density values for northern squawfish in both Wanapum and Rock Island tailrace BRZs were higher than density values in John Day Reservoir BRZs.

Our estimates of abundance and predation indices were lower than John Day Reservoir. However, there were similarities between mid-Columbia river reservoirs and John Day Reservoir. Higher predation of juvenile salmonids by northern squawfish was observed in the non-boat restricted zone of tailrace areas. Similarly, Rieman et al. (1991) and Ward et al. (1993) found most predation in John Day Reservoir occurred in non-boat restricted zones. Seasonally, Ward et al. (1993) observed higher predation occurring during the summer sampling season than in spring. Likewise, we found predation to be higher during summer sampling. Increased activity levels by predators due to warmer water temperatures and better river flow conditions during summer may have improved our ability to capture northern squawfish.

The purpose of predator indexing is to rapidly assess large areas to provide information on the relative importance of predation by northern squawfish for a location or reservoir (Petersen et al., 1991). Surface area is an important component in the model for estimating abundance index values. Surface area is used as an expansion factor. Consequently, our estimates are affected by reservoir surface area (i.e., large mid-reservoir areas vs. tailrace areas). Our estimate of abundance and predation index values for mid-Columbia River reservoirs are lower than John Day Reservoir index values in part due to the larger relative size of John Day Reservoir to mid-Columbia reservoirs. For example, within the mid-Columbia River study area, Rock Island reservoir is about six times smaller than the largest reservoir (Wanapum). In contrast, John Day Reservoir is about 20 times larger than Rock Island reservoir.

Our estimate of predation index values for mid-Columbia reservoirs were lower than observed for John Day Reservoir. We believe that predation indexing of mid-Columbia reservoirs identified important differences between locations and reservoirs. Predator index results suggest predation is most important at Rocky Reach, Wanapum, and Preist Rapids tailrace areas. Seasonally, summer predation was most important at Rocky Reach, Preist Rapids and Wanapum Dam tailrace areas. A partial reason for high predation volumes for these areas are due to spring Chinook releases at Rocky Reach.

In conclusion, we determined that on a per capita basis predator densities were similar in the mid-Columbia reservoirs compared to John Day Reservoir. The use of surface area to calculate abundance index values combined with low consumption index values resulted in low predation index values for mid-Columbia River reservoirs. We feel that future work to better define the area specific predation rate in the mid-Columbia reservoirs should be considered. Additionally, work to determine the feasibility of reducing predation for juvenile salmonids by northern squawfish through predator control or prey protection should be conducted. Efforts to evaluate these activities should be an integral component of any future work.

LITERATURE CITED

Beamesderfer, R.C., and B.E. Rieman. 1991. Abundance and distribution of northern squawfish, walleye, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 439-447.

Nigro, A.A., R.C. and Beamsderfer, J.L. Elliot, M.P. Faller, L.M. Miller, B.L. Uremovich, D.L. Ward. 1985. Abundance and distribution of walleye, northern squawfish, and smallmouth bass in John Day Reservoir, 1985. Annual Progress Report. Project Number 82-12. Contract DE-AI79-84BP35097, Bonneville Power Administration, Portland Oregon.

NPPC (Northwest Power Planning Council). 1987. Columbia River Basin Fish and Wildlife Program. Adopted November 15, 1982, amended October 10, 1984, and February 11, 1987. Northwest Power Planning Council, Portland, Oregon.

Petersen, J.H., D.B. Jepsen, R.D. Nelle, R.S. Shively, R.A. Tabor, and T.P. Poe. 1991. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1990. Bonnevile Power Administration, Portland, Oregon.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleye, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 448-458.

Sims, C.W., W.W. Bently, and R.C. Johnson. 1978. Effects of power peaking operations on juvenile salmon and steelhead trout migrations -- Progress 1977. Final Report Contract DACW68-77C-0025) to U.S. Army Corps of Engineers, Portland, Oregon.

Uremovich, B.L., S.P. Cramer, C.F. Willis, and C.O. Junge. 1980. Passage of juvenile salmonids through the ice-trash sluiceway and squawfish predation at Bonnevile Dam, 1980. Report to U.S. Army Corps of Engineers, Portland, Oregon.

Vigg, S., and C.C. Burley. 1989. Developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River. *IN* A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. 1989 Annual Report A. Contract DE-BI79-88BP92122, Bonneville Power Administration, Portland, Oregon.

Vigg, S., and C.C. Burley. 1990. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River Basin. Report A.[IN] A.A. Nigro, editor. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River Basin. 1990 Annual Report. Contract DE-BI79-90BP07084, Bonneville Power Administration, Portland, Oregon.

Ward,D.L., M.P. Zimmerman, R.M. Parker, and S. S. Smith. 1993. Development of a system-wide predator control program: Indexing, fisheries evaluation, and harvesting technology development. Report G. [IN] Willis, C.F. and A.A. Nigro, editors. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River Basin. Annual Report 1991 April - December. Project Number 90-077. Contract Number DE-BI79-90BP07084, Bonneville Power Administration, Portland, Oregon.

APPENDIX A

Significance of predation in the Columbia River from Priest Rapids Dam to Chief Joseph Dam: Catch and Biological Data.

INTRODUCTION

This project was a joint research effort by the Washington Department of Fish and Wildlife (WDFW; formerly Department of Wildlife) and the National Biological Survey (NBS) to determine the impact of predator species: northern squawfish (*Ptychocheilus oregonensis*), walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieui*) and channel catfish (*Ictalurus punctatus*) on migrating juvenile salmonids (*Oncorhynchus spp.*) in the mid-Columbia River, 1993. We summarized catch and biological data collected during April through August, 1993.

The specific objectives of this appendix were to report: (1) biological data for predator species collected during electrofishing and gillnet sampling, target species catch data by reservoir, age composition of predator populations, and fecundity characteristics of northern squawfish and (2) catch-per-unit-effort data for northern squawfish and other predators in mid-Columbia River reservoirs.

METHODS

CATCH

The sampling season was stratified into two seasons, spring (April-June) and summer (June-August), to minimize differences in catch due to varying flows, water temperature, and abundance of juvenile salmonids. The WDFW started sampling for each period at Priest Rapids Dam tailrace and worked upriver to Chief Joseph Dam tailrace while NBS sampling started at Chief Joseph Dam tailrace and worked downriver to Priest Rapids Dam tailrace (Table 1, Report A).

WDFW biologists used two gillnet boats and one Smith-Root[1] electroshocking (ES) boat at each location. Each gillnet boat sampled a minimum of three randomly chosen transects per day, while the electroshocker sampled a minimum of six. At least one boat restricted zone (BRZ) transect in each tailrace and forebay was sampled by the ES boat. All sampling was started 90 minutes before sunrise and typically lasted eight hours. Transect locations are reported in Appendix B.

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[1] Use of a trade name does not imply endorsement by the Washington Department of Wildlife.

Table 1 Sampling schedule for Washington Department of Wildlife, mid-Columbia River, 1993.

Dam	Location	Early Season	Late Season	Supplemental[a]
Priest Rapids	Tailrace	4/13-4/14	6/21-6/22	6/17
	Forebay	4/15-4/16	6/23-6/27	6/17
	Mid-reservoir	4/19-4/20	6/28-6/29	---
Wanapum	Tailrace	4/21-4/22	6/30-7/1	---
	Forebay	4/26-4/27	7/6-7/7	6/18
	Mid-reservoir	4/28-4/29	7/8-7/9	---
Rock Island	Tailrace	5/3 + 5/6	7/19-7/20	6/18
	Forebay	5/10 + 5/13	7/21-7/22	---
	Mid-reservoir	5/4-5/5	7/12-7/13	---
Rocky Reach	Tailrace	5/11-5/12	7/14-7/15	---
	Forebay	5/17-5/18	7/26-7/27	---
	Mid-reservoir	5/19-5/20	7/28-7/29	---
Wells	Tailrace	5/24-5/25	8/2-8/3	---
	Forebay	5/26-5/27	8/4-8/5	---
	Mid-reservoir	6/1-6/2	8/9-8/10	---
Chief Joseph	Tailrace	6/3-6/4	8/11-8/12	---

Electroshocking was performed at 600 volts at five amperes and a pulse frequency of 60 hrz. A unit of effort for electroshocking was 900 seconds (15 minutes). Target species were netted and placed into live wells. Non-target species were counted but not netted. Both NBS and WDFW were concerned about injuring adult fish wile eletrofishing. When an adult salmonid was encountered, we temporarily turned off the electric power to the electroshocker ending the electric field thereby allowing the adult salmonid to swim free of the electroshocking area and escape.

Each gillnet boat sampled with both a bottom net and a surface net. Both gillnets were placed in the same transect for one hour. Target species were removed from the nets and placed in live wells while non-target species were counted and returned to the river. Gillnets were 45.6 m long and 2.4 m deep and were constructed in two halves, with each half containing three 7.6 m panels with bar mesh sizes of 3.2 cm, 4.4 cm, and 5.1 cm. Bottom nets had a 14 kg lead line and a foam core float line. The surface net had a 14 kg. lead line and a float line consisting of 11.5 cm by 7.1 cm floats spaced 61 cm apart.

Biological data collected from target species included: fork length (± 1 mm), weight (± 1 g), sex, fish disposition, scale sample, and gonad sampled taken. Northern squawfish and walleye ≥250 mm in length and smallmouth bass ≥200 mm were tagged with white Floy tags. Tags were pierced through the fish posterior to the soft dorsal fin through the dorsal musculature (Willis et al., 1985). In addition, the left ventral fin of tagged fish was clipped as a secondary mark.

Catch-per-unit-effort (CPUE) was calculated by gear type for northern squawfish, walleye, and smallmouth bass.

$$CPUE = C_i / f_i$$

where,

C_i= number of fish caught in an area or zone i,

F_i= number of gillnet sets or units of electroshocking time) in an area or zone i.

We used an ANOVA to test differences in fork length-weight and CPUE relationships. In addition, Student-Newman-Keuls multiple comparison test, Mann-Whitney and Kruskal-Wallis single factor analysis of variance by rank were used to analyze fork length-weight and CPUE relationships. In cases of non-normal distribution data, we normalized the data using natural log transformation to meet assumptions of normality (Zar, 1974).

Age and Growth

Northern squawfish, walleye and smallmouth bass scales were collected in the field using techniques described by Bagenel and Tesch (1978). Approximately 20 scales were removed from the left side of northern squawfish within a region just posterior to the dorsal fin and two to three scale rows above the lateral line. Similarly, walleye and smallmouth bass scales were collected from the left side but below the lateral line near the posterior end of the pectoral fin.

Northern squawfish scale samples were stratified by reservoir and fork length (25 mm increments). Walleye and smallmouth bass were not stratified by reservoir due to insufficient sample size. Methodology used for age determination using scales was similar to that described by Olson and Rien (1987) and Bagenel and Tesch (1978). Scales were soaked in water for two minutes, then cleaned by removing mucus and skin using a denture brush. After cleaning, scales were examined under a dissecting scope for uniformity, regeneration and damaged edges. Up to four scales from each fish were placed onto a gummed card and overlaid with acetate film.

Impressions of the scales were made using a press to apply 422 kgs./sq. cm. (6000 psi) pressure for three minutes, between 104°C and 121°C.

The acetate impressions were read independently by two readers using microfiche viewers (42x). Using a strip of white paper laid over the screen of the microfiche, each reader independently marked the focus of each scale read and measured the distance between each annuli from the focus to the outer edge of the scale for backcalculations. June 15 was designated as the date annulus was formed in 1993. If the two readers disagreed on the age of the scale, the scale was read concurrently by both readers and a common age was determined for the scale.

Percentage agreement was used to assess the precision of age estimates by both readers (Kennedy 1970). Percentage agreement was calculated as follows using 200 randomly selected scales:

$$P = (x / n) * 100$$

where,

P = percent agreement,
x = number of times readers agreed, and
n = sample size.

Mean fork lengths for a given year-class were determined by backcalculation methods described by Bagenel and Tesch (1978). The best fit model for all predators was:

$$\ln y = a + b \ln x$$

where,

y = fork length (mm), and
x = anterior scale radius (mm)
a = constant
b = slope

Fecundity

Female northern squawfish gonad samples (n=53) were collected from five reservoirs of the mid-Columbia River. Gonad samples were collected between April 13-August 12, 1993. We collected female gonad samples throughout the sampling season. The following data were recorded for each fish: collection date, time, location, fork length (mm), total weight (g) of fish, scale sample, sex and gonad weight (g). The gonads excised from 53 female fish were weighed and placed in labeled plastic containers. The samples were weighed using an electronic scale to the nearest 0.001g and preserved in Gilson's solution (Snyder, 1983) for later fecundity determination.

The sampling procedure used for collecting gonad samples in the field differed from that of earlier investigations (Table 2). For example, Oregon Department of Fish and Wildlife (ODFW) collected only ripe gonad samples for fecundity estimates. ODFW defines ripe as eggs which are characterized by relatively large size and orange color (Chris Knutsen ODFW, personal communication). We sampled fish of various maturity levels, including immature, developing (maturing) and ripe.

Analysis of gonad data was similar to Wolfert (1969) and Vigg and Burley (1990). Under a vented hood, Gilson's solution was drained from the ovary samples through sieves (0.333 and 0.270 mm) that had been pre-weighed and tared on a Mettler PC 440 Delta range scale. The eggs were rinsed thoroughly with water to remove any remaining preservative. Paper towels were used to draw off any remaining water from the underside of the sieve, excess tissue and fat were removed using dissecting needles and tweezers. Any eggs remaining clumped together were separated. The sample was then weighed (± 0.001 g) and recorded. From the total sample, three subsamples containing about 200 eggs were separated out and weighed individually to the nearest (± 0.001 g). Eggs were submerged in water to aid in separating the egg masses. The number of eggs in each subsample was counted and recorded. Egg diameters were measured from randomly selected eggs in each subsample (± 0.01 mm), fifteen total from the original sample. We measured egg diameters using a Bausch and Lomb 1.0x-2.5x dissecting scope and a Reichert stage micrometer.

Table 2 Criteria used to determine maturity of gonads excised from captured northern squawfish; mid-Columbia River, 1993.

CODE	DEFINATION
0	Undetermined
1	Immature: gonads thin and threadlike, females with greater venation than males.
2	Developing: sex easily determined from gonads (testes are white, ovaries yellow, tinged with red), but eggs or milt do not flow freely with gentle pressure.
3	Ripe: eggs or milt flow freely with gentle pressure.
4	Spent: sex easily determined but gonads are flaccid and may show striations; some eggs or sperm may be present.

Total numbers of eggs were calculated by direct proportion for both subsample (F_s) and overall fecundity (F) estimates:

(1) $$F_s = \frac{W_t \cdot N_i}{W_i}$$

(2) $$F = \frac{W_t \cdot \Sigma N_i}{\Sigma W_i}$$

where,

W_t = total gonad weight (g)(preserved),
W_i = weight (g) of subsample,
N_i = number of eggs counted in subsample, and
i = 1 to 3.

The mean egg diameter (D_m) for each fish was calculated:

(3) $$D_m = \frac{\Sigma D_i}{15},$$

where,

Di = diameter of an individual egg (mm), and
i = 1 to 15.

Least square regression was used to determine relationships between fish characteristics and fecundity. We also calculated frequency distributions and descriptive statistics for each variable. We used criteria similar to ODFW in determining the maturity of gonads in the field (Table 2).

Gonadal Somatic Index

Gonadal Somatic Index (GSI), was determined using the total weight of the fish (W_t), and gonad weight (W_g) measured in the laboratory ($\pm$ 0.1 g)(Snyder, 1983). The GSI was calculated as:

4) $$GSI = \frac{W_g \cdot 100}{W_t}$$

We sampled a total of 3,264 target predators during the sampling season from the mid-Columbia River, 1993. Northern squawfish accounted for 91 percent (2971), compared to 4.7 percent (154) smallmouth bass, and 4.3 percent (139) walleye. Target predators sampled varied by reservoir throughout the mid-Columbia River (Table 3). No channel catfish were captured during the 1993 sampling season (Appendix C).

Northern squawfish

Of the total northern squawfish sampled, the tailrace boat restricted zones (TR-BRZ) and tailrace non-boat restricted zones (TR non-BRZ), accounted for 49 percent of the catch. Mid-reservoirs yielded 31 percent whereas forebay boat restricted zones (FB-BRZ) and forebay non-boat restricted zones (FB non-BRZ) contained 20 percent of the total northern squawfish sampled (Table 3).

Electroshocking was most effective in capturing northern squawfish (CPUE 1.98) followed by bottom (CPUE 1.33) and surface gillnets (CPUE 0.35). CPUE varied for northern squawfish between reservoirs. CPUE values were highest for northern squawfish in Priest Rapids Dam tailrace using electroshocking (Table 4). Bottom gillnet CPUE was significantly higher ($P = 0.001$; ANOVA) than surface gillnet CPUE. There were no significant differences in electroshocking efficiency between reservoirs ($P = 0.132$; Kruskal-Wallis). However, in comparing seasonal differences, summer electroshocking CPUE was significantly greater than spring CPUE for northern squawfish ($p = 0.007$; Mann-Whitney; Table 5).

Average fork length of northern squawfish varied by reservoir. Northern squawfish had an overall size of 327 mm $\pm$ 3 mm (n=2971) and 543 g $\pm$ 14 g (n=2875). The average size of northern squawfish demonstrated a decreasing trend moving upstream from Priest Rapids Dam through Rocky Reach reservoir (Table 6).

Tailrace locations yielded larger northern squawfish than other sampling areas (Table 7). Northern squawfish captured in tailrace areas averaged 358 mm and 675 g for forklength and weight, respectively. Northern squawfish captured in forebays (average 327 mm and 511 g) and mid-reservoirs (average 276 mm and 338 g) were smaller than northern squawfish captured in tailrace areas (Table 7).

The length frequency distribution for northern squawfish varied between reservoirs (Figures 17-23). A significant length-weight relationship existed for northern squawfish (r^2=0.95; n=2875; Figure 24). Also, significant differences ($p \geq 0.05$) in average fork lengths were found between and within reservoirs.

Table 3 Numbers of Northern squawfish, walleye and small mouth bass captured by location for all gear types by the Washington Department of Wildlife mid-Columbia River, 1993. (PR Priest Rapids, WANA=Wanpaum, RI=Rick Island, RR=Rocky Reach, TR tailrace, MR mid-reswevoir, FB forebay)

		Predators									
		Northern squawfish			Walleye			Smallmouth bass			
Reservoir	Location	spring	summer	total	spring	sumer	total	spring	summer	total	Grand Total
PR Dam	TR	52	57	109	7	8	15	0	0	0	124
	TR-BRZ	16	79	95	0	0	0	0	0	0	95
sub-total		68	136	204	7	8	15	0	0	0	219
PR	FB	8	17	25	0	0	0	15	20	35	60
	FB-BRZ	13	6	19	0	0	0	28	6	34	53
	MR	23	27	50	0	0	0	1	22	23	73
	TR	17	32	49	0	3	3	0	0	0	52
	TR-BRZ	30	114	144	2	8	10	0	0	0	154
sub-total		91	196	287	2	11	13	44	48	92	392
WANA	FB	19	49	68	0	1	1	1	1	2	71
	FB-BRZ	27	15	42	0	0	0	0	1	1	43
	MR	37	186	223	1	3	4	0	0	0	227
	TR	8	47	55	2	1	3	0	0	0	58
	TR-BRZ	77	246	323	6	30	36	0	0	0	359
sub-total		168	543	711	9	35	44	1	2	3	758
RI	FB	24	26	50	0	0	0	0	1	1	51
	FB-BRZ	15	11	26	0	0	0	0	1	1	27
	MR	38	208	246	0	1	1	0	1	1	248
	TR	37	116	153	2	7	9	0	2	2	164
	TR-BRZ	68	81	149	2	3	5	0	0	0	154
sub-total		182	442	624	4	11	15	0	5	5	644
RR	FB	40	97	137	0	0	0	0	13	13	150
	FB-BRZ	41	39	80	0	3	3	0	0	0	83
	MR	85	260	345	1	6	7	0	1	1	353
	TR	49	72	121	16	1	17	1	10	11	149
	TR-BRZ	8	80	88	0	8	8	0	13	13	109
sub-total		223	548	771	17	18	35	1	37	38	844

Table 3 Numbers of Northern squawfish, walleye and small mouth bass captured by location for all gear types by the Washington Department of Wildlife mid-Columbia River, 1993. (PR - Priest Rapids, WANA = Wanpaum, RI = Rick Island, RR Rocky Reach, TR tailrace, MR = mid-reswevoir, FB = forebay).

		Predators									
		Northern squawfish			Walleye			Smallmouth bass			
Reservoir	Location	spring	summer	total	spring	sumer	total	spring	summer	total	Grand Total
Wells	FB	42	53	95	0	0	0	0	1	1	96
	FB-BRZ	15	23	38	0	0	0	0	2	2	40
	MR	25	37	62	0	2	2	3	10	13	77
	TR	15	39	54	3	8	11	0	0	0	65
	TR-BRZ	7	118	125	3	1	4	0	0	0	129
sub-total		104	270	374	6	11	17	3	13	16	407
Totals	FB	133	242	375	0	1	1	16	36	52	428
	FB-BRZ	111	94	205	0	3	3	28	10	38	246
	MR	208	718	926	2	12	14	4	34	38	978
	TR	178	363	541	30	28	58	1	12	13	612
	TR-BRZ	206	718	924	13	50	63	0	13	13	1000
Grand Total		836	2,135	2,971	45	94	135	49	105	154	3,264

Table 4 Catch-per-unit-effort (CPUE) by location and gear type of northern squawfish, smallmouth bass, and walleye (of all sizes) caught by Washington Department of Fish and Wildlife and National Biological Survey (random transects only), mid-Columbia River reservoirs, 1993[a].

	Predators								
	Northern Squawfish			Smallmouth Bass			Walleye		
Reservoir	ES[b]	SGN[c]	BGN[d]	ES	SGN	BGN	ES	SGN	BGN
PRTR	2.85	0.04	0.35	0.00	0.00	0.00	0.21	0.00	0.04
PR	0.97	0.12	0.96	0.45	0.00	0.07	0.02	0.00	0.11
WANA	2.82	0.42	1.34	0.02	0.00	0.00	0.06	0.00	0.34
RI	2.27	0.27	1.46	0.02	0.00	0.01	0.01	0.00	0.13
RR	2.38	0.78	2.33	0.19	0.00	0.01	0.13	0.03	0.07
WELLS	1.26	0.21	0.77	0.06	0.00	0.03	0.05	0.02	0.04
Average	1.98	0.35	1.33	0.14	0.00	0.02	0.06	0.01	0.13

[a]PRTR Priest Rapids Dam Tailrace; PR -- Priest Rapids; WANA - Wanapum; RI Rock Island; RR rocky reach
[b]ES - Electroshocking; CPUE = fish caught per 15 minutes of electroshocking.
[c]SGN = Surface gillnet; CPUE = caught per 1 hour soak time
[d]BGN - bottom gillnet; CPUE fish caught per 1 hour soak time.

Table 5. Analysis of catch-per-unit effort (CPUE). Washington Department of Fish and Wildlife and national Biological Survey (random transects only mid-Columbia River reservoirs, 1993. Total effort = number of replicates; NSF = Northern squawfish, WAL = Walleye, SMB = smallmouth bass, H_o:CPUEs are the same.

Geartype	Relationship	Species	Total Catch	Total Effort	Total CPUE	Significant difference at a = 0.05	P-Value
Gillnet	Surface vs. Botton [a,b]	NSF	864	1000	0.86	YES	0.0012
Gillnet	Res. vs. Res. [a,b]	NSF	864	1000	0.86	NO	0.7716
Electroshocking	Early vs. Late [c]	NSF	1666[d]	1054	1.58	YES	0.0070
Electroshocking	Res. vs. Res. [b,c]	NSF	1473	990	1.49	NO	0.2875
Electroshocking	Res. vs. Res. [c]	WAL	53	990	0.05	NO	0.4983
Electroshocking	Res. vs. Res. [b,e]	SMB	143	990	0.15	NO	0.1450

[a]Two way ANOVA with repication
[b]Priest Reapids dam tailrace not included in comparison; RES Reservoir
[c]Mann Whitney test
[d]Number represents northern squawfish ≥ 250 mm in fork length
[e]Kruskal Wallis single factor ANOVA by ranks.

Table 6. Size relationships of northern squawfish (NSF), Walleye and Smallmouth bass (SMB), Washington Department of Fish and Wildlife and National Biological Survey combined catch in mid-Columbia River, 1993. CI = Confidence interval.

Species, Reservoir	a	Length (mm) Mean ± 95% CI	Range (mm)	n	Weight (g) Mean ±95%	Range (g)
NSF						
Priest Rapids Dam Tailrace	204	405.6±7.3	200 -528	204	922.3±53.1	120 -2400
Priest Rapids	287	363.8±9.1	110 - 533	280	751.1±51.3	20 - 2450
Wanapum	711	346.0±5.8	121 - 540	692	613.8±26.2	20 - 2000
Rock Island	624	304.5±6.2	49 - 561	602	459.8±30.7	10 - 2175
Rocky Reach	771	295.7±5.4	115 - 515	733	403.8±22.3	10 - 2200
Wells	374	318.2±6.9	115 - 565	365	450.6±30.0	30 - 2400
Walleye						
Priest Rapids Dam Tailrace	15	555.7±41.5	380 - 620	14	2190.0±562.3	610 - 3650
Priest Rapids	13	463.6±90.6	198 - 710	13	1563.5±774.1	90 - 4750
Wanapm	44	478.6±33.1	210 - 686	44	1650.8±303.0	100 - 4600
Rock Island	15	512.6±40.2	360 - 645	15	1852.4±463.5	610 - 3400
Rocky Reach	35	468.8±52.1	174 - 729	35	1717.7±441.0	45 - 4850
Wells	17	472.4±53.6	171 - 630	17	1518.2±420.7	75 - 3450
SMB						
Priest Rapids Dam Tailrace	0	----	----	0	----	---
Priest Rapids	92	255.9±13.5	110 - 435	91	336.1±58.6	55 - 1550
Wanapum	3	208.0±6.9	200 - 214	3	146.7±15.1	136 - 165
Rock Island	5	259.6±70.0	185 - 348	5	336.0±229.3	90 - 750
Rocky Reach	38	312.5±15.7	175 - 363	38	556.6±72.5	65 - 910
Wells	16	381.1±39.3	176 - 390	16	461.9±190.6	90 - 1260

Table 7. Size relationships of northern squawfish by location within mid-Columbia River reservoirs, 1993. Washington Department of Wildlife and National Biological Survey combined catch. TR=Tailrace; FB=Forebay; MR=Mid-Reservoir; CI=Confidence interval

Reservoir	Location	n	Length (mm) Mean ± 95% CI[a]	n	Weight (g) Mean ± 95% CI
Priest Rapids Dam Tailrace	TR	204	405.6±7.3	204	922.3±53.1
Priest Rapids	TR	193	379.4±10.3	190	832.8±63.3
	FB	44	323.4±24.4	41	560.9±116.9
	MR	50	339.7±23.0	49	593.6±105.4
Wanapum	TR	378	376.6±5.7	375	731.4±33.6
	FB	110	363.6±11.8	109	644.9±65.5
	MR	223	285.5±10.7	208	385.4±41.2
Rock Island	TR	302	331.3±8.8	295	594.6±49.6
	FB	76	331.1±17.7	74	554.6±84.0
	MR	246	262.8±17.9	233	259.1±23.7
Rocky Reach	TR	209	331.9±9.5	209	515.4±49.5
	FB	217	305.3±9.5	216	424.6±38.1
	MR	345	267.8±7.7	308	313.5±27.9
Wells	TR	179	317.7±8.5	177	430.4±40.9
	FB	133	330.4±11.5	129	500.8±48.4
	MR	62	293.3±22.4	59	401.4±91.7
Totals by location	TR	1465	358.1±3.7	1450	675.8±20.9
	FB	580	327.1±5.9	569	484.2±26.6
	MR	926	276.3±4.9	857	338.2±18.4

[a] a = 0/05.

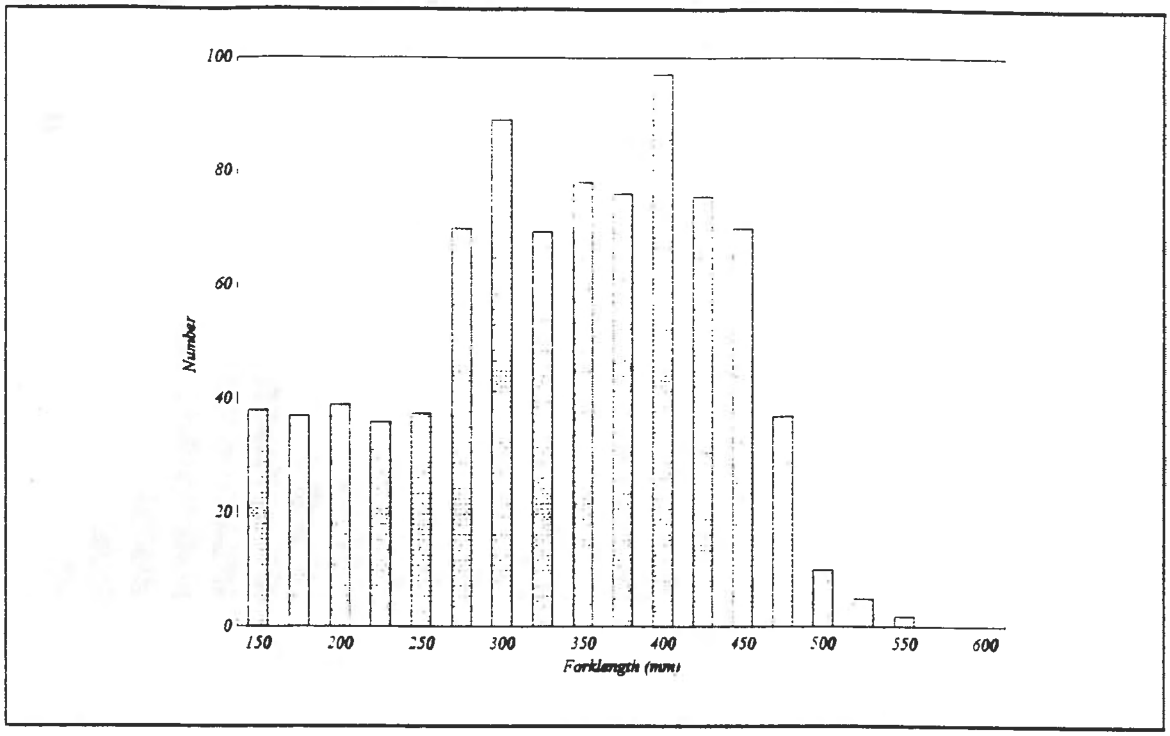


Figure 17. Frequency distribution of northern squawfish forklength for all reservoirs of the mid-Columbia River combined during 1993.

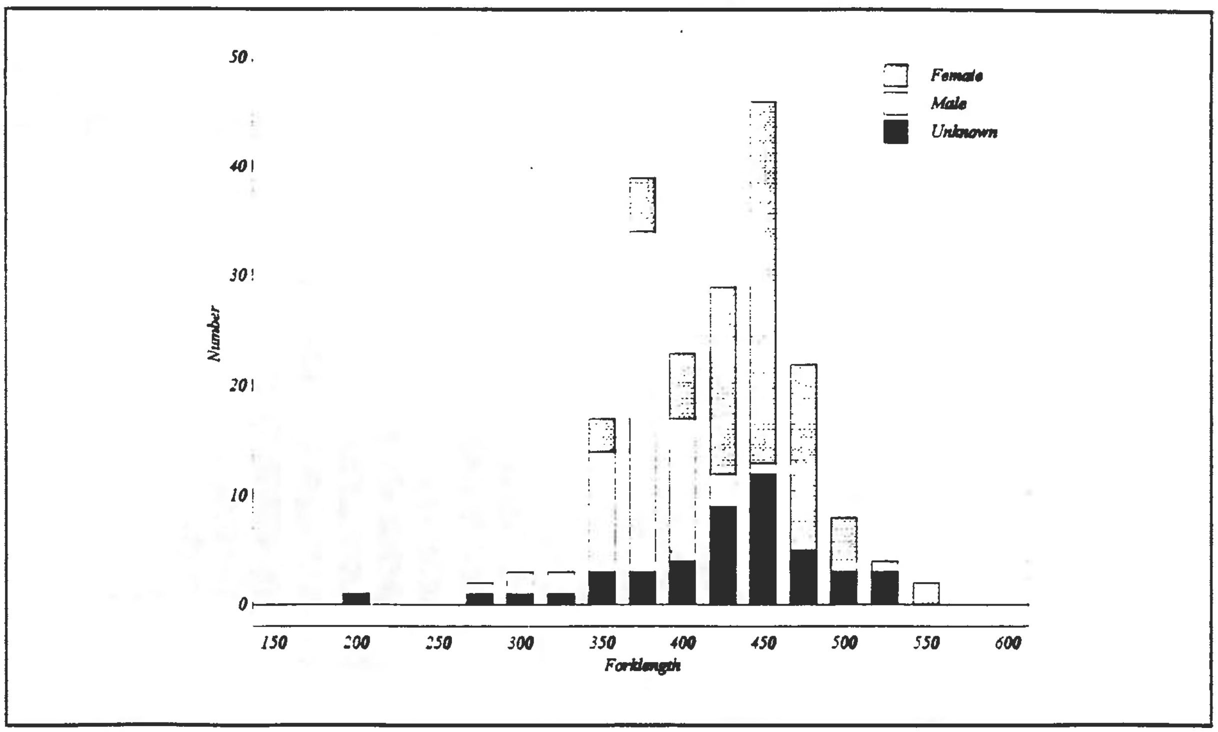


Figure 18. Frequency distribution of northern squawfish forklength for Priest Rapids Dam tailrace, mid-Columbia River, during 1993.

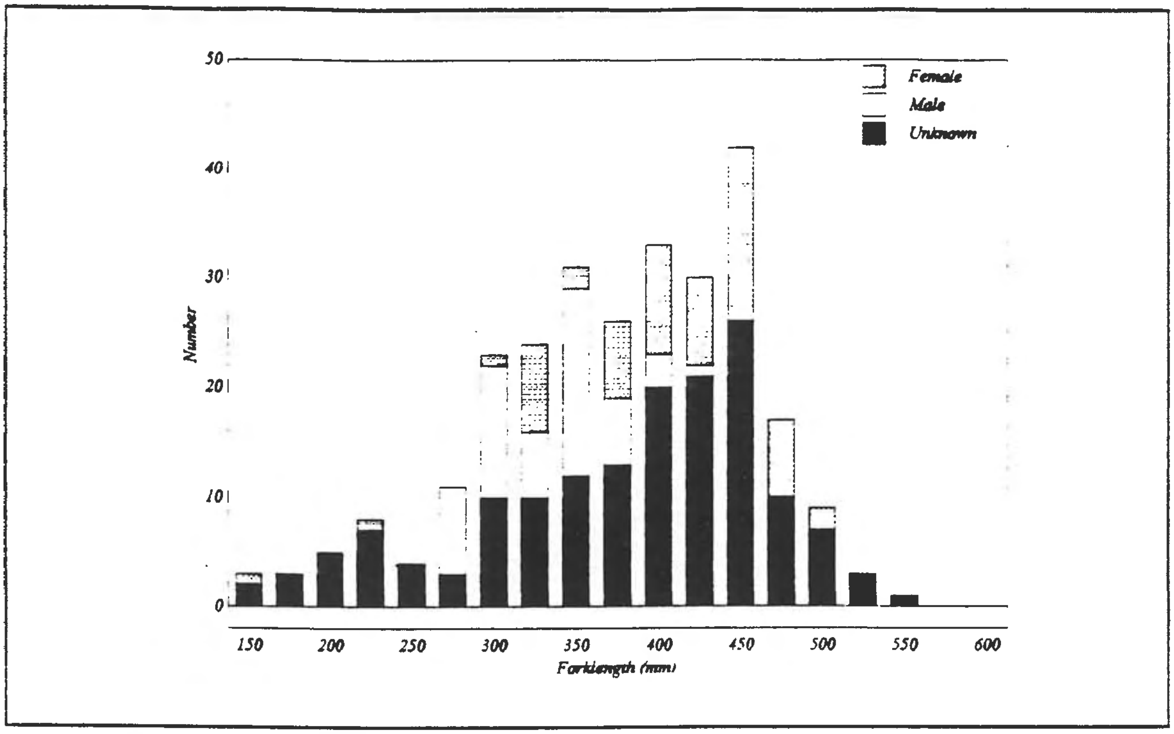


Figure 19. Frequency distribution of northern squawfish forklength for Priest Rapids reservoir, mid-Columbia River, during 1993.

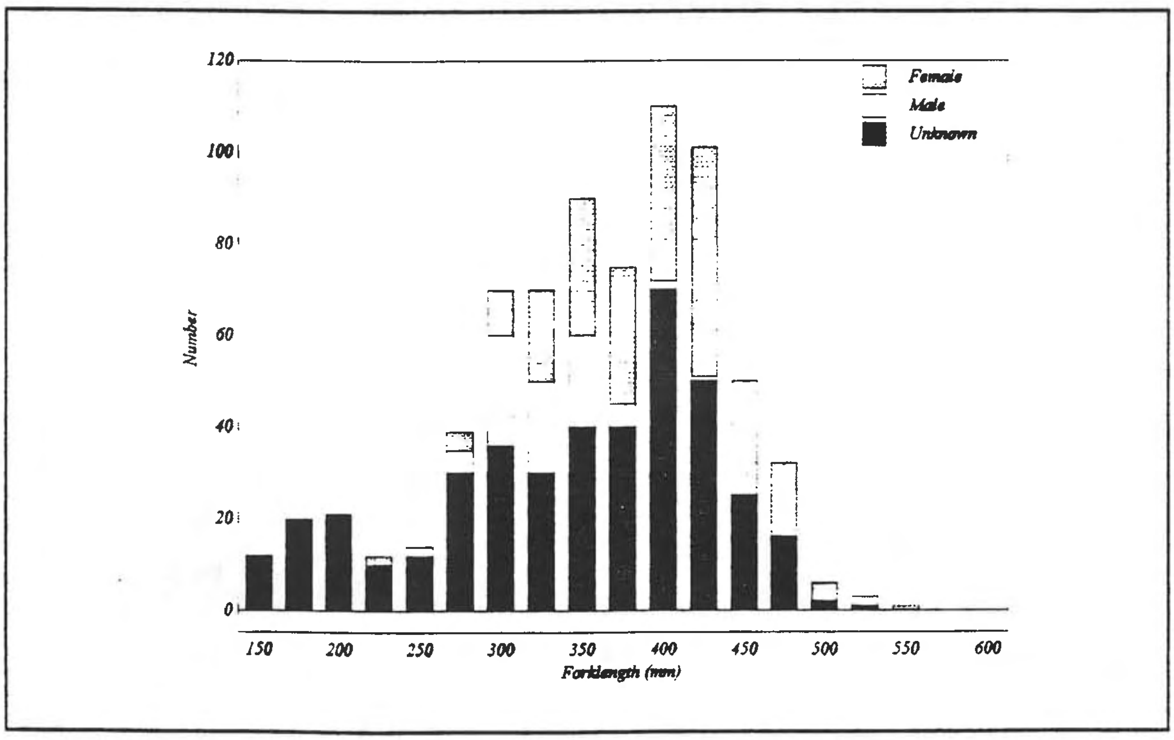


Figure 20. Frequency distribution of northern squawfish forklwngth for Wanapum reservoir, mid-Columbia River, during 1993.

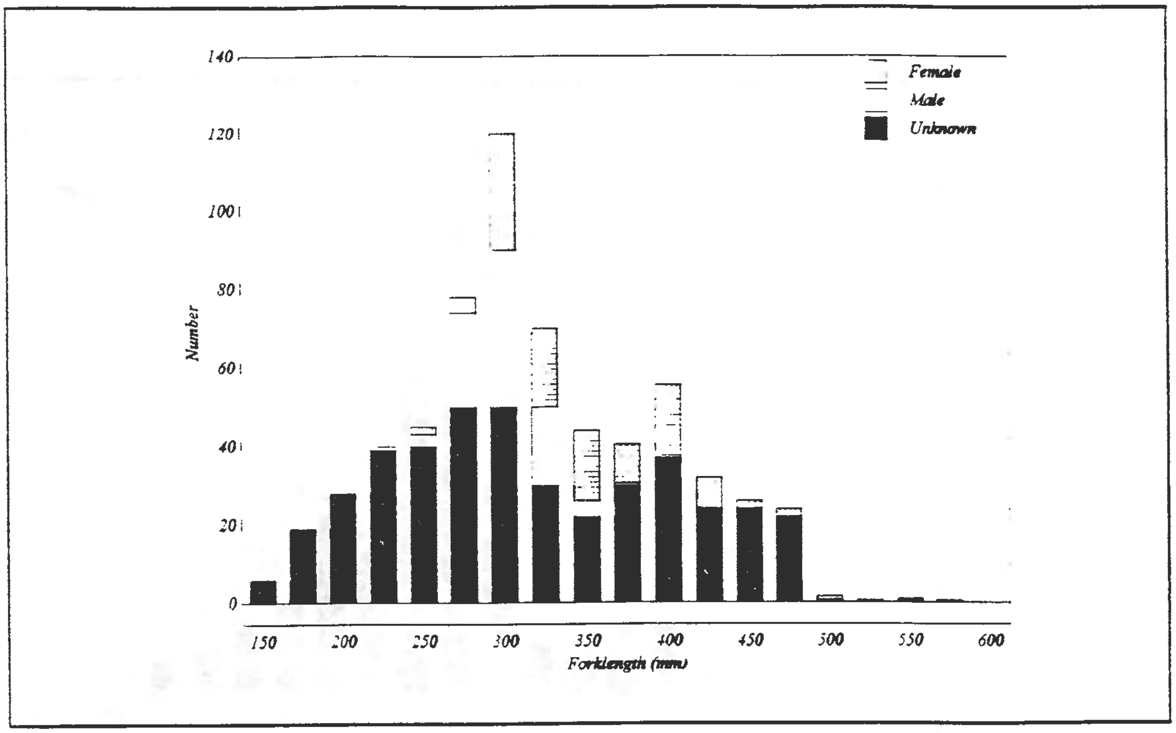


Figure 21. Frequency distribution of northern squawfish forklength for Rock Island reservoir, mid-Columbia River, during 1993.

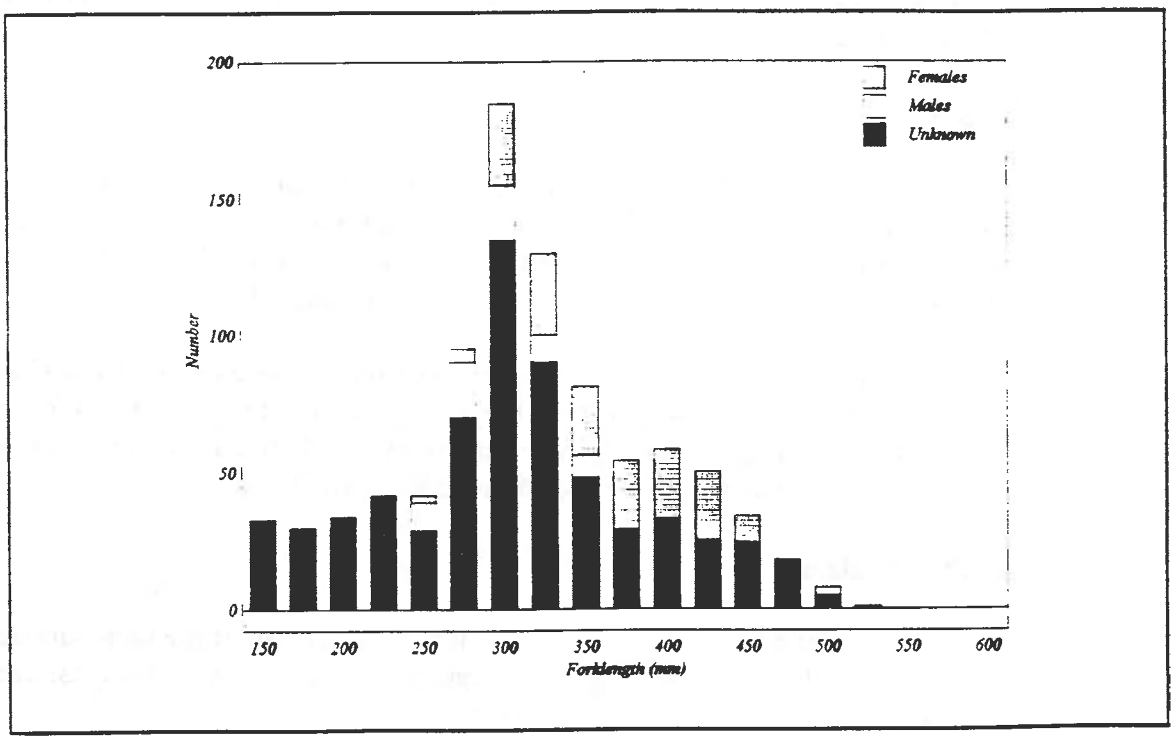


Figure 22. Frequency distribution of northern squawfish forklength for Rocky Reach reservoir, mid-Columbia River, during 1993.

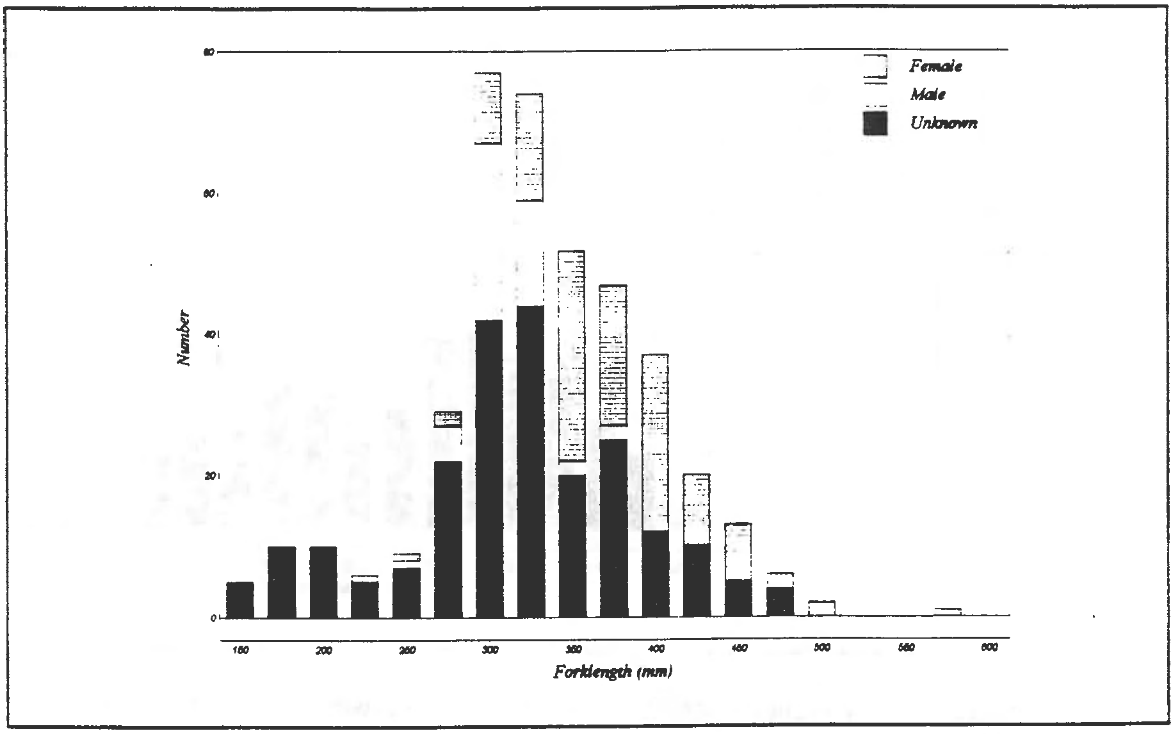


Figure 23. Frequency distribution of northern squawfish forklength for Wells reservoir, mid-Columbia River, during 1993.

Walleye

Walleye were the least abundant predator captured in mid-Columbia reservoirs. Most walleye were collected from Wanapum (32%) and Rocky Reach (25%) reservoirs (Table 3). Tailrace areas accounted for 87 percent of all walleye sampled. Mid-reservoir and forebays combined yielded 13 percent of the total walleye captured (Table 3)

Walleye varied by size according to reservoir. Walleye ranged from 171 mm to 729 mm and 45 g to 4850 g. Overall mean fork length and weight of walleye was 486 mm ± 20 mm (n=139) and 1720 g ± 178 g (n=138), respectively (Table 6). A fork length-weight relationship curve indicated a significant fit (r^2=0.96; n=138; Figure 25).

Smallmouth Bass

Smallmouth bass were the second most abundant target predator sampled. Fifty-eight percent (90) of the smallmouth bass were caught in forebay areas. Whereas, mid-reservoirs (25%) and tailrace (17%) accounted for the remainder (Table 3).

Differences in gear type effectiveness were evident for smallmouth bass. Electroshocking CPUE was 0.14 (fish/15 minutes of electroshocking) smallmouth bass. Bottom gillnet CPUE was 0.02 (fish/hour). Surface gillnets did not capture any smallmouth bass (Table 4).

Average fork length and weight of smallmouth bass varied by reservoir (Table 6). Smallmouth bass fork length ranged from 110 mm to 435 mm (n=154) while weight ranged between 55 g to 1550 g (n=153). The overall average fork length and weight of all smallmouth bass sampled was 272 mm ± 11 mm and 401 g ± 47 g, respectively. A length-weight relationship curve indicated a significant fit (r^2=0.96; n=153; Figure 26).

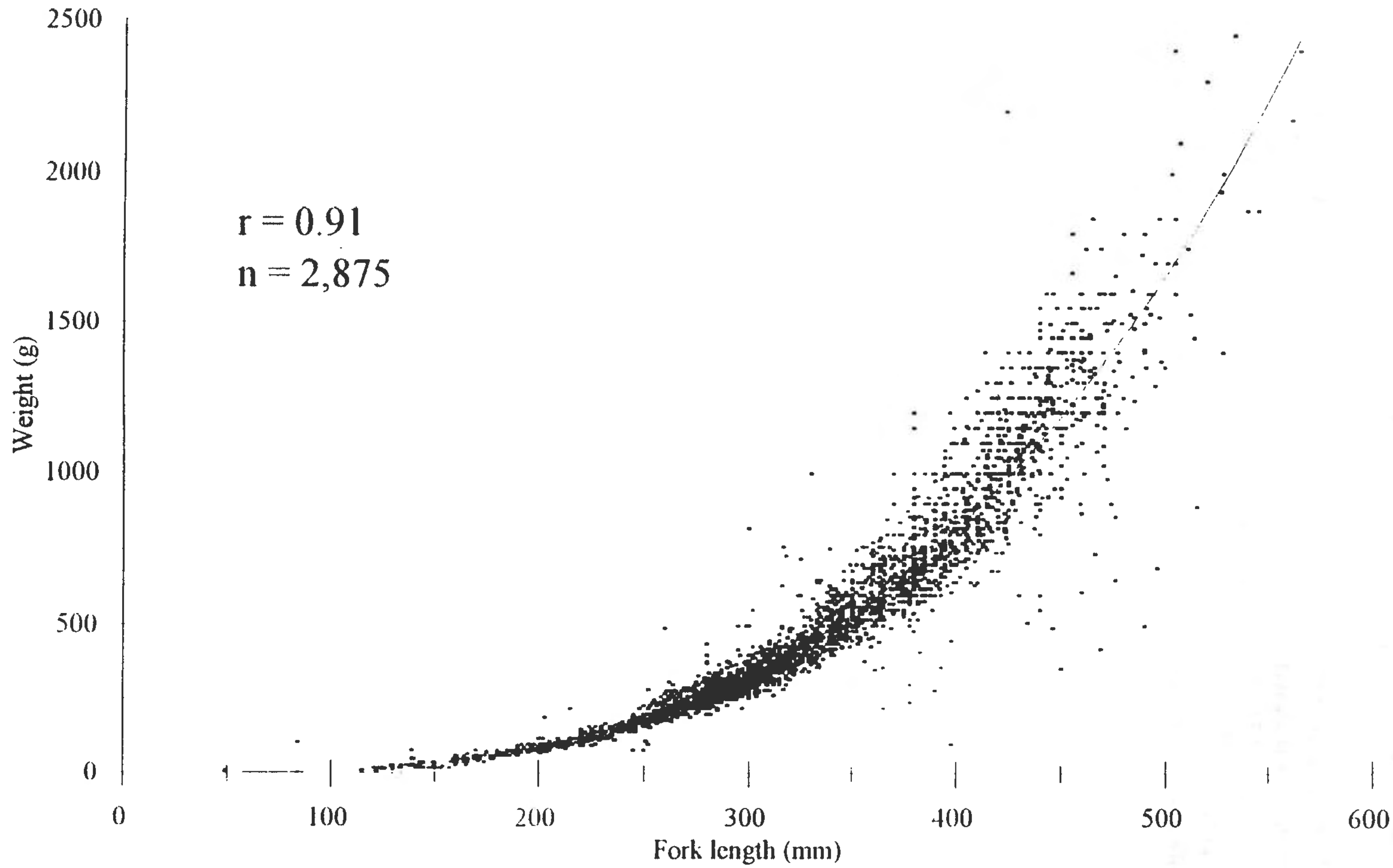


Figure 24. Length-weight relationship of northern squawfish captured in the mid-Columbia River reservoirs, 1993.

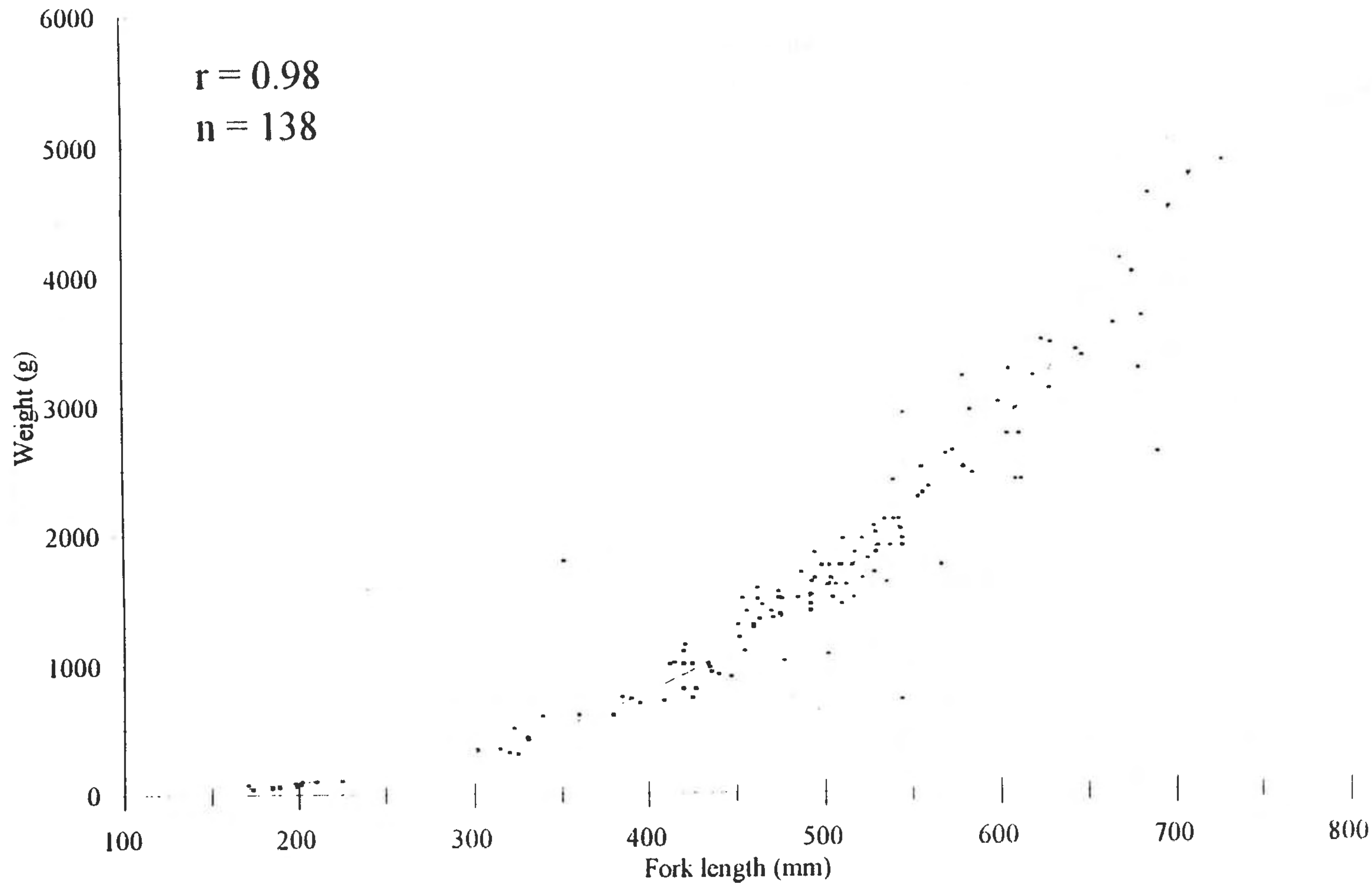


Figure 25. Length-weight relationship of walleye captured in the mid-Columbia River reservoirs, 1993.

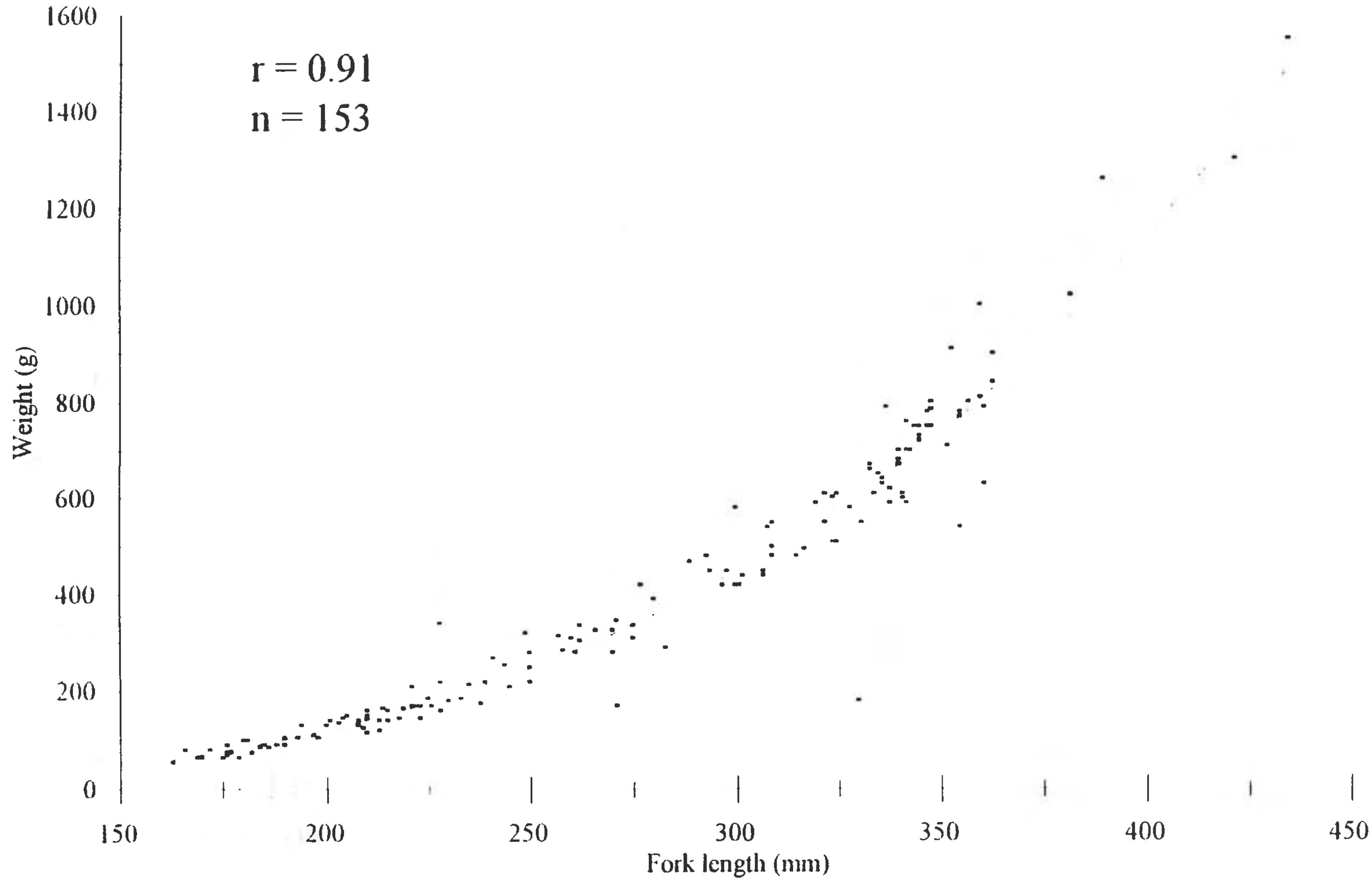


Figure 26. Length-weight relationship of smallmouth bass captured in the mid-Columbia River reservoirs, 1993.

Incidentals

A total of 25,584 fish were enumerated by WDFW, 92 percent were incidental or non-target species. Catostomidae family (suckers)comprised 66.1 percent of the incidental species caught. Salmonid species comprised 15 percent of the total incidental catch (66.1 % juveniles and 31.9 % adults). Our gillnets captured few adult salmonids (≤5%). Most large adult salmon and steelhead swan through our experimental surface and bottom gillnets. These nets were not designed for capturing large salmonid species (i.e., chinook and steelhead). Less than seven percent of all chinook and steelhead counted wre captured in gillnets. However, of the 549 sockeye salmon counted 81 (15%) were captured by gillnets. No adult salmon mortalities were recorded. All incidental species captured by all gear types are summarized on Appendix C.

Tag Recovery

Overall, 82.0 percent of all predator fish captured by the WDFW were tagged and released. Of the 1,801 northern squawfish caught, 1,474 were tagged (81.8%), of which 21 (1.2%) were recovered by WDFW, USFWS or anglers.

Ninety-one (84.3%) walleye were tagged and released, two (2.2%) of which were recovered. We tagged and released 28 of the 35 (80.0%) captured smallmouth bass and recovered 1 (3.6%; Table 8).

All recaptured fish had moved downstream, with the exception of one smallmouth bass that was caught within the same transect where it was tagged the previous day. One northern squawfish tagged in Wanapum forebay traveled downstream through Wanapum Dam and Priest Rapids Dam to be recovered 19.3 km downstream in McNary reservoir by an angler. The average number of days a fish was recaptured after being tagged was 40 ± 12d. While the average distance traveled from the location tagged was 8.5 ± 3.5 kilometers downstream before recovery. Distance traveled by tagged fish ranged from 0.0 to 22.5 km (Table 9).

Age and growth

Northern squawfish

Overall age of northern squawfish ranged from 2-15 with 8-10 year-olds accounting for 38 percent of the fish scales aged. Northern squawfish age composition between reservoirs varied slightly by age class and range (Table 10). There was no statistical difference in growth between reservoirs for northern squawfish. Growth model for northern squawfish was:

$$Y=4.51+1.0 \ln x$$

Walleye and Smallmouth Bass

Walleye and smallmouth bass scale samples were not separated by reservoir due to small sample size. Ages ranged from 1-8 years old (Table 11). The dominant age classes for walleye were 2 to 4 year old, with age four being the most abundant. Smallmouth bass ages ranged from 1-5 and were most abundant at age four (Table 12). No growth rate comparisons were made for walleye and smallmouth bass due to small sample size.

Percent Agreement Between Readers

Percent agreement between the scale readers for northern squawfish was 78 percent when calculated within two years of assigned age. Agreements on first aging were best for fish that were age 7-10, but declined as ages increased. Percent agreement and growth rates of walleye and smallmouth bass were not performed due to small sample sizes (n=99, and n=35, respectively).

Table 8. Tag recovery (Rec.) data for northerem squawfish (NSF), walleye (WAL), and smallmouth bass (SMB), mid-Columbia River, 1993.

	NSF ≥ 250 (mm)		WAL ≥ 250 (mm)		SMB ≥ 200 (mm)	
Reservoir	No.	Rec.	No.	Rec.	No.	Rec.
Priest Rapids Dam Tailrace	58	10	8	0	0	0
Priest Rapids	180	2	10	0	18	0
Rock Island	323	1	29	0	0	0
Rocky Reach	294	2	10	1	1	1
Wanapum	448	2	24	1	5	0
Wells	171	1	10	0	4	0
Total	1474	18	91	2	28	1
Recovered (%)		1.2		2.2		3.6

Table 9. Tag recovery (Rec.) date, and distance traveled for northern squawfish (NSF), walleye (WAL) and smallmouth bass (SMB), mid-Columbia River, 1993.

Reservoir	Species	Julian Date[a] Tagged	Julian Date[a] Rec.	Total Days	Transect Tagged	Transect Rec.	Distance Traveled (km)
Priest Rapids	NSF	103	137	34	530-180	RBPR[b]	8.1
Dam Tailrace	"	103	216	113	530-180	530-170	0.5
" "	"	104	183	79	530-060	RBPR	9.7
" "	"	168	190	22	530-020	RBPR	9.7
" "	"	168	201	33	530-020	RBPR	9.7
" "	"	168	182	14	530-020	RBPR	20.9
" "	"	168	178	10	530-020	RBPR	9.7
" "	"	172	199	27	530-010	RBPR	9.7
" "	"	173	192	19	530-210	RBPR	8.1
" "	"	173	216	43	530-210	530-010	0.5
Priest Rapids	NSF	182	210	28	2130-200	2120-100	12.9
" "	"	112	157	45	2131-030	RATTD[c]	UNK[d]
Wanapum	NSF	117	208	91	2211-030	RATTD	19.3
Rock Island	NSF	125	195	70	2320-110	2310-130	22.5
" "	"	132	182	50	2331-010	2330-160	1.6
" "	WAL	196	227	31	2330-170	2330-UNK	UNK
Rocky Reach	NSF	140	181	41	2420-090	2420-080	0.5
" "	"	143	157	14	2431-010	2430-UNK	UNK
" "	WAL	144	195	51	2430-090	UNK	UNK
" "	SMB	207	208	1	2410-160	2410-060	0.0
Wells	NSF	146	175	29	2510-040	2510-050	0.5
Average		150	190	40			8.5

[a]Julian date is equal to one year (i.e., January 1 = Julian day 1, December 31 = Julian day 365).
[b]RBTR = recaptured below Priest Rapids Dam.
[c]RATTD = recaptured after traveling downstream through at least one dam.
[d]Unknown

Table 10. Age frequency of northern squawfish, by reservoir, mid-Columbia River, 1993.

	Reservoir							
Age	Priest Rapids Tailrace	Priest Rapids	Wanapum	Rock Island	Rocky Reach	Wells	Total	Percent
2	0	0	2	10	13	2	27	3.3
3	0	1	9	16	20	7	53	6.5
4	0	7	11	13	10	10	51	6.3
5	1	3	15	7	13	5	44	5.4
6	2	10	21	26	13	12	84	10.4
7	5	27	26	14	9	14	95	11.7
8	3	30	32	19	10	12	106	13.1
9	7	30	41	13	12	7	110	13.6
10	4	19	40	15	16	6	100	12.3
11	1	19	21	5	5	3	54	6.7
12	1	15	18	3	7	4	48	5.9
13	2	9	7	4	1	2	28	3.5
14	0	6	1	0	2	0	9	1.1
15	0	1	0	1	0	0	2	0.2
Total	26	177	244	146	134	84	811	
Percent	3.2	21.8	30.1	18.0	16.5	10.4		

Table 11. Age frequency by 25 mm fork length increments of walleye, mid-Columbia River, 1993

Fork Length Group	Age									
(mm)	1	2	3	4	5	6	7	8	Total	Percent
200	1								1	1.0
225	2								2	2.0
250	1								1	1.0
275									0	0.0
300									0	0.0
325		4							4	4.1
350		2	1						3	3.1
375			1						1	1.0
400			2						2	2.0
425		1	7	1					9	9.2
450		1	3						4	4.1
475			4	11	1				16	16.3
500			3	5	1				9	9.2
525			1	3	5	6			15	15.3
550				2	7	2			11	11.2
575				2	3				5	5.1
600				1	1	2			4	4.1
625					1	2	1		3	3.1
650					1				2	2.0
675					1			1	2	2.0
700				1		1		1	3	3.1
725						1			1	1.0
Sum	4	8	22	26	21	14	1	2	98	
Percent	4	8	22	27	21	14	1	2		

Table 12. Age frequency by 25 mm fork length increments for smallmouth bass in the mid-Columbia River, 1993.

Fork length group	Age						
(mm)	1	2	3	4	5	Sum	Percent
175						0	0.0
200	1	4				5	14.3
225		2	1			3	8.6
250			3			3	8.6
275			1			1	2.9
300			2	2		4	11.4
325			2	4		6	17.1
350				5	2	7	20.0
375				2	2	4	11.4
400					1	1	2.9
425						0	0.0
150						1	2.9
Total	1	6	9	13	6	35	
Percent	3	17	26	37	17		

Fecundity

Characteristics of female northern squawfish collected were as follows: average fish length of 404.8 mm, fish weight of 1029.6 g, ovary weight in field of 71.4 g, GSI (%) was 4.16, fecundity was calculated to be 26,056. and average egg diameter (Dm) of 1.11 mm. The 53 fish sampled were stratified into 50 mm length increments (Table 13).

Egg Diameter

The average egg diameter from all eggs sampled was 1.11 mm, with a range of 0.25 to 1.99 mm (Table 13). The overall egg diameter suggests a bell shaped frequency distribution, skewed towards the lower diameters (Figure 27). Results from gonad samples collected in the field revealed that 66 percent of our samples were in the developing stage (Table 14).

Spawning Period

Weekly water temperature was graphed against time and accumulative proportion of GSI collected by week (Figure 28). Results indicate that the peak spawning period might have occurred from the last week of June to the first week of July, 1993 at a river temperature of approximately 12^{0}C.

Gonadal Somatic Index

Our results indicate an average GSI was 6.4 percent (Table 15). Gonadal Somatic Index values ranged from 0.3 to 19.0 percent for the 53 northern squawfish examined. We calculated modeled relationships between various size and reproductive variables of gonad samples from northern squawfish. Our results indicate that fish weight was the best predictor of gonad weight (Table 16).

Age and Fecundity

Of the 53 northern squawfish sampled for fecundity estimates, 26 were aged. Northern squawfish age ranged from 5 to 13 years old (Table 17). Overall, fish length and weight increased with age while fecundity characteristics were more variable between ages.

Table 13. Average values of biological characteristics of female northern squawfish used for gonad analysis stratified by fork length group, mid-Columbia River, 1993. Fl=fork length; Wt=weight

Fl Range (mm)	n	Fl (mm)	Wt (g)	Ovary Weight Field-(g)	GSI (%)	Fecundity (no. of eggs)	Average Egg Dm (mm)
276-325	4	290	475	23	4.8	15,342	1.2
326-375	11	355	583	28	4.8	11,927	1.1
376-425	19	406	997	70	6.7	33,521	1.0
426-475	17	451	1384	95	6.7	26,755	1.2
>475	2	500	1925	217	11.2	48,337	0.9
Average		405	1030	71	6.4	26,056	1.1
n		53	53	53	5.3	53	53.0
SD		53	408	66	4.3	21,438	0.4
covariance (%)		13	40	93	67.2	82.3	32.4

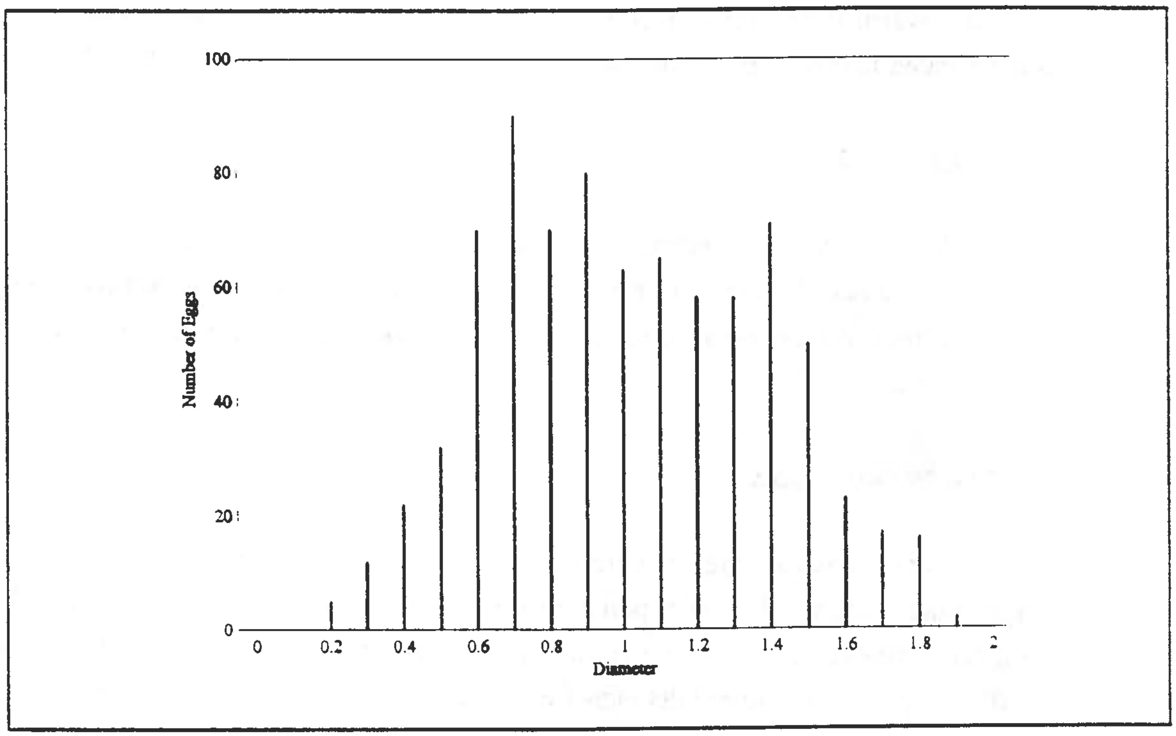


Figure 27. Frequency distribution of egg diameters from 53 northern squawfish (15 eggs per fish) collected from the mid-Columbia River, 1993 (stratified by 0.20 mm increments).

Table 14. Maturity levels of gonad samples from female northern squawfish collected from the mid-Columbia River 1993.

Code	Definition	Number	Percentages
0	Not defined	5	9.4
1	Immature	5	9.4
2	Developing	35	66.0
3	Ripe	5	9.4
4	Spent	3	5.6
Total		53	100

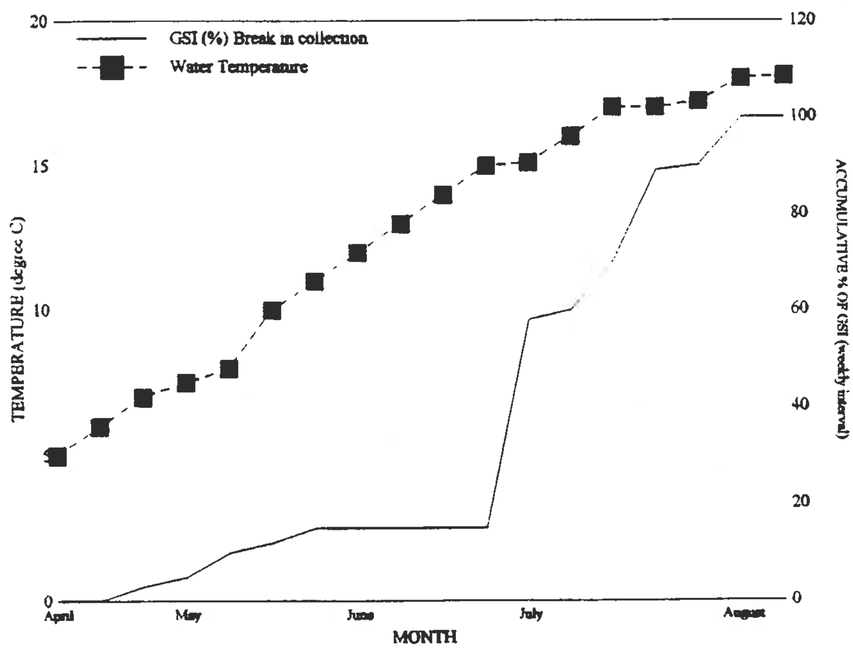


Figure 28. Mean weekly water temperatures and accumulative percentage of Gonadal Somatic Index (GSI) collected by week, from mid-Columbia River, 1993.

Table 15. Modeled relationships between various size and reproductive varible of gonad samples from northern squawfish collected from the mid-Columbia River, 1993. In addition, Vigg and Burley (1990) data has been added for comparison.

Criterion/Predator Variables	Model	Intercept	Slope	df	r	r^2
<u>Fish Weight:</u>						
Fish Length	Linear	-1,810.05	7.02	51	0.91*	0.82
	Ln	14,722.20	2,627.76	51	0.89*	0.79
	Exp	3.66	0.01	51	0.93*	0.86
	Power	-11.16	3.01	51	0.93*	0.85
<u>Fecundity:</u>						
Fish Length	Linear	-20,001.8	113.78	51	0.28*	.0.07
	Ln	-218,912.00	44,202.46	51	0.28*	0.08
	Exp	8.28	0.01	51	0.22	0.86
	Power	0.62	1.53	51	0.23	0.85
Fish Weight	Linear	4,745.85	20.69	51	0.39*	0.15
	Ln	-106,422.00	19,344.67	51	0.40*	0.16
	Exp	9.084,397	0.01	51	0.32*	0.10
	Power	4.89	0.72	51	0.36*	0.12
Fresh Gonad Weight	Linear	14,260.78	165.26	51	0.51*	0.26
	Ln	-14,842.20	10,483.23	51	0.43*	0.18
	Exp	9.44	0.01	51	0.40*	0.16
	Power	8.22	0.41	51	0.40*	0.16
<u>Gonadal Somatic Indes:</u>						
Fish Length	Linear	-0.41	0.02	51	0.19	0.04
	Ln	-30.05	6.03	51	0.19	0.03
	Exp	0.41	0.01	51	0.20	0.04
	Power	-4.85	1.07	51	0.62*	0.39
<u>Fresh gonad Weight:</u>						0.45
Fish Weight	Linear	-41.42	0.11	51	0.67*	0.37
	Ln	-547.42	90.36	51	0.61*	0.58
	Exp	2.22	0.01	51	0.76*	0.57
	Power	-6.14	1.47	51	0.75*	
<u>Preserved Gonad Weight:</u>						
Fresh Gonad Weight	Linear	-4.01	0.70	51	0.90*	0.81
	Ln	-130.90	45.37	51	0.77*	0.59
	Exp	2.50	0.01	51	0.74*	0.55
	Power	-0.47	0.97	51	0.79*	0.64

* Significant at a 0.05

Table 16. Fecundity and Gonadal somatic index (GSI) results from northern squawfish collected from Oregon, Idaho and Washington

Agency/State	Fecundity Average ± 95% CI	Fecundity Range	GSI (%) Average ± 95% CI	GSI (%) Range	Source
WDFW[a]	26,056±5,911	1,639 - 109,321	6.4±1.2	0.3 - 19.0	This study
Washington	---[b]	6,037 - 95,089	9.9±---	---	Olney, 1975
ODFW[c]	50,521±---	8,337 - 114,781	9.8±---	---	Bigg and Burley, 1990
ODFW	---	---	7.0±---	---	Vigg
Idaho	20,136±---	2,700 - 75,115	---	---	Reid, 1971
Idaho	40,000±---	12,000 - 100,000	---	---	Jeppson and Platts, 1959
Idaho	---	---	---	2.0 - 11.0	Beamesderfer, 1992
Idaho	---	4,000 - 59,000	---	---	Casey, 1962
Idaho	--	---	---	5.0 - 16.0	Beamesderfer, 1983

[a]Washington Department of Fish and Wildlife
[b]Data not available
[c]Oregon Department of Fish and Wildlife

Table 17. Age and decundity characteristics of 26 female northern squawfish caputured on the mid-Columbia River, 1993.

Age	Sample Size	Mean Fork Length (mm)	Mean Fish Weight (g)	Mean Fecundity (no. eggs)	Mean Egg Diameter (mm)	Mean GSI (%)
5	1	(284)	(340)	(12343)	(1.22)	(7.88)
6	--	--	--	--	--	--
7	--	--	--	--	--	--
8	2	315	530	7723	1.30	6.93
9	3	365	683	17697	0.90	4.80
10	8	416	1131	44309	1.13	10.50
11	3	444	1348	10175	1.18	6.91
12	5	431	1245	18837	1.07	7.49
13	4	463	1434	21912	1.46	7.06

Catch

Results indicate northern squawfish and walleye were captured in greater numbers within tailrace areas. In contrast, most smallmouth bass were captured in forebay areas. One reason for northern squawfish and walleye capture being high in tailrace areas is due to the high concentration of prey. Juvenile salmonid emigrants are usually disorientated following passage and are vulnerable to predation. Smallmouth bass are "lie-in-wait" predators (Moyle and Cech 1988), explaining their presence in the slower flowing waters of the forebay areas. Locations of highest captures of northern squawfish were Priest Rapids, Wanapum and Wells tailrace areas whereas, walleye were more abundant at Wanapum and Rocky Reach tailrace areas.

Gear type effectiveness varied in success rate. For example, electroshocking was more effective at capturing predator fish than both bottom and surface gillnetting. Bottom gillnets were the most effective gear type for capturing walleye. An explanation for the increased effectiveness of the bottom gillnet for walleye over the other gear types may by because walleye are opportunistic bottom or near bottom dwelling predators (Wydoski and Whitney, 1979). Conversely, surface gillnets extending only 2.4 meters down into the water column were minimally effective in capturing walleye.

Although sample size was small, our tag recovery results suggest that some movement by predators within and between reservoirs occurred throughout the sampling season. All predators that had been tagged and recovered had moved downriver.

Age and Growth

Our results indicated no difference in growth of northern squawfish by reservoir. Yet, age composition of northern squawfish differed between reservoirs. Larger and older fish were found in lower reservoirs versus younger and smaller fish in the upper reservoirs.

Gillnets were size selective. Gillnet mesh sizes used during field sampling selected for fish greater than 200 mm FL. Also, we found electrofishing was less effective at stunning smaller fish. Consequently, we sampled few small fish. As a result, age composition for northern squawfish by reservoir may be biased toward older and larger fish. Few walleye and smallmouth bass were captured to allow inferences about growth rates.

We found differences in the percent agreement of age assignments for northern squawfish by the two readers. Because of the subjectivity in aging, caution should be used when basing conclusions on these findings.

Fecundity

Our laboratory analysis of northern squawfish indicated a high variability of ovum development within each sample (overall covariance of 32.4 %). Similarly, Vigg and Burley (1990), found variability in egg diameters and suggested northern squawfish ovaries contained eggs in various stages of development just prior to spawning.

Northern squawfish have eggs in their maturing oocytes that are in various states of development, eggs are usually barely distinguishable from reserve oocytes, to those approaching running-ripe condition. This differential gonadal development can make fecundity estimates difficult to determine and suggests that northern squawfish maybe multiple or batch spawners. Snyder (1983), hypothesized that fecundity can be difficult to determine for multiple or batch spawning species in which batches of maturing oocytes are likely to be in various states of development. When determining fecundity from immature gonads, oocyte counts could be overestimated, due to small oocyte size. Collection of only ripe gonad samples for fecundity estimates could lead to inaccurate fecundity estimates, because a partial spawn could have occurred before capture, resulting in underestimation in the lab. Further study is needed in this area.

The egg size of northern squawfish could not be correlated with any fish variables. Average egg diameters tended to be consistent throughout all size ranges, even though, egg diameters within each sample tended to be much more variable. The variability of egg diameters within each individual sample, indicated that northern squawfish have eggs in different developmental stages in their egg sacks.

For northern squawfish, average GSI (6.4 %) results were lower than previous GSI studies. Olney (1975), found GSI to be 9.9 percent for northern squawfish, where Vigg and Burley (1990) reported 9.8 percent for GSI of northern squawfish sampled from the Columbia River. The low GSI results may be partially explained by our small sample size.

LITERATURE CITED

Bagenel, T.B. and F.W. Tesch 1978. Age and Growth. In: Methods for assessment of fish production in fresh waters. T. Bagenel [editor]. Blackwell Scientific Publication, Oxford London Edinburgh Melbourne. Third edition. pp. 101-136.

Beamesderfer, R.C. 1983. Reproductive biology, early life history, and microhabitat of northern squawfish,(*Ptychocheilus oregonensis*) in the St. Joe River, Idaho. Master's thesis. University of Idaho, Moscow Idaho, USA. 144pp.

Beamesderfer, R.C. 1992. Reproduction and early life history of northern squawfish (*Ptychocheilus oregonensis)*, in Idaho's St. Joe River. Environmental Biology of Fishes 00:00-00,1992.

Beamish, R.J. and D.A. Fournier 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fish and Aquatic Sciences. 38:982-983.

Casey, O.S. 1962. The life history of the northern squawfish in Cascade reservoir. Master's thesis. University of Idaho, Moscow, Idaho.

Hill, C.W. 1962. Observations of the life history of the peamouth (Mylocheilus *caurinus*) and the northern squawfish (*Ptychoceilus oregonensis*)in Montana. Proceedings of the Montana Academy of Science. 22:27-44.

Jeppson, P. 1957. The control of squawfish by use of dynamite, spot treatment, and reduction of lake levels. Progressive Fish Culturist 19(4):168-171.

Jeppson, P.W. and W.S. Platts, 1959. Ecology and control of Columbia squawfish in northern Idaho lakes. Transactions of the American Fisheries Society 88:197-202.

Kennedy, W.A. 1970. Reading scales to age pacific cod from Hecate strait. Fisheries Research Board of Canada. Volume 27(5): 915-922.

Knutsen, Chris. Personal communication 1993. Oregon Department of Fish and Wildlife, Clackamas, OR.

Moyle, P.B., and Cech, J.J. Jr. 1988 Fishes. An introduction to ichthyology. Prentice Hall, Englewood Cliffs, New Jersey. pp. 12.

Olney, F.E. 1975. Life history of the northern squawfish, *(Ptychocheilus oregonensis)* (Richardson), in Lake Washington. Master's thesis. University of Washington, Seattle, Washington, USA. 75 pp.

Olson, D.E. and T.A. Rien 1987. Methods of aging northern squawfish. Oregon Department of Fish and Wildlife, Dam and Hydro Studies Program, Columbia River Predatory-Prey Studies, March 1987. Unpublished Report.

Patten, B.G., and D.T. Roman. 1969. Reproductive behavior of the northern squawfish, *(Ptychocheilus oregonensis)*. Transactions of the American Fisheries Society 98(1):108-111.

Reid, G.E. 1971. Life history of the northern squawfish, (*Ptychocheilus oregonensis*) (Richardson), in the St. Joe River, Idaho. Master's thesis. University of Idaho, Moscow, Idaho, USA. 61 pp.

Snyder, D.E. 1983. Fish Eggs and Larvae. In: Nielsen L.A. and Johnson D.L. [editors.] Fisheries Techniques. American Fisheries Society. Southern Printing Company, Inc., Blacksburg, Virginia. pp.165-197.

Vigg, S. and C.C. Burley. 1990. Developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River Basin. Final report December 1990. Contract DE-A179-88BP92122, Bonneville Power Administration, Portland, OR.

*Vigg, S., L.A. Pendergast, and W.R. Nelson. 1986. Unpublished Masters thesis. Gonad development and spawning of northern squawfish in a mainstem Columbia River Reservoir. USFWS - Columbia River Field Station, Cook, Washington.

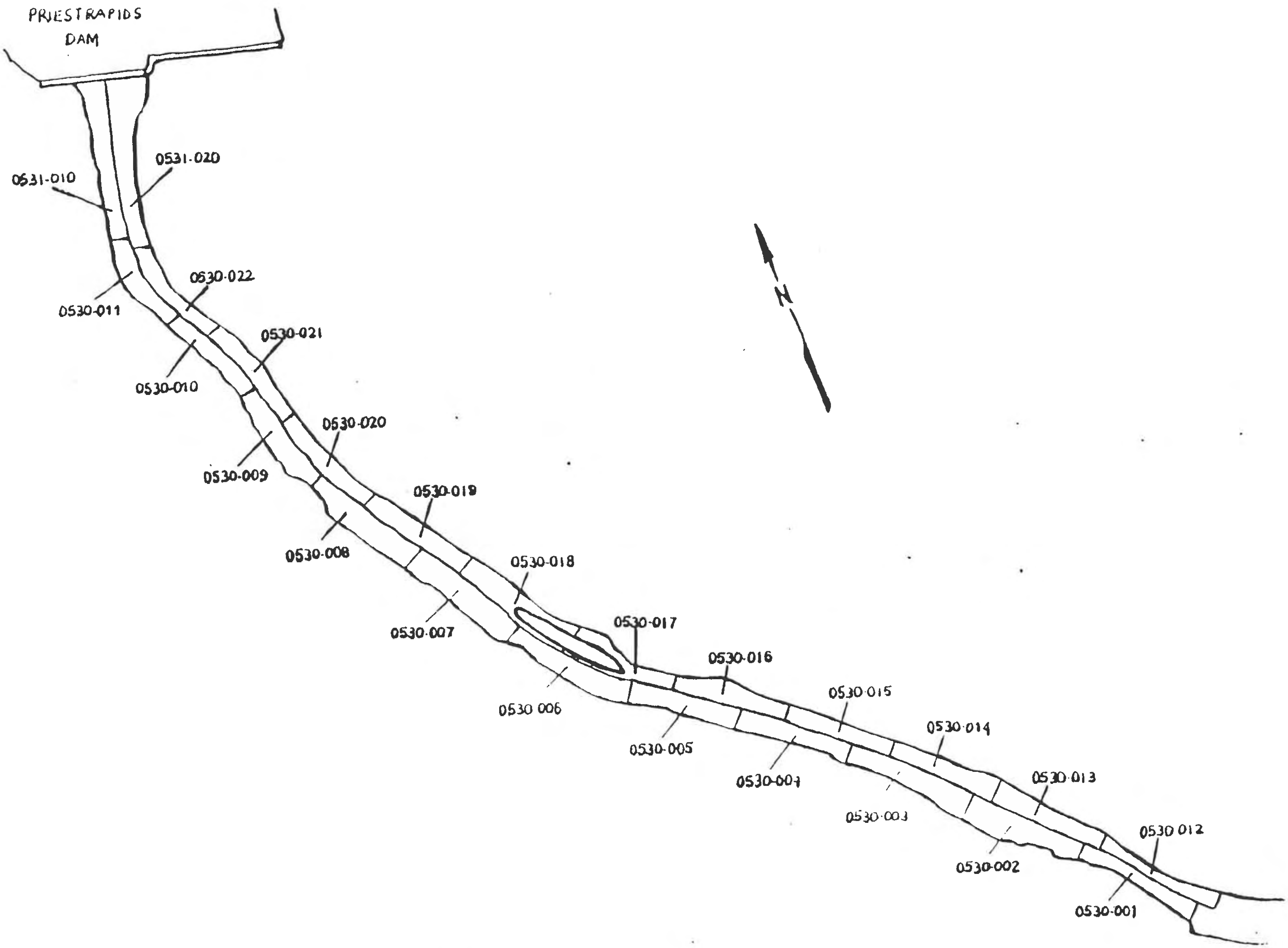
Willis, C.F., A.A. Nigro, B.L. Uremovich, J.C. Elliott, and W.J. Knox. 1985. Abundance and distribution of northern squawfish and walleye in John Day Reservoir and Tailrace, 1982. Annual Report to Bonneville Power Administration by Oregon Department of Fish and Wildlife, contract Number DE-AI79-82BP35097, Portland, Oregon, USA.

Wolfert, D.R. 1969. Maturity and fecundity of walleyes from the eastern and western basins of Lake Erie. Journal of the Fisheries Research Board of Canada 26:1877-1888.

Wydoski, R.S., and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press.

Zar, J.H. 1974. Biostatistical Analysis. Prentice-Hall, Inc. Englewood Cliffs, N.J. 620 p.

Transect locations sampled by
Washington Department of Fish and Wildlife
and
National Biological Survey
during the
mid-Columbia River Predation Index Study
1993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0530-021
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0530-019
0530-008
0530-018
0530-007
0530-017
0530-016
0530 006
0530-015
0530-005
0530-014
0530-004
0530-013
0530-003
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0530-002
0530-001
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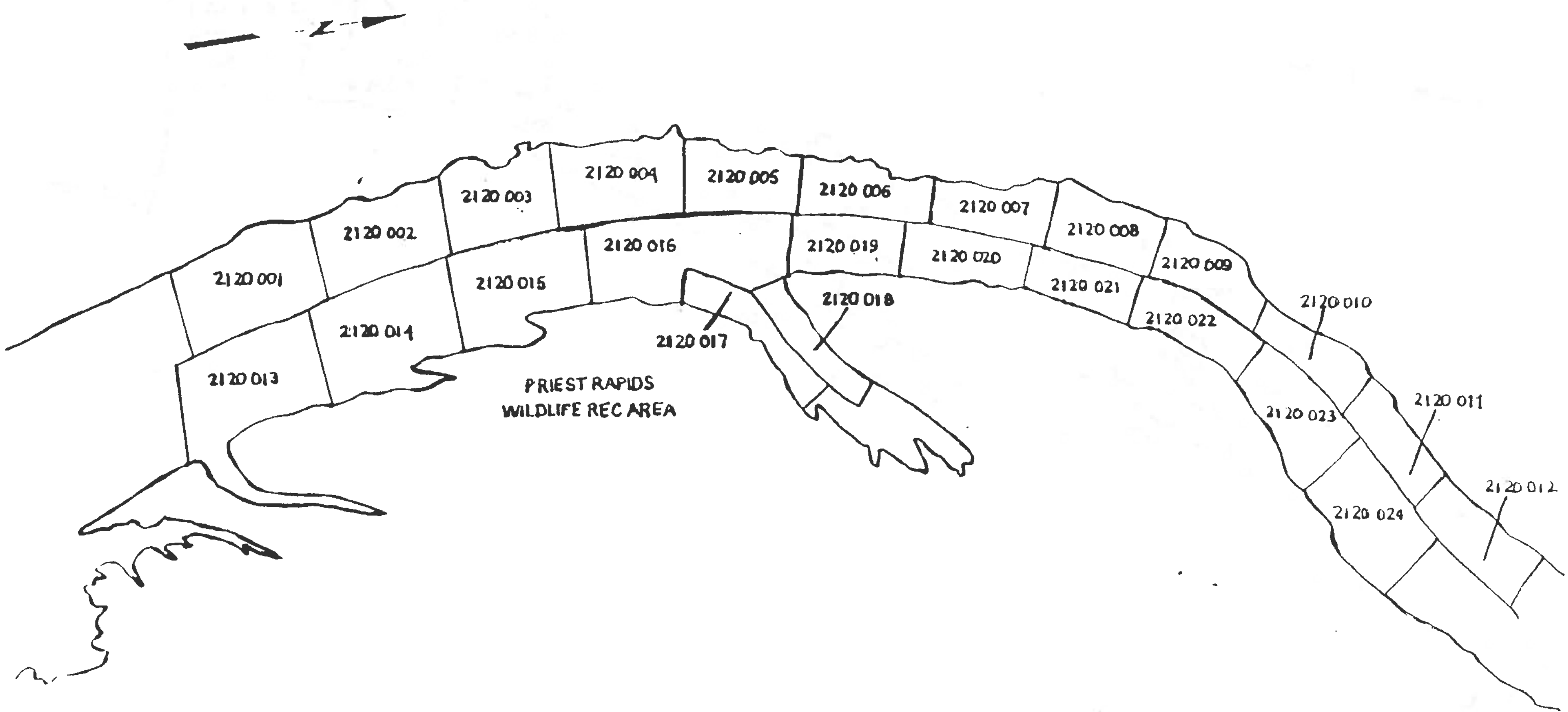
Figure 2. Northern squawfish abundance indexing location codes, Priest Rapids forebay, 1993.



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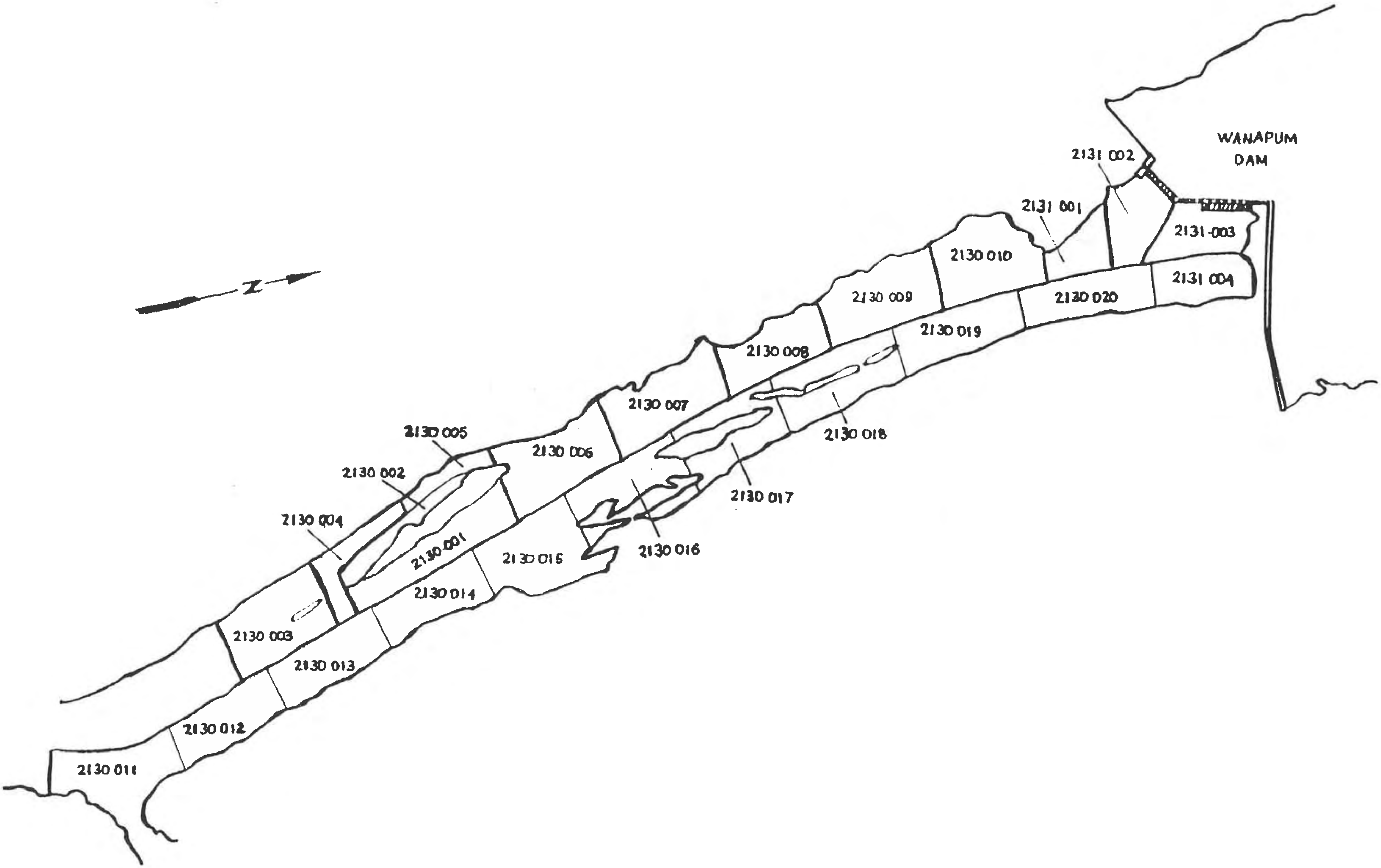
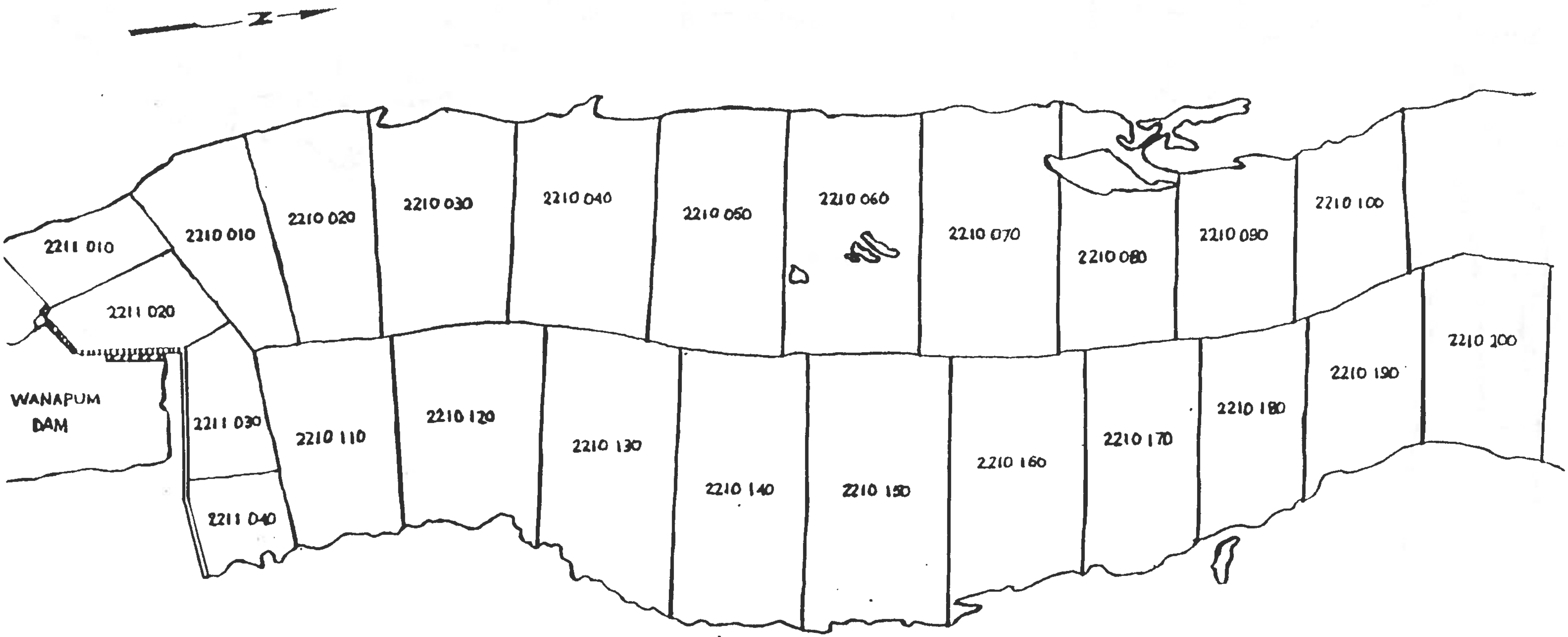


Figure 4. Northern squawfish abundance indexing location codes, Wanapum tailrace, 1993.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2211 020
WANAPUM
DAM
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2211 040
2210 010
2210 020
2210 030
2210 040
2210 050
2210 060
2210 070
2210 080
2210 090
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2210 200

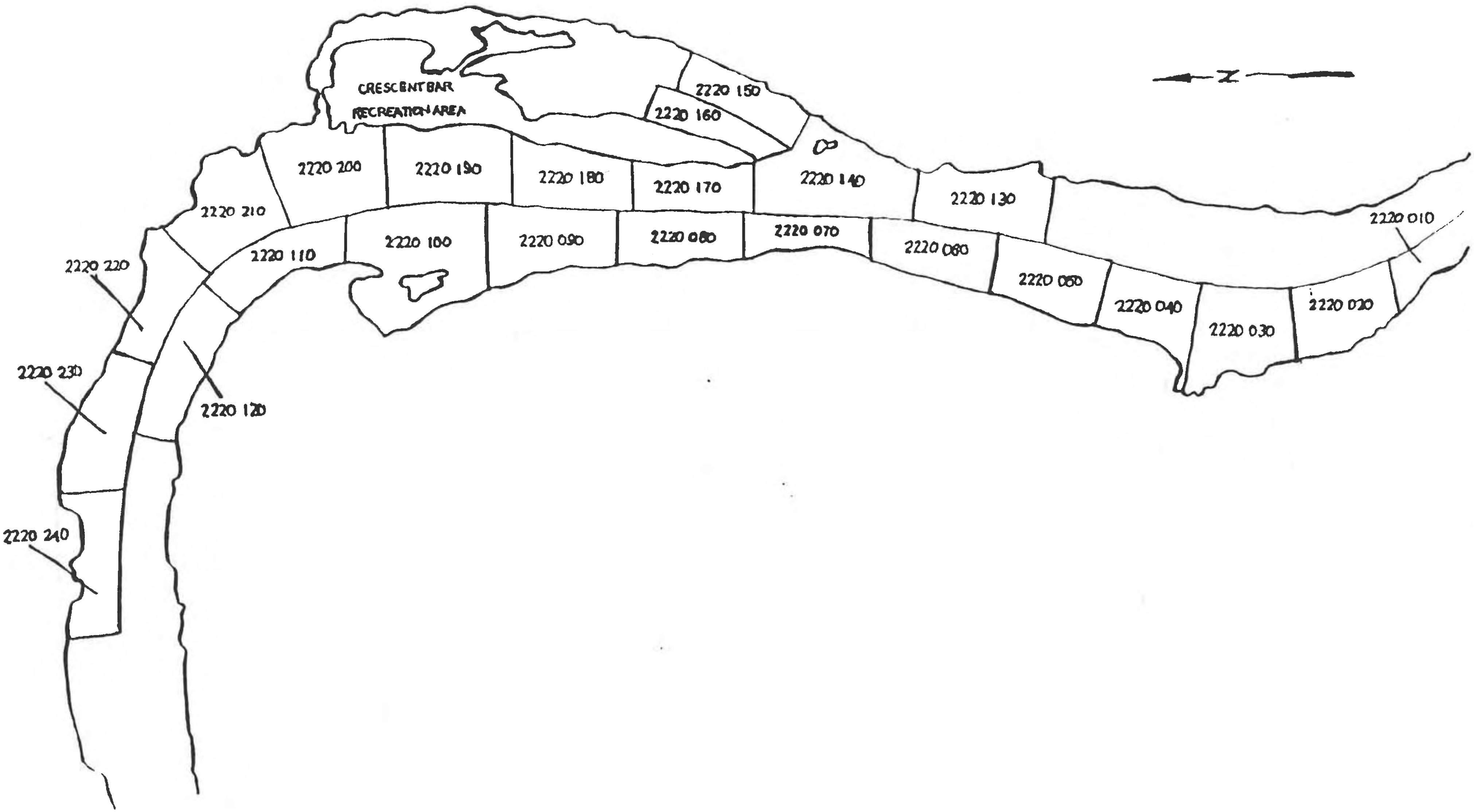
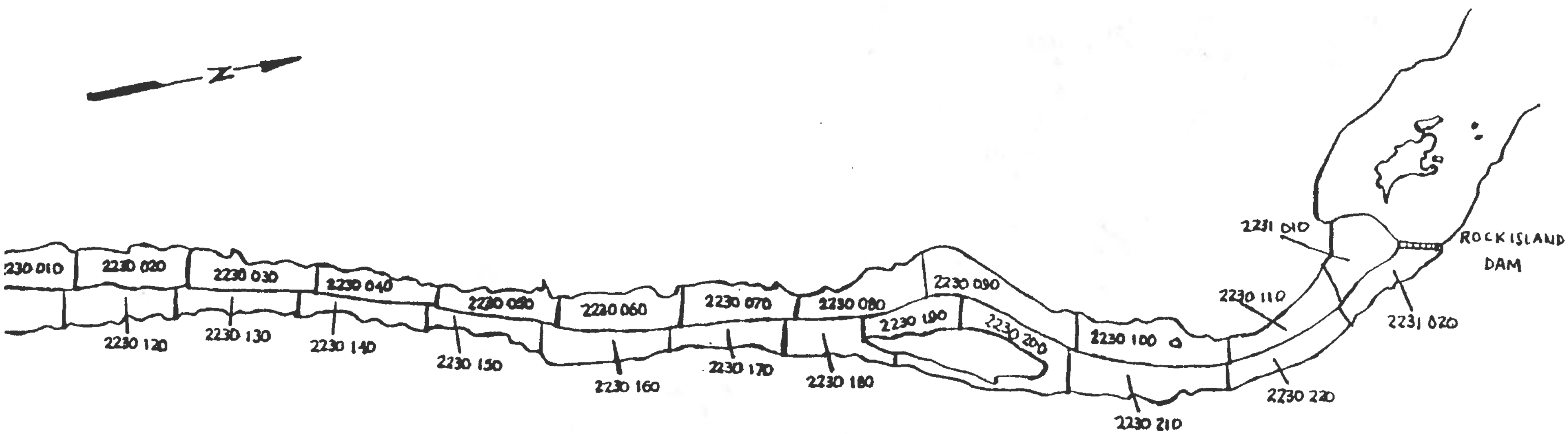


Figure 6. Northern squawfish abundance indexing location codes, Wanapum mid-reservoir, 1993.


N
ROCK ISLAND
DAM
2231 010
2231 020
230 010
2230 020
2230 030
2230 040
2230 050
2230 060
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2230 080
2230 090
2230 100
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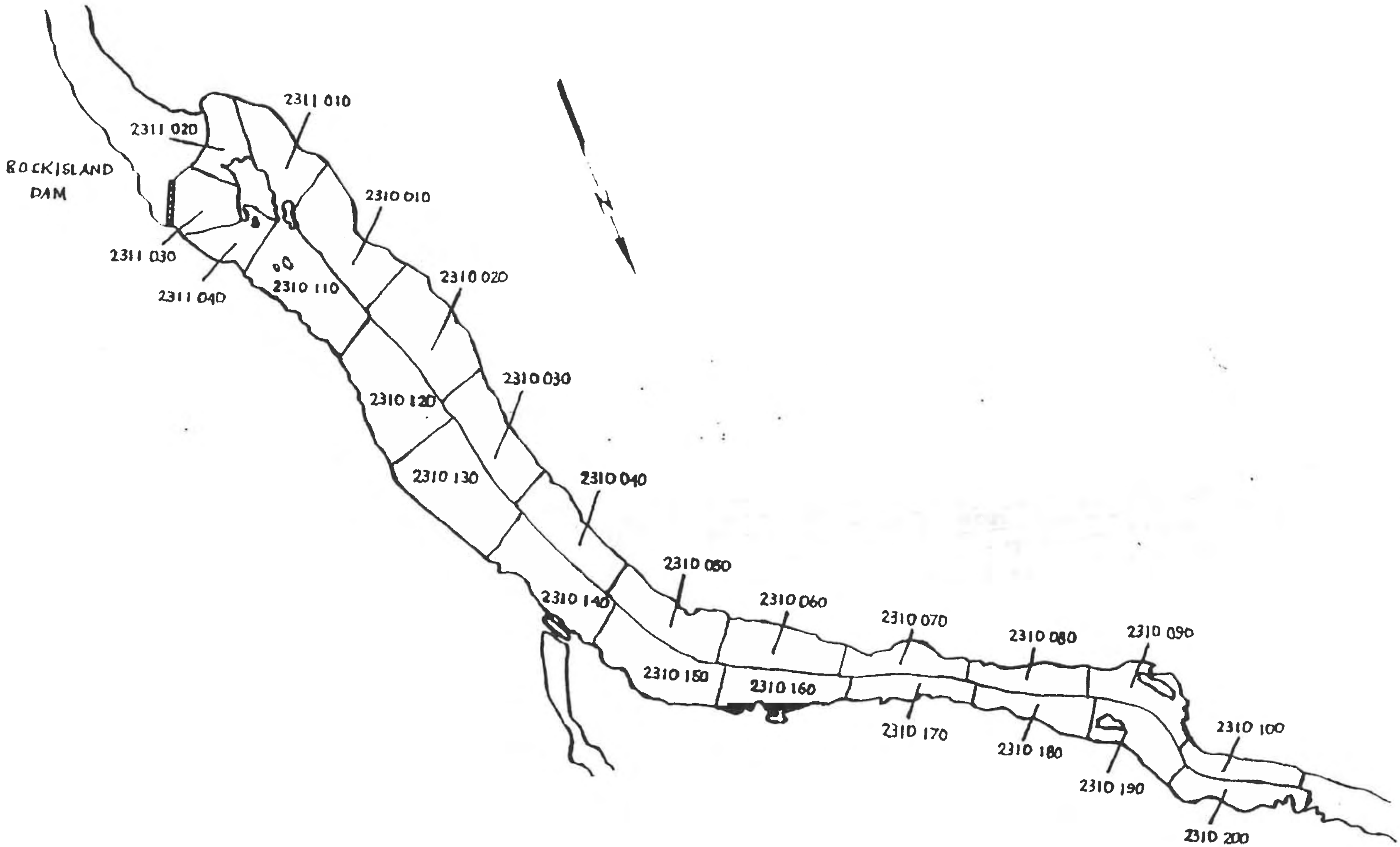


Figure 8. Northern squawfish abundance indexing location codes, Rock Island forebay, 1993.

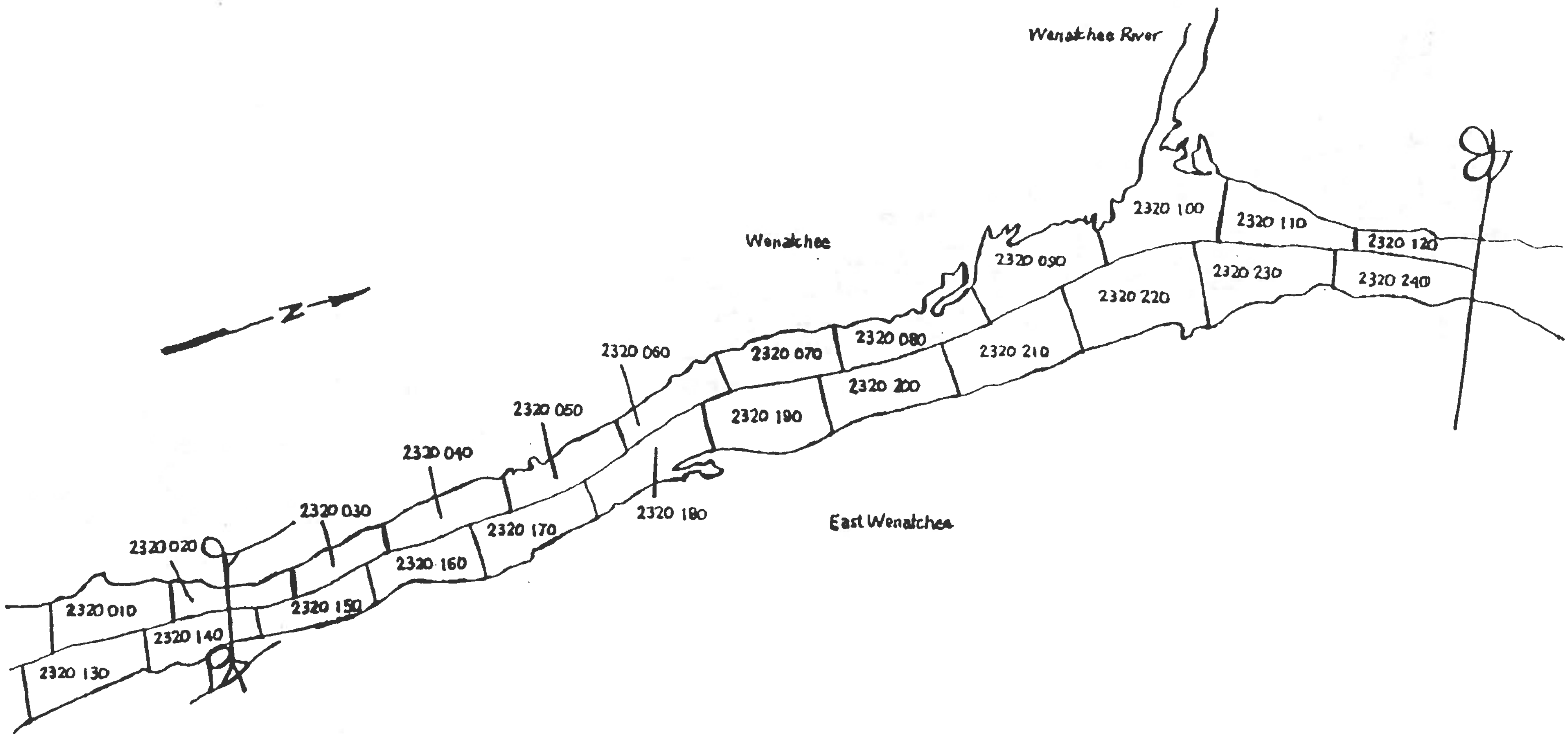


Figure 9. Northern squawfish abundance indexing location codes, Rock Island mid-

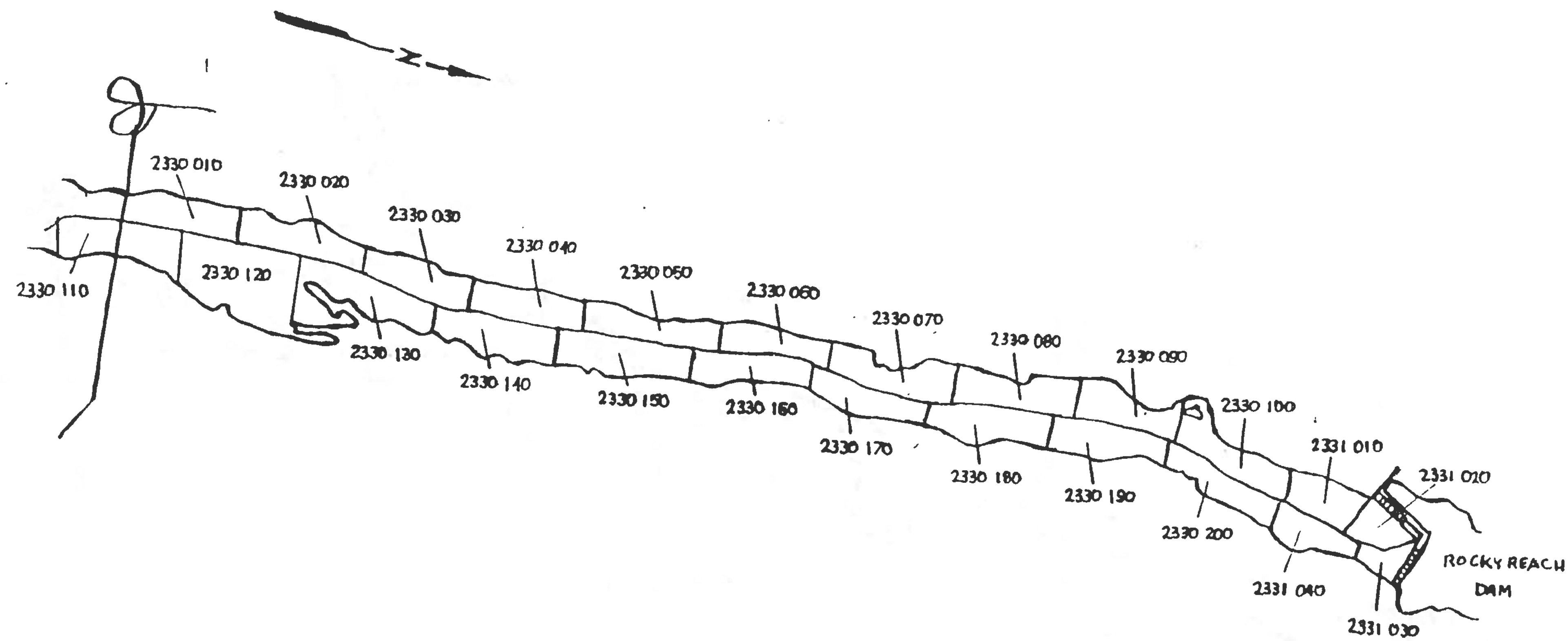


Figure 10. Northern squawfish abundance indexing location codes, Rocky Reach tailrace, 1993.

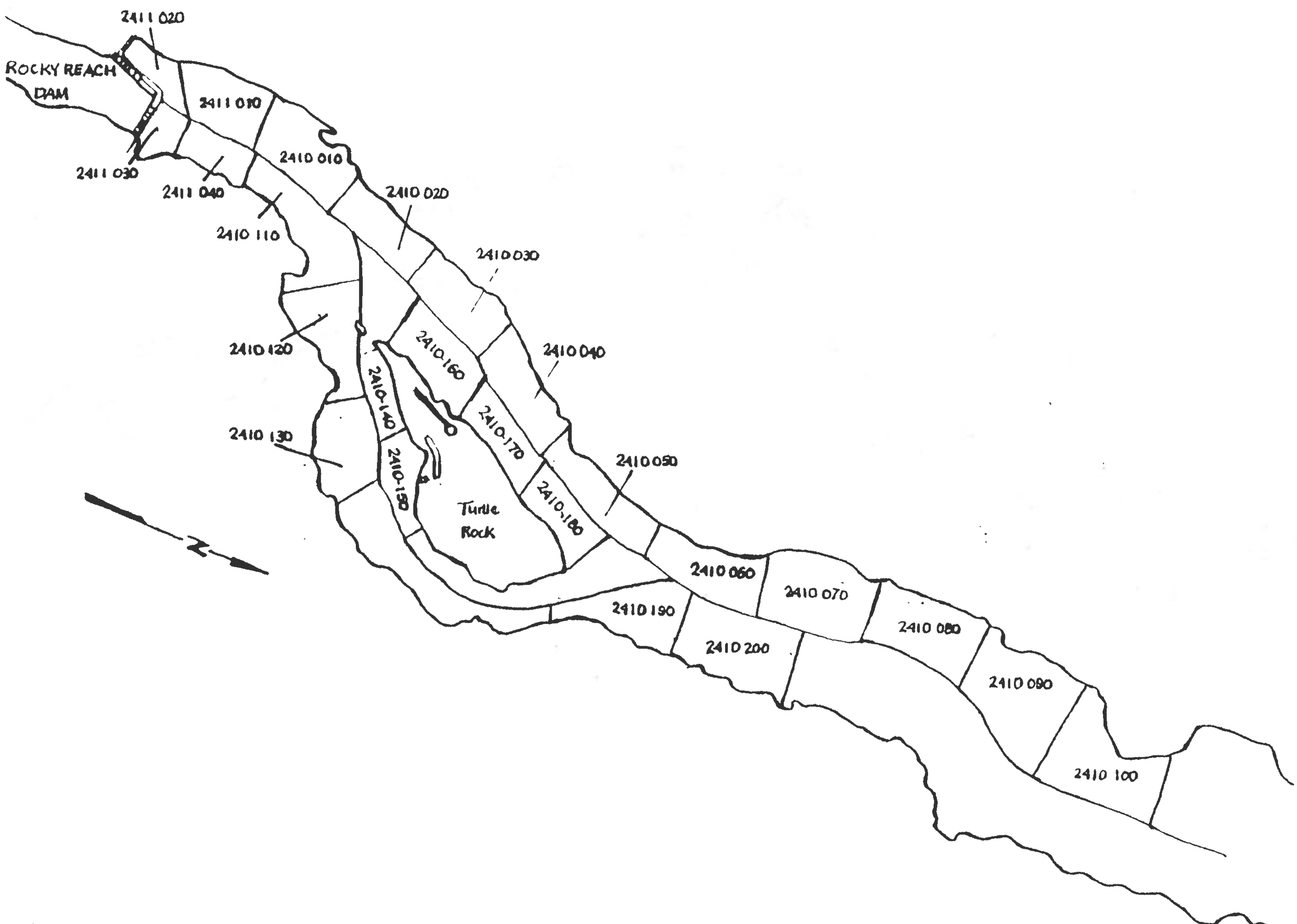


Figure 11. Northern squawfish abundance indexing location codes, Rocky Reach forebay.

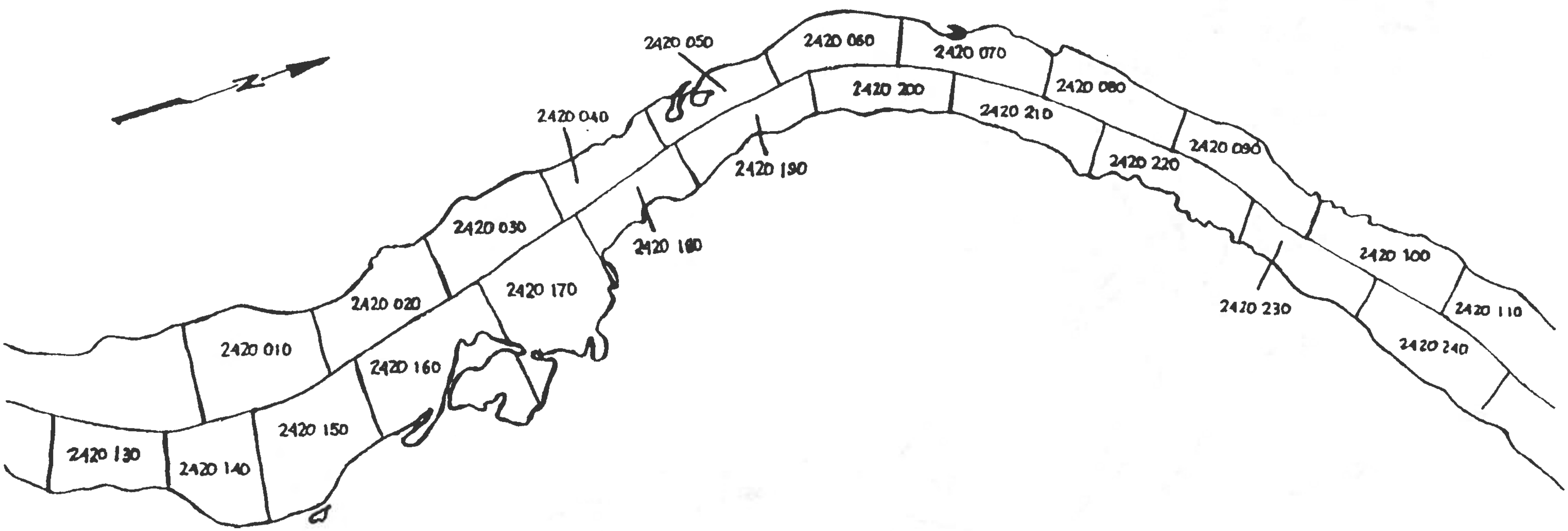
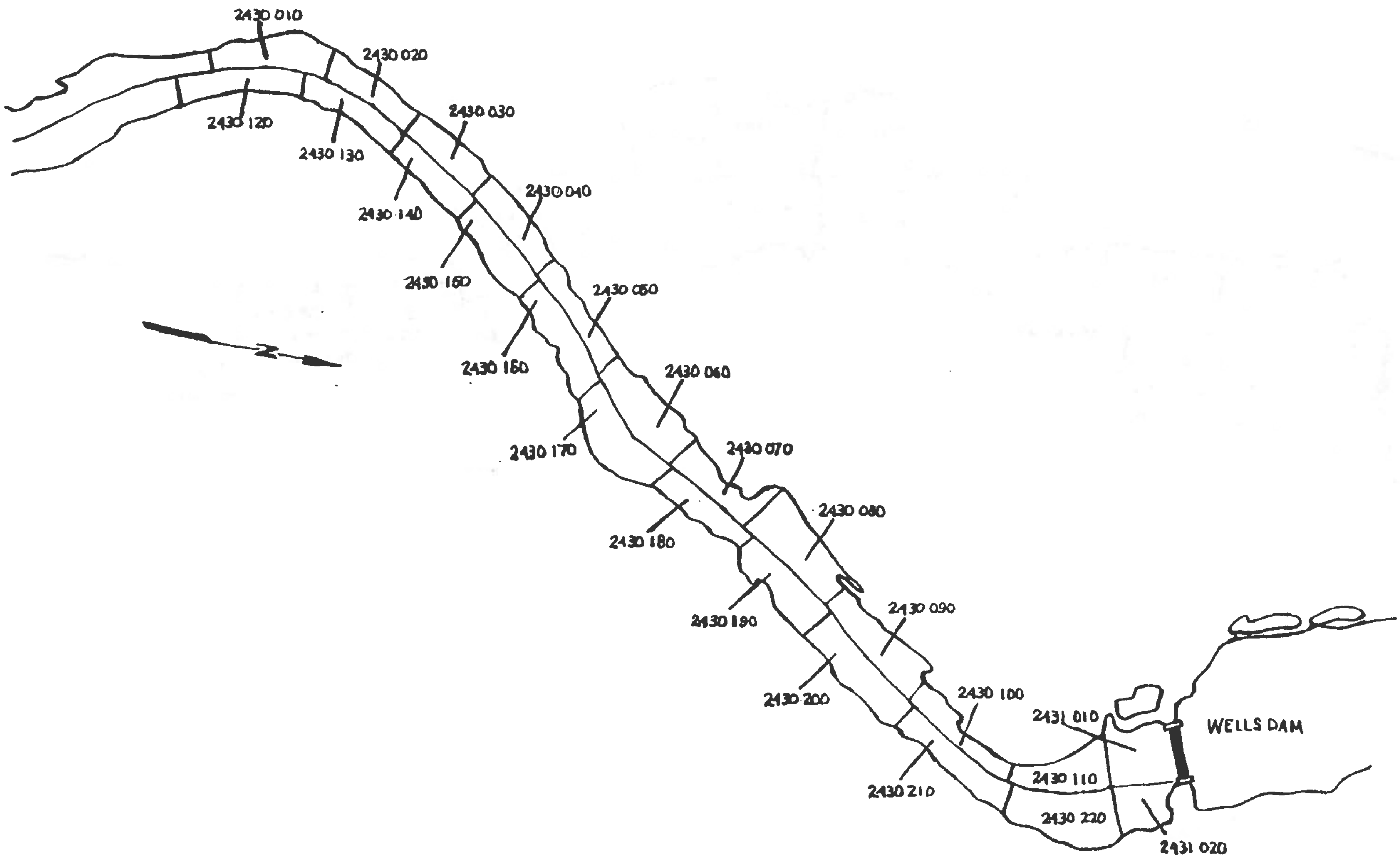


Figure 12. Northern squawfish abundance indexing location codes, Rocky Reach mid-reservoir, 1993.



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2430 010
2430 020
2430 030
2430 040
2430 050
2430 060
2430 070
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2430 100
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2430 210
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N

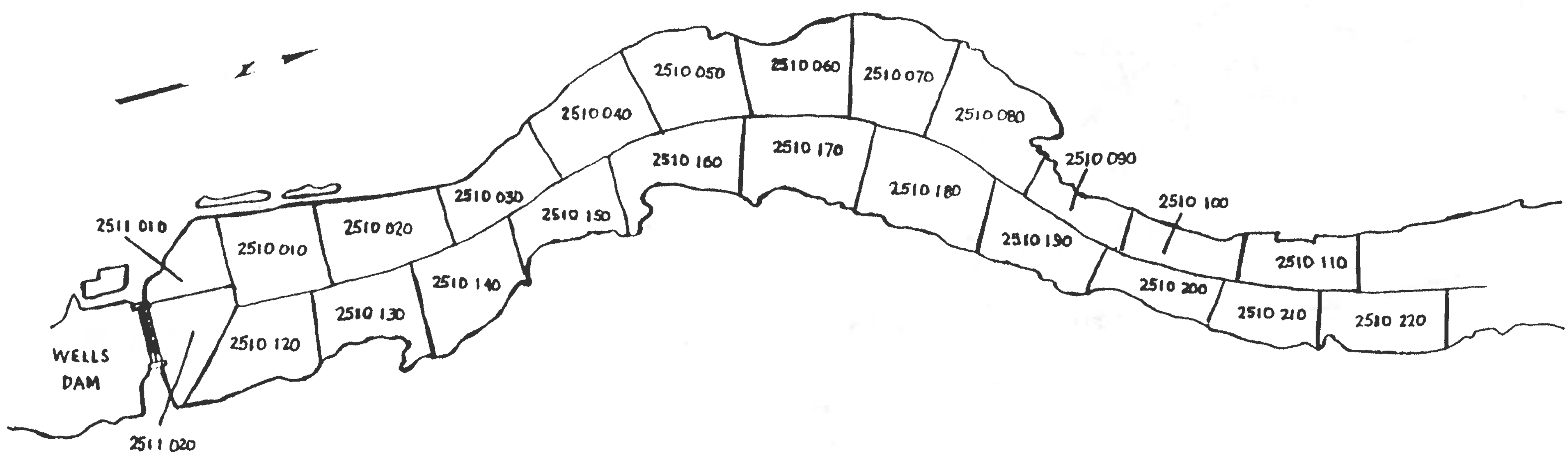
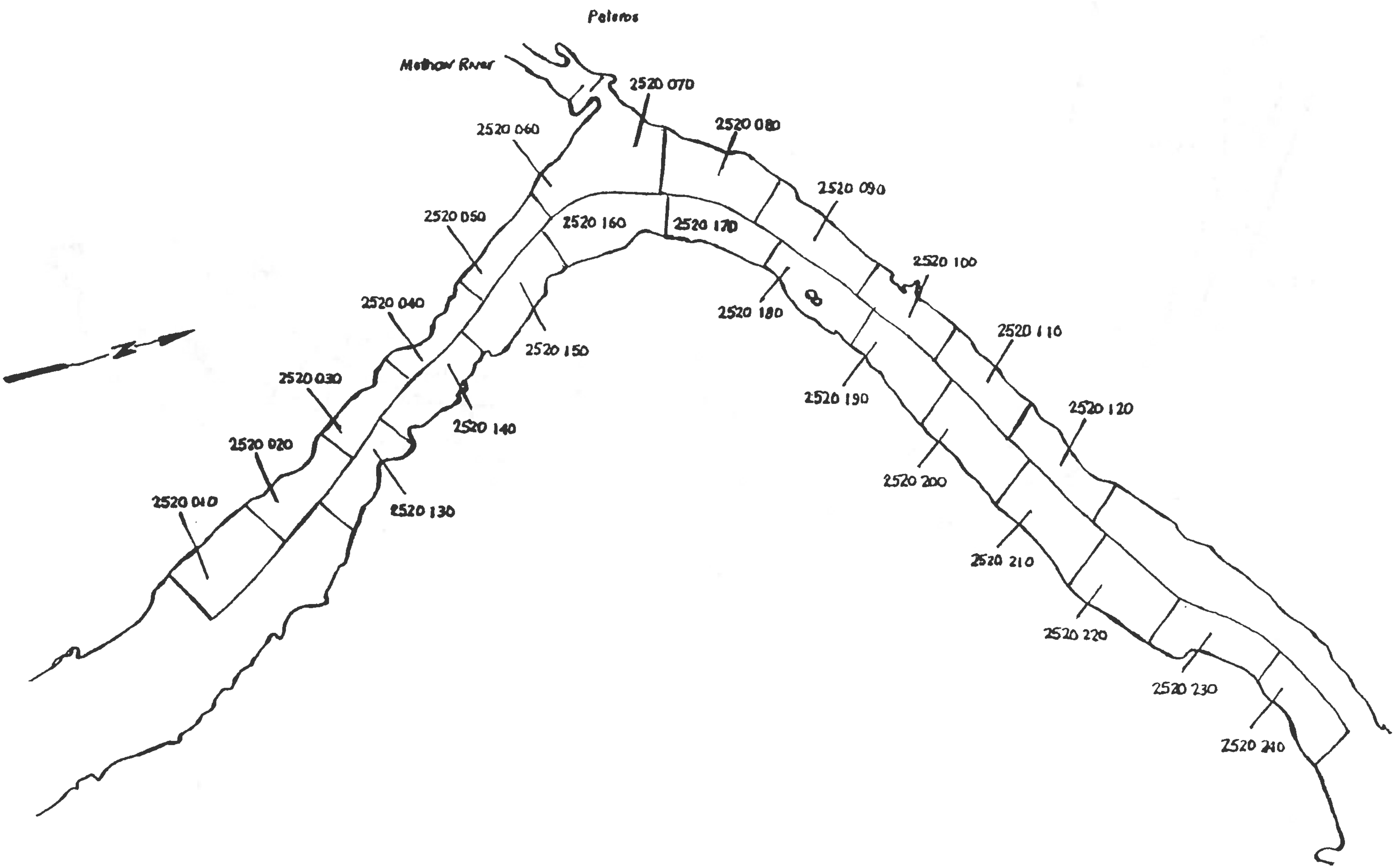


Figure 14. Northern squawfish abundance indexing location codes, Wells forebay, 1993.



Pateros
Methow River
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2520 020
2520 030
2520 040
2520 050
2520 060
2520 070
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2520 100
2520 110
2520 120
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2520 230
2520 240
8

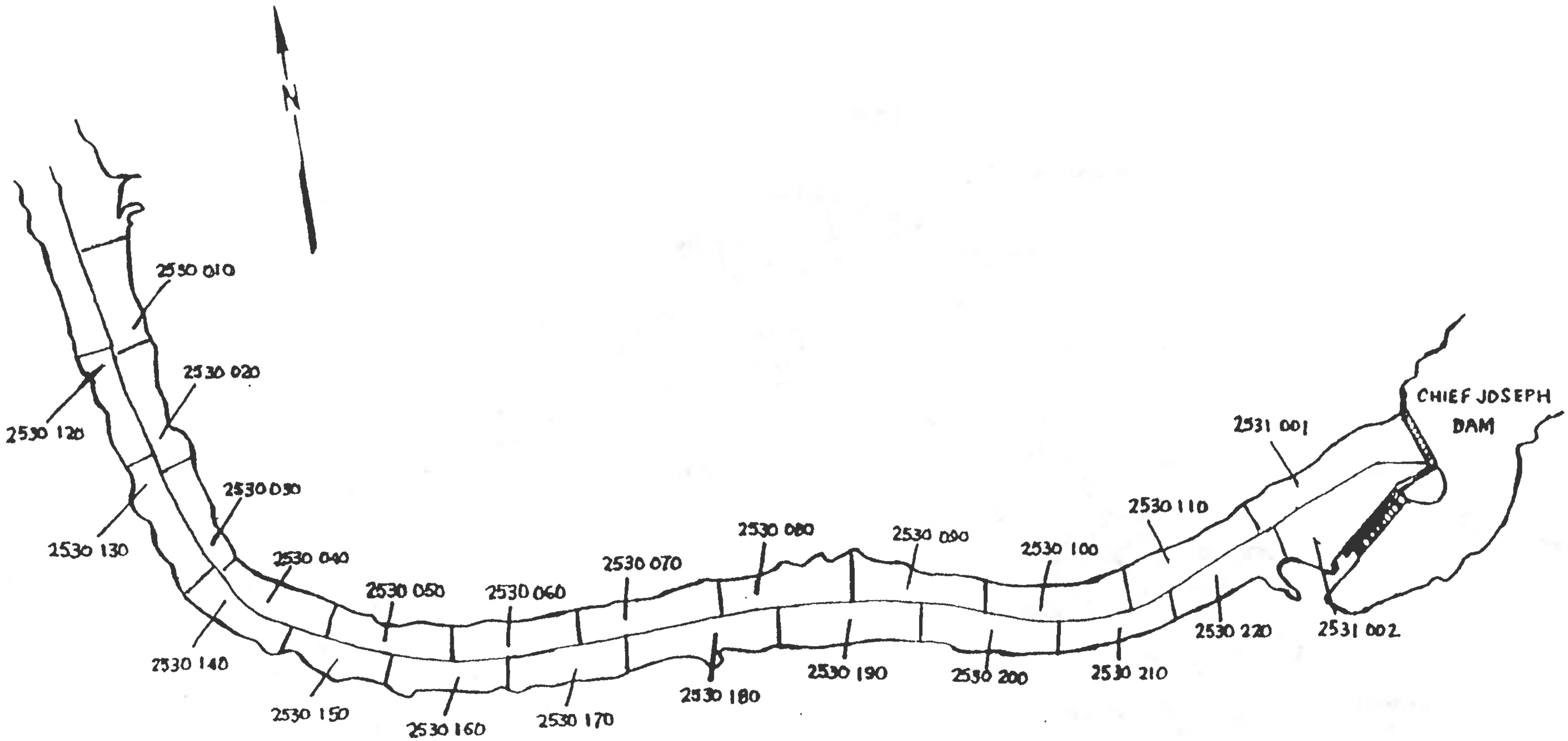

Figure 16. Northern squawfish abundance indexing location codes, Chief Joseph tailrace, 1993.

Fish identified and incidental species counted by
Washington Department of Fish and Wildlife
during the mid-Columbia River Predation Index Study
1993

Appendix C-1 Fish identified by Washington Department of Fish and Wildlife mid-Columbia Predator Index Study, 1993

Species Code	Common Name	Scientific Name
AMS	American shad	*Alosa sapidissima*
BG	Bluegill	*Lepomis macrochirus*
BRS	Bridgelip sucker	*Catostomus columbianus*
BT	Brown trout	*Salmo trutta*
BUR	Burbot	*Lota lota*
C	Crappie (species unidentified)	*Pomoxis spp.*
CK	Chinook salmon	*Oncorhynchus tshawytscha*
CMO	Chiselmouth	*Acrocheilus alutaceus*
CO	Coho salmon	*Oncorhynchus kisutch*
COT	Sculpin (species unidentified)	*Cottus spp.*
CP	Carp	*Cyprinus carpio*
CT	Cutthroat trout	*Salmo clarki*
DB	Bull trout/Dolly Varden	*Salvelinus malma*
EB	Eastern brook trout	*Salvelinus fontinalis*
HYB	Northern squawfish X Chiselmouth hybrid	*P. oregonensis X A. alutaceus*
HYB	Northern squawfish X Peamouth hybrid	*P. oregonensis X M. caurinus*
LMB	Largemouth bass	*Micropterus salmides*
LNS	Longnose sucker	*Catostomus catostomus*
LRS	Largescale sucker	*Catostomus macrocheilus*
LW	Lake whitefish	*Coregonus clupeaformis*
MRS	Margined sculpin	*Cottus marginatus*
NSF	Northern squawfish	*Ptchocheilus oregonensis*
PS	Pumpkinseed	*Lepomis gibbosus*
RS	Redside shiner	*Richardsonius balteatus*
RU	Rainbow trout	*Oncorhynchus mykiss*
SA	Pacific salmon (species unidentified)	*Oncorhynchus spp.*
SH	Steelhead	*Oncorhynchus mykiss*
SK	Sucker (species unidentified)	*Catostomus spp.*
SMB	Smallmouth bass	*Micropterus dolomieui*
SO	Sockeye salmon	*Oncorhynchus nerka*
TNC	Tench	*Tinca tinca*
TSS	Three-spined stickelback	*Gasterosteus aculeatus*
WAL	Walleye	*Stizostedion vitreum*
WF	Whitefish	*Prosopium williamsoni*
WS	White sturgeon	*Acipenser transmontanus*
YP	Yellow perch	*Perca flavescens*

Appendix C-2 Incidental species counted by Washington Department of Fish and Wildlife mid-Columbia Predator Index Study, 1993.

	Reservoir						
Speicies	Priest Rapids Tailrace	Priest Rapids	Wanapum	Rock Island	Rocky Reach	Wells	Total
AMS	67	0	0	0	0	0	67
BG	0	0	10	0	0	0	10
BRS	6	19	64	49	30	46	214
BT	0	0	0	0	0	2	2
BUR	0	0	0	0	1	3	4
C	0	8	9	0	1	0	18
CK	0	23	0	9	78	8	120
CK (juv)	17	43	0	18	0	1	79
CMO	21	1	5	46	471	45	589
CMO (juv)	0	0	5	100	100	0	205
CO	1	0	0	0	1	0	2
COT	0	0	4	3	47	207	261
CP	12	42	20	21	141	75	311
CP (juv)	0	1	0	0	0	0	1
CT	0	0	0	1	0	0	1
DB	0	0	0	0	1	0	1
EB	0	0	0	0	1	0	1
HYB	0	0	1	3	9	2	15
LMB	0	0	1	1	2	0	4
LNS	0	25	1	0	24	24	74
LRS	19	784	456	509	235	302	2305
LW	18	6	4	5	27	7	67
MRS	0	0	0	1	0	0	1
PMO	31	1	29	20	125	14	220
PS	0	0	1	0	0	0	1
RS	0	26	125	2	132	45	330
RU	0	0	1	3	3	3	10
SA	0	19	149	59	131	53	411
SA (juv)	0	466	1189	439	300	7	2401
SH	13	16	16	11	80	17	153
SH (juv)	0	0	0	2	0	0	2
SK	597	2873	1558	2191	3681	1632	12532
SK (juv)	0	91	30	103	109	124	457
SMB (juv)	0	0	0	0	0	33	33
SO	1	233	38	132	139	6	549
TNC	0	0	9	3	8	2	22
TSS	0	30	0	0	2	0	32
WF	271	45	2	26	9	39	392
WF (juv)	1	0	0	4	0	0	6
WS	4	0	0	0	0	0	4
YP	0	0	5	0	0	1	6
Total	1150	5007	3869	4142	6490	2926	23584

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Mid-Columbia River Fishery Resource Office

P.O. Box 549
Leavenworth, WA 98826

Phone: (509) 548-7573

MEMORANDUM July 21, 1994

To: Stuart Hammond, Grant PUD

From: Brian Cates

Subject: Draft 1993 Mid-Columbia River Predator Index Study

Although I have been on vacation the last couple of weeks I felt a need to make a few comments on the draft Predator Index Study. I apologize for not making the July 20 deadline. My comments are intended not as a critique of the work done, but as identifying information needed to help the committee decide how to apply the results of the study.

Several references are made in the report with regard to CWT recoveries from several hatchery releases (p. 27, 28, 29). Do these represent all of the CWT recoveries? A table or appendix showing all CWT recoveries by tag code, catch location, date etc. would be valuable. The relationship between hatchery releases, predators, and impact to wild fish is an issue where even a little information would improve our knowledge and lead to valuable changes.

On page 7 the report mentions that spill closures occurred from 4:00-5:00 a.m. to allow sampling in the restricted tailrace and forebay areas. How might the lack of spill be affecting predator abundance and consumption in those areas? If spill causes fish to move more quickly or differently through forebay areas to the spill and if the spill disrupts typical non-spill squawfish holding and feeding patterns below the dam, then indices for those areas may be inaccurate, especially during spill days. It is feasible that manipulations of spill, flow velocities, and reservoir levels could be important to disrupt squawfish habitat use, consumption levels, and possible spawning success (tailrace) in high impact forebay and tailrace areas.

Any information the study might provide on spawning location or ripe female squawfish recapture areas could be useful.

On page 73 the authors note that salmonid adults represented nearly 32% of the salmonids incidentally caught. By my calculation this represents over 1100 fish. Most of these were apparently sockeye, steelhead, chinook, and unidentified salmon. Due to the potential losses resulting from spinal injury by electrofishing and mortality from gillnets, the Committee and the researchers should be concerned about such large scale study efforts on dwindling salmon populations.

The statement on page 86 that "age composition for northern squawfish by reservoir may be biased toward older and larger fish" is a significant <u>understatement</u> and should be strengthened. If the length frequency distributions (Fig. 17-23) of squawfish represent anywhere near the true population then our squawfish problem will soon be over as there are very few young squawfish to be recruited into future spawning populations. The report should emphasize that the sampling methods employed, especially gillnetting, are highly selective and that the length frequencies of fish collected and their age structure probably are not representative of the populations sampled. They may also be introducing additional error in their length frequency histograms by combining gillnet catches with electrofishing efforts, both of which exert different selection pressures.

These type of biases along with relatively small sample sizes at certain locations in the spring and lack of definitive littoral area calculations for these reservoirs (for abundance indexing) make reservoir by reservoir comparisons of predator biological characteristics and impacts difficult to accurately delineate. Despite these problems the study probably does indicate where the greatest problems exist.

Brian C Cates

State of Washington
Department of Fish and Wildlife
1114 Castleman Drive, Longview, WA 98632 (206) 414-7238

August 29, 1994

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FISHERIES MGMT DIV

Craig Burley
Fisheries Resource Program Manager
Washington Department of Fish and Wildlife
600 Capitol Way, North
Olympia, WA 98501-1091

SUBJECT: **RESPONSE TO COMMENTS ON THE DRAFT "MID-COLUMBIA PREDATION INDEX STUDY" REPORT B, APPENDIX A**

Craig:

Per your request, I have read Mr. Brian Cates comments regarding the draft report entitled "Mid-Columbia Predation Index Study" Report B, Appendix A. I am providing you with our response to Mr. Cates' comments. Mr. Cates suggestions were useful and constructive.

(1) In paragraph 5, Mr. Cates commented on the potential loss resulting from spinal injury by electrofishing. A similar concern was expressed regarding gillnet mortality of large salmonids. Mr. Cate's comments regarding spinal injuries due to electroshocking and mortality of large salmonids captured by gillnets are important points.

NBS and WDFW were concerned about possible injuring of large salmonids while sampling. Every attempt was made to reduce injurious effects of electrofishing and gillnetting on large salmonids. For example electrofishing, when an adult salmonid was encountered, we temporarily turned off the electric power to the electroshocker ending the electric field thereby allowing the adult salmonid to swim out of the shocking area and escape. We do not know whether our electrofishing resulted in any mortality of adult salmonids. There is much yet to learn about the relationship of electrofishing and injuries to fish.

Gillnets were tended hourly. Captured fish were removed and released. No salmonid mortalities were recorded from gillnet sets.

To clarify these issues in text, we have added the following sentences to the Methods section (page 57):

"Both NBS and WDFW were concern about injuring adult fish while electrofishing. When an adult salmonid was encountered, we temporarily turned off the electric power to the electroshocker ending the electric field thereby allowing the adult salmonid to swim free of the electroshocking area and escape."

On page 73, under Incidentals:

"Our gillnets captured few adult salmonids ($\leq$5%). Most large adult salmon and steelhead swam through our experimental surface and bottom gillnets. These nets were not designed for capturing large salmonid species (i.e., chinook and steelhead). Less than 7 percent of all chinook and steelhead counted were captured in gillnets. However, of the 549 sockeye salmon counted, 81 (15%) were captured by gillnets. No adult salmon mortalities were recorded."

(2) We found an error under the section incidentals. The total fish counted was **25,584** not 25,578.

(3) We, also, made minor editing changes:

(a) Second footnote on Table 10 should be "Percent" not "Total."

(b) Table 15. Delete "In addition Vigg and Burley (1990) data has been added for comparison." This information was deleted from Table 15 but not from heading.

(4) Mr. Cates comments regarding page 86, age composition of northern squawfish.

I have modified sentence five, paragraph two under section entitled Age and Growth as follows:

"Therefore, the age composition we observed for northern squawfish captured from each reservoir only reflects age structure of the fish captured in our sampling and not the true population within each reservoir."

(5) Mr. Cates noted in paragraph five that our report should emphasize that our sampling methods employed were highly selective.

On page 86, second paragraph, we stated that gillnets were size selective and that mesh sizes used during the field sampling selected for fish greater than 200 mm FL. Also, we found electroshocking was less effective at capturing small fish.

Please contact me if you have more questions.

Sincerely,

John Loch
Portland District Fish Passage Supervisor

cc: file

United States Department of the Interior

NATIONAL BIOLOGICAL SURVEY
PACIFIC NORTHWEST NATURAL SCIENCE CENTER
COLUMBIA RIVER RESEARCH LABORATORY
M.P. 5.48L, COOK-UNDERWOOD ROAD
COOK, WASHINGTON 98605

Craig C. Burley
Washington Dept. of Fish and Wildlife
600 Capitol Way N.
Olympia. WA 98501 - 0191

AUG 8 1994

August 5, 1994

Dear Craig:

Per our telephone conversation earlier this week I am providing you with our response to comments made by Brian Cates, USFWS, on the consumption indexing portion of the Mid-Columbia Index Report.

We truly appreciate Brian's comments. They were constructive and the revisions/additions made in response to these comments should improve the utility of the report.

(1) The second paragraph of Brian's memo asks if we have additional CWT data not included in the report. We do and I have enclosed a table of CWTs recovered in northern squawfish digestive tracts which can be included in an appendix of the report.

(2) In paragraph 3 Brian asks if the short-term spill closures for sampling affect the accuracy of the predation index. The digestive tracts we collect from these samples contain prey which were consumed prior to the spill closure, so I don't think the closures significantly affect the index accuracy. This procedure was also followed for indexing in John Day Reservoir and throughout the rest of the system, so we needed to follow this protocol to be consistent. In the second part of this paragraph Brian mentions that dam and reservoir manipulations could be used to reduce predation. This may indeed be possible. Data from our ongoing BPA research at The Dalles and John Day dams indicate that dam operations have a major impact on northern squawfish distribution and behavior.

(3) In paragraph 4 Brian suggests that we might have information from the study indicating spawning locations or where aggregations of ripe females could be captured. In our sampling efforts we did not collect any such specific data.

(4) While cross-checking our CWT data we found one error in the report; on page 29, paragraph 1, line 17 change 4 CWTs to 3 CWTs.

Please contact me if you have any questions re these responses.

Sincerely,

Thomas P. Poe

Tom

Enclosure

Coded wire tags recovered from northern squawfish digestive tracts from the mid-Columbia river consumption index study in 1993.

TAG CODE	HATCHERY	RELEASE SITE	RELEASE DATE	RECOVERY SITE	RECOVERY DATE
634604	SIMILKAMEEN	SIMILK. R.	4/9	WELLS FB	4/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
052851	WINTHROP	METHOW R.	4/15	WELLS TR	4/24
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/24
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
052236	WINTHROP	METHOW R.	4/15	WELLS TR	4/24
052844	WINTHROP	METHOW R.	4/15	WELLS TR	7/22
634609	WELLS DAM	WELLS DAM	4/16	WELLS TR	4/22
052815	ENTIAT	ENTIAT R.	5/14	ROCKY RCH. FB	6/30
635058	ROCKY RCH.	TURTLE ROCK	6/30	ROCKY RCH. TR	7/2
635058	ROCKY RCH.	TURTLE ROCK	6/30	ROCKY RCH. TR	7/2
635058	ROCKY RCH.	TURTLE ROCK	6/30	ROCKY RCH. TR	7/1
052727	LEAVENWORTH	ICICLE CR.	4/22	ROCK ISL. MR	4/30
052920	LEAVENWORTH	ICICLE CR.	4/22	ROCK ISL. FB	5/11
634609	WELLS DAM	WELLS DAM	4/16	ROCK ISL. FB	5/12
052846	WINTHROP	METHOW R.	4/15	ROCK ISL. FB	5/11
052236	WINTHROP	METHOW R.	4/15	ROCK ISL. TR	5/4
634604	SIMILKAMEEN	SIMILK. R.	4/9	ROCK ISL. TR	5/4
052844	WINTHROP	METHOW R.	4/15	ROCK ISL. TR	5/5
634603	METHOW	METHOW R.	4/14	ROCK ISL. TR	5/5
052555	LEAVENWORTH	ICICLE CR.	4/22	WANAPUM FB	5/6
052858	LEAVENWORTH	ICICLE CR.	4/22	WANAPUM FB	5/6
052919	LEAVENWORTH	ICICLE CR.	4/22	WANAPUM TR	5/6
635058	ROCKY RCH.	TURTLE ROCK	6/30	WANAPUM TR	7/29
634609	WELLS DAM	WELLS DAM	4/16	WANAPUM TR	5/7
052843	WINTHROP	METHOW R.	4/15	WANAPUM TR	5/6
634603	METHOW	METHOW R.	4/14	WANAPUM TR	5/7
052844	WINTHROP	METHOW R.	4/15	WANAPUM TR	5/7
052920	LEAVENWORTH	ICICLE CR.	4/22	WANAPUM TR	5/7
634609	WELLS DAM	WELLS DAM	4/16	WANAPUM TR	5/7
634603	METHOW	METHOW R.	4/14	PR. RAPIDS MR	5/12
634604	SIMILKAMEEN	SIMILK. R.	4/9	PR. RAPIDS FB	5/14
634603	METHOW	METHOW R.	5/12	PR. RAPIDS TR	5/13
634603	METHOW	METHOW R.	5/12	PR. RAPIDS TR	5/14
634604	SIMILKAMEEN	SIMILK. R.	4/9	PR. RAPIDS TR	5/13
634604	SIMILKAMEEN	SIMILK. R.	4/9	PR. RAPIDS TR	5/13
052236	WINTHROP	METHOW R.	4/15	PR. RAPIDS TR	5/13
634604	SIMILKAMEEN	SIMILK. R.	4/9	PR. RAPIDS TR	5/14
103601	RAPID RIVER	RAPID R.	4/14-19	MCNARY TR	5/18
052935	DWORSHAK	N.FK.CLRWAT.	4/8	JOHN DAY MR	5/25

METHOW RIVER BASIN SPRING CHINOOK SALMON HATCHERY PROGRAM EVALUATION; 1992 ANNUAL REPORT

BY

HEATHER BARTLETT AND BOB BUGERT

APPENDIX - J

METHOW RIVER BASIN SPRING CHINOOK SALMON HATCHERY PROGRAM EVALUATION

1992 ANNUAL REPORT

by

Heather Bartlett and Bob Bugert

Washington Department of Fish and Wildlife
P.O. Box 43135
Olympia, Washington 98504-3155

Prepared for:

Douglas Public Utility District
1151 Valley Mall Parkway
East Wenatchee, Washington 98802-4497

June 1994

ABSTRACT

Spring chinook salmon escapement to Wells Dam in 1992 was 1,703 adults (age 3+) and 31 jacks (Appendix A). This is the last place that Methow Basin spring chinook salmon can be counted. The recent ten-year average for spring chinook salmon counted over Wells Dam is 2,274 (adults and jacks), with half the run counted by 23 May (Bugert 1994). The Winthrop National Fish Hatchery (WNFH) spring chinook salmon escapement in 1992 was 332 adults.[1] WNFH has a maximum escapement goal of 850 adults with an average of 471 collected. Based upon spring chinook salmon redd counts in the Methow Basin from 1987-1993, the distribution into the Methow, Chewuch and Twisp Rivers from counted adults at Wells Dam were 45.7%, 27.6% and 26.6% respectively.[2]

Methow River spring chinook salmon were not collected for broodstock in 1992. Twenty adult Chewuch and thirty adult Twisp spring chinook salmon were collected for Methow FH broodstock in 1992.[3] Only naturally produced salmon are collected for hatchery broodstock. Adult prespawn survival for Chewuch spring chinook salmon was 85%. Adult prespawn survival for Twisp spring chinook salmon was 80%. Total eggtake was 47,660 and 39,164 respectively. Green egg to fry survival for the Chewuch stock was 88.2%, and for the Twisp stock it was 94.2%. Fry to smolt survival was 97.2% for both spring chinook salmon stocks. In April 1994 the Methow FH Complex had its first release of smolts. The hatchery released 40,862 or 1,237 Kg. of Chewuch spring chinook salmon into the Chewuch River. In addition, 35,861 or 1,086 Kg. of Twisp spring chinook salmon were released into the Twisp River.

---

[1]Bill Edwards, U.S. Fish and Wildlife Service, Winthrop National Fish Hatchery, Winthrop, Wa. 98862

[2]Joel Hubble, Yakima Indian Nation Fish Management, Yakima, Wa. 98901

[3]This does not include six males and four females that died from stranding on the Twisp River weir.

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ACKNOWLEDGMENTS

This 1992 Methow Fish Hatchery Complex Evaluation report is the culmination of a number of peoples' work, both administratively and technically within the Washington Department of Fish and Wildlife (WDFW) Salmon Program. The authors thank Tami Black, Lee Blankenship, Bob Foster, Larry Peck, Kathy Hopper, Gary Schurmann, Patty Michak, John Schandl, Jim Shaklee and Rod Woodin for making this project work.

Technician Norm Switzler contributed much in field data collection. Hatchery managers Bob Jateff and Guy Wiest and fish culturist Dave Dinsmore were cooperative and supportive to the hatchery sampling needs.

All electrophoretic analyses were done by the WDFW genetics unit; Craig Busack, Anne Marshall, Steve Phelps, Jim Shaklee, and Sewall Young. Scale analyses and age determination was done by John Sneva. Rich Eltrich and Kristine Petersen gave invaluable philosophical and technical assistance.

Rick Klinge and Mike Erho from Douglas Public Utility District have been more than helpful with important issues regarding the project's objectives or direction. They possess great insight into the future of salmon hatcheries.

Alec Maule and Robin Schrock of U.S. Fish & Wildlife Service (USFWS) provided all ATPase analyses. The USFWS Winthrop Hatchery crew provided much historical information and has been cooperative to the project's sampling needs. Brian Cates of USFWS Mid-Columbia Fishery Resource Office reviewed and provided comments for the Draft Report.

SECTION 1: INTRODUCTION

Mitigation for the effects of hydroelectric development on downstream migrant salmon and steelhead was not considered in the agreements which guided past fishery mitigation efforts for Wells Dam. Following the low flow years experienced in the 1970's, fisheries' agencies and tribal interests petitioned the Federal Energy Regulatory Commission (FERC) about requiring Douglas County Public Utility District to provide juvenile salmonids with a migrant bypass system. This would prevent the juveniles from passing through the turbines. The migrant bypass system was completed in 1988, but apparently no matter how effective the bypass system was there would still be unavoidable losses at Wells Dam. To compensate for these losses Douglas County Public Utility District built a hatchery on the Methow River. This hatchery is dedicated to enhancing the natural production of spring chinook salmon on the Chewuch, Methow and Twisp Rivers without changing the genetic characteristics.

Phase I of the Wells Settlement Agreement provides specific goals and objectives for meeting mitigation requirements. The goal of the Methow Fish Hatchery Complex (MFHC) is to supplement adult production lost from smolt mortalities at Wells Dam. The specific objective for the hatchery production is 50,000 pounds or 22,700 Kilograms (Kg.) of spring chinook salmon yearlings released as 30-35 gram fish. This requires trapping sufficient broodstock to meet program release numbers. In addition, the MFHC must use fish cultural methods that maintain genetic integrity of native stock(s) and release high quality smolts from the facility (Peck, 1993).

A comprehensive evaluation plan was developed by the Wells Coordinating Committee to monitor progress toward meeting the objectives of the hatchery programs. The Wells Coordinating Committee includes representatives of the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service, Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife, the Yakima Indian Nation, the Colville Confederated Tribes and Douglas County Public Utility District. The evaluation is to document whether the MFHC can produce the Phase I hatchery compensation required under the Wells Project Settlement Agreement.

Three broad-based objectives provide a framework for long-term monitoring of the hatchery based compensation plan. The objectives are as follows:

1. Determine if the Methow Fish Hatchery Complex can meet Phase I requirements of the Agreement.

2. Determine that actions taken under the Methow Phase I hatchery program conserve the genetic success, genetic integrity, and long-term fitness of the natural spawning populations of salmon in the Columbia River above Wells Dam.

3. Determine whether smolts released from the acclimation facilities disperse

and migrate downstream without affecting the natural populations.
The objectives may be modified yearly to better accomplish the goals of the evaluation plan. This report includes comprehensive information about the 1992 broodyear at the MFHC. The contract period is 1 August 1993 to 31 July 1994 between Douglas County Public Utility District and Washington Department of Fish and Wildlife.

SECTION 2: STUDY SITE

The MFHC consists of a central hatchery, two satellite acclimation ponds, and two satellite adult trapping facilities. The complex, designed by Fish Pro Inc., has many unique features.

2.1: Methow Fish Hatchery

The Methow Fish Hatchery (FH) provides for separate incubation and rearing of the three Methow Basin spring chinook salmon stocks in a central location. It is located in Winthrop, WA along the Methow River approximately 72 Km from its confluence with the Columbia River. The central hatchery has three canopy covered 2.4 m x 24.4 m x 1.2 m adult salmon holding ponds, twelve canopy covered 2.4 m x 24.4 m x 1.2 m juvenile raceways and twenty-four indoor 0.91 m x 4.6 m x 0.76 m start tanks. In addition, there are three separate incubation rooms with 15 single stack (eight trays/stack) vertical incubators and a 33.5 m x 18.3 m x 1.4 m plastic lined acclimation pond releasing into the Methow River.

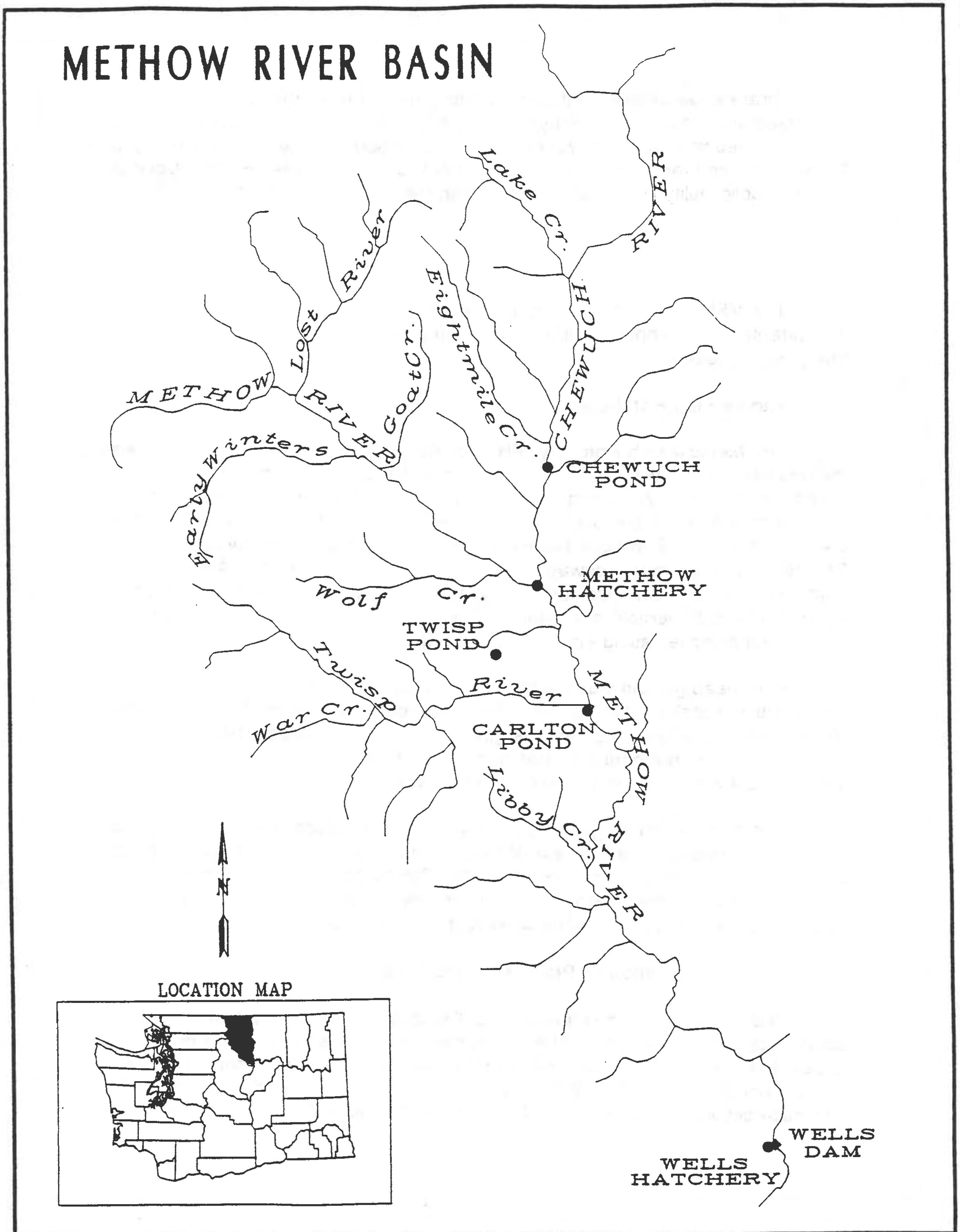
Four deep ground water wells provide 0.28 m^3/s of water. The water temperature is stable year around at 9^{0}C. An additional right of 0.51 m^3/s Methow River water is provided; 0.31 m^3/s is guaranteed, while the additional 0.2 is shared with the Winthrop National Fish Hatchery (WNFH) during the spring months. The WNFH is 2.4 Km downstream from the Methow FH.

The Methow FH programs use only naturally produced fish as broodstock. While in the hatchery the fish rear at reduced densities under conditions that better prepare them for their natural environment. The hatchery program production is 250,000 yearling spring chinook salmon per river (Mark Kimbel pers. comm.). The actual number will depend on the availability of the broodstock.

2.2: Chewuch Acclimation Pond and Adult Trap

The Chewuch pond is located 9.6 Km up the Chewuch River from its confluence with the Methow. The facility has one large 33.5 m x 21.3 m x 1.4 m cobble lined pond. Chewuch River water is supplied by gravity from the Chewuch Canal Company's irrigation ditch. Maximum flow is 0.16 m^3/s. Chewuch broodstock collection occurs at Fulton Dam 2.4 Km up the Chewuch River from its confluence

Figure 1.



METHOW RIVER BASIN
Lake Cr.
CHEWUCH RIVER
Lost River
Eightmile Cr.
Goat Cr.
METHOW RIVER
Early Winters
CHEWUCH POND
METHOW HATCHERY
Wolf Cr.
TWISP POND
Twisp River
War Cr.
CARLTON POND
METHOW RIVER
Libby Cr.
N
LOCATION MAP
WELLS DAM
WELLS HATCHERY

with the Methow. Fulton Dam is a fabricated barrier of boulders redirecting upstream migrants to a denil (steep-pass) ladder and into a v-trap.

2.3: Twisp Acclimation Pond and Adult Trap

The Twisp acclimation pond is located 8 Km up the Twisp River from its confluence with the Methow. This facility has one large 33.5 m x 18.3 m x 1.4 m cobble lined pond and an adjacent adult collection site. The pond is gravity fed with Twisp River water from the Valley Power irrigation canal. Maximum flow is 0.16 m^3/s. The adjacent broodstock collection site includes a floating picket weir to redirect fish into a v-trap.

SECTION 3: BROODSTOCK MANAGEMENT

3.1: Chewuch Spring Chinook Salmon

In 1992 Chewuch spring chinook salmon[1] were collected from the trap at Fulton Dam. Thirty-three adult (15 males and 18 females) salmon were trapped. Using redd count expansion and percent contribution from Wells Dam counts, about 360 adult salmon escaped to the Chewuch River (Meekin, 1993). Trapping efficiency was 10%. Attraction flow through the trap was low and during spring runoff fish moved easily over the dam (Bob Jateff, personal communication).

3.1.1: Trapping

Trapping began 10 May 1992 and continued throughout the duration of the run ending 8 September. The first adult arrived 18 May. Peaks in trapping occurred the last week of May and the last week of August. When the salmon began arriving sex determination was difficult because the fish had underdeveloped secondary sex characteristics. A sex was assigned along with a hog ring to the collected adults. The mid-July erythromycin injection provided precise sex determination. Previous arrivals' sexes were changed if necessary. Eight males and five females were passed upstream, while seven males and thirteen females were collected for broodstock. An additional four males were gaffed off the spawning grounds for use as hatchery broodstock. Daily discharge for the Chewuch River is included with the trapping summary in Appendix A.

The first five adults collected at the Chewuch trap were tagged with a hog ring on the dorsal fin. Chelan P.U.D. transported the fish to the Carlton Pond on the Methow River. The adult holding ponds were not completed at the Methow FH. On

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[1]Spring chinook is implied with salmon from here on, unless otherwise noted.

12 June these adult salmon were injected with erythromycin at a dosage of 20 mg/Kg, and transported to the completed adult ponds at the Methow FH.

3.1.2: Transport

Subsequent collections went directly from the trap to the Methow FH in a 300 gallon tank. A rubber sock filled with water was used to move fish reducing handling stress and abrasions on the salmon. Travel time from the trap to the hatchery was about 20 minutes. Flow to the pond was 0.018 m^3/s. The maximum loading density set for the Methow FH is one fish/0.28 m^3 (Wells Settlement Agreement 1990). In 1992 the loading density was extremely low at one fish/3.5 m^3. Average monthly water temperature during the holding period was 9^0C. A sprinkler system over the pond provided shade and reduced movement.

3.1.3: Prophylaxis

Formalin was used to control fungus during the holding period. Treatments began 15 June and continued for 10 consecutive days. After the tenth day, treatments were reduced to every other day. The bath concentrations were one part formalin to 6,000 parts water. A second injection of 10 mg/Kg erythromycin was given 4 August to all the fish in the holding pond. It was administered at half the original dosage because one female died the week ending 11 July from erythromycin toxicity after the first injection.[3] Two females received both injections. No mortalities occurred after the second injection. Two males died at the end of spawning. The Chewuch prespawn survival was 85%.

3.1.4: Spawning

Spawning began 20 August and finished 17 September. Males were live spawned with females the first three weeks. A total of 12 females and 10 males (including three collected from the spawning grounds) were used for the Chewuch broodstock. The adjusted eggtake was 48,664. Average fecundity was 4,424 with a range of 3,025 to 5,783. This total does not include eggs collected from a Looking Glass FH marked female crossed with a Chewuch male.

---

[3]Tami Black, Washington Department of Fish and Wildlife, Wenatchee, Wa. 98801

Table 1. Chewuch spring chinook salmon broodstock management 1992
Trapping and Spawning Summary

Week	Number Passed Upstream		Adults Collected		Fish Spawned		Eggtake
Ending	**Male**	**Female**	**Male**	**Female**	**Males**	**Female**	
23-May-92	1	1		2			
30-May-92	7	2		2			
06-Jun-92		1		1			
13-Jun-92	1						
20-Jun-92							
27-Jun-92	2	1	2	1			
04-Jul-92	1	2					
11-Jul-92							
18-Jul-92							
25-Jul-92							
01-Aug-92							
08-Aug-92	1						
15-Aug-92				1			
22-Aug-92	1		1	1	3	2	8,000
29-Aug-92			4	5	5	4	15,000
05-Sep-92					7	5	20,000
12-Sep-92					3		
19-Sep-92					2	1	4,000
Season Totals	14	7	7	13	10	12	48,664*

* This is the adjusted total after the eggs were hand counted.

Standard spawning procedure for the Methow FH is as follows: Females are spawned into individual buckets. The primary male milt is added, mixed and allowed to sit 60 seconds before addition of the secondary male milt. To ensure complete fertilization eggs remain in the buckets for fifteen minutes. Then the eggs are placed in a disinfecting solution of 1 part iodophor to 150 parts water for one hour.

3.1.5: Virology and ELISA

Ovarian fluid from females and kidney/spleen tissue from males was collected for viral sampling. Ovarian fluid is the tissue of choice for Infectious Hematopoietic Necrosis Virus (IHNV) testing.[4] Since broodstock numbers were low, kidney and spleen tissue from the males was tested under conditions to detect IHNV. Additional kidney tissue was collected from all the viral sampled fish and tested for BKD using enzyme linked immunosorbent assay (ELISA).[5]

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[4]Joan Thomas, Washington Department of Fish and Wildlife, Natural Resource Bldg., Olympia, WA 98504

[5]Patty Michak, Washington Department of Fish and Wildlife, Natural Resource Bldg., Olympia, Wa. 98504

Table 2. Chewuch spring chinook salmon ELISA and virology

GSI # female	ELISA	Virology	GSI # male	ELISA	Virology
92DO1	low	negative	92DO22	low	negative
92DO2	low	negative	92DO23	high	negative
92DO3	low	negative	92DO24	low	negative
92DO4	low	negative	92DO42	below low	negative
92DO5	high	negative	92DO43	below low	negative
92DO6	low	negative			
92DO10	below low	negative			
92DO11	low	negative			
92DO12	low	negative			
92DO21	low	negative			
92DO41	low	negative			

3.1.6: Age Class and Sex Ratio

Forty-six genetic samples were taken by WDFW from the adult Chewuch salmon.[6] This included 21 adult hatchery broodstock and 28 adult natural spawners. Three males gaffed off the spawning grounds and included in the hatchery broodstock are also numerically included in the natural spawners. Scales were analyzed to learn the age and origin of each fish.[7] Statistical analysis using t-test two samples assuming equal variance showed no difference in age composition or mean POH length of the hatchery broodstock from the natural spawners.

Table 3. Age composition and mean fork length by sex of Chewuch spring chinook salmon hatchery broodstock 1992

SEX	Age 3	Age 4	Age 5	Unknown	TOTAL
Male	1	7	1	1	10
	52.0 cm	59.2 cm	68.0 cm	55.0 cm	58.6 cm
Female	0	4	6	1	11
		59.0 cm	68.3 cm	64.0 cm	63.8 cm
Total	1	11	7	2	21
		59.1 cm	68.2 cm		61.1 cm

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[6]Norm Switzler, Washington Department of Fish and Wildlife, Natural Resource Bldg., Olympia, Wa. 98504

[7]John Sneva, Washington Department of Fish and Wildlife, Natural Resource Bldg., Olympia, Wa. 98504

Figure 2.

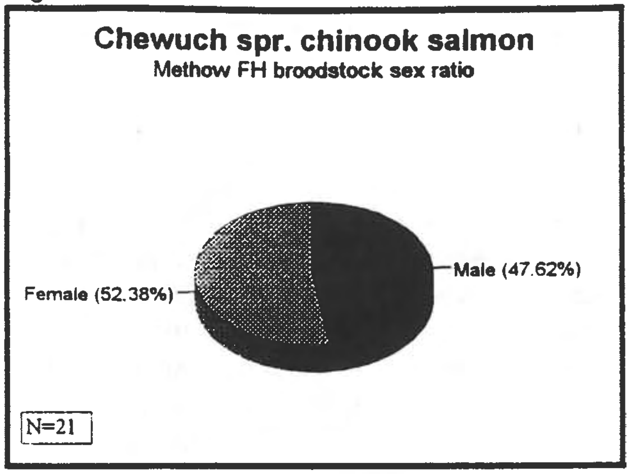


Figure 3.

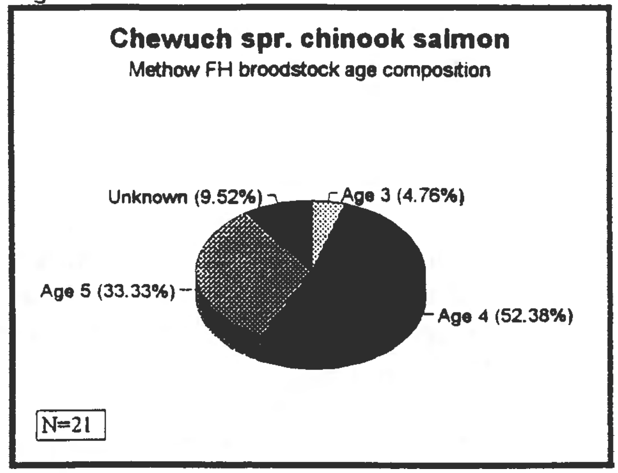


Table 4. Age composition and mean fork length by sex of Chewuch spring chinook salmon natural spawners 1992

SEX	Age 3	Age 4	Age 5	Unknown	TOTAL
Male	1	14	1	0	16
	49.0 cm	57.6 cm	68.0 cm		57.8 cm
Female	0	8	3	1	12
		57.9 cm	67.0 cm	56.0 cm	60.0 cm
Total	1	22	4	1	28
		57.7 cm	67.3 cm		58.7 cm

Figure 4.

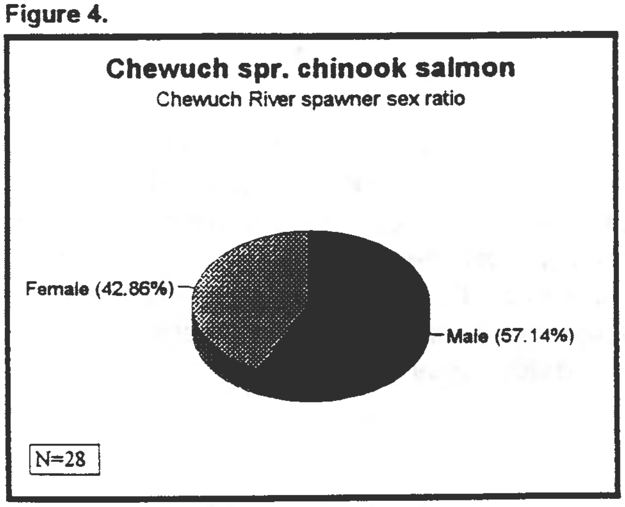
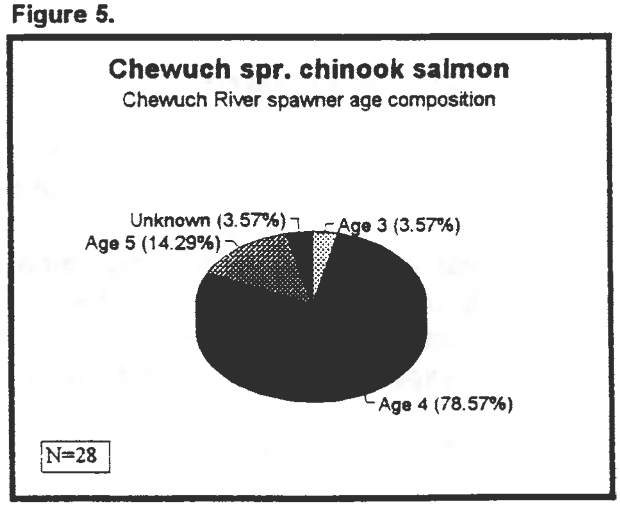


Figure 5.



3.2: Twisp Spring Chinook Salmon

Broodstock for the Twisp program was collected at the adult trap on the Twisp River. The trap collected 71 salmon, although fish were seen entering and exiting. The estimated Twisp River escapement from redd count expansion and Wells Dam count contribution was 300 spring chinook salmon (Meekin, 1993). Trap efficiency was 24%.

3.2.1: Trapping

Trapping began 10 May 1992 and continued until 8 September. The first adults arrived 22 May. A peak in trapping occurred the week ending 6 June. Twenty-two males and four females were passed upstream, while eighteen males and twelve females were collected for hatchery broodstock. During the season six males and four females died when they became stranded on the weir. To prevent further stranding sheets of plywood were placed over the weir pickets 25 June. No mortalities associated with the weir occurred after the modifications. Daily discharge for the Twisp River is included with the trapping summary in Appendix A.

3.2.2: Transport

The nine fish collected the week ending 6 June were transported to the Carlton Pond. On 12 June these fish were injected with 20 mg/Kg of erythromycin and transported to the completed adult holding ponds at the Methow FH. Subsequent collections from the trap went directly to the Methow FH. Handling and transport procedures were the same used for the Chewuch salmon. Travel time from the trap to the hatchery was about 25 minutes. Flow rate to the pond was 0.018 m^3/s, and the loading density did not exceed one fish/2.3 m^3. The water temperature was constant at 9^0C throughout the holding period. A sprinkler system over the pond provided shade and reduced movement.

3.2.3: Prophylaxis

Standard formalin treatments of 1:6,000 were given to control fungus. The same treatment program administered to the Chewuch stock was followed for the Twisp stock. A second erythromycin injection of 10 mg/Kg (half the original dosage) was given 4 August.[8] Two females died shortly after the first injection, and another female receiving both injections died after the second. All three mortalities resulted from erythromycin toxicity. Three males also died during the holding period. Prespawn survival for the Twisp salmon broodstock was 80%.

3.2.4: Spawning

Spawning began 13 August and continued to 3 September. All males were live spawned and not used more than once as the primary contributor. Nine females and

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[8]John Morrison recommended this dosage based upon his work with the WNFH spring chinook salmon.

fifteen males comprised the hatchery broodstock. The adjusted eggtake was 38,951. Average fecundity was 4,328 with a range of 3,262 to 5,481.

Table 5. Twisp spring chinook salmon broodstock management 1992
Trapping and Spawning Summary

Week	Number Passed Upstream		Adults Collected		Fish Spawned		Eggtake
Ending	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
23-May-92							
30-May-92		1					
06-Jun-92	10	2	5	4			
13-Jun-92	1	1					
20-Jun-92	1		4	2			
27-Jun-92			4				
04-Jul-92	1			1			
11-Jul-92							
18-Jul-92							
25-Jul-92	2						
01-Aug-92							
08-Aug-92							
15-Aug-92	3			1	3	1	4,000
22-Aug-92			2	1	4	2	8,000
29-Aug-92	2		1	2	6	5	20,000
05-Sep-92	7		2	1	2	1	4,000
12-Sep-92							
Season Totals	27	4	18	12	15	9	38,951*

* This is the adjusted total after the eggs were hand counted.

The spawning procedure followed was the same as the one used for the Chewuch salmon.

3.2.5: Virology and ELISA

All females and nine males were sampled for IHNV and ELISA.

Table 6. Twisp spring chinook salmon ELISA and virology

GSI # female	ELISA	Virology	GSI # male	ELISA	Virology
92DQ1	low	negative	92DQ52	low	negative
92DQ2	low	**negative**	92DQ51	low	negative
92DQ3	low	negative	92DQ61	high	negative
92DQ8	high	negative	92DQ50	moderate	negative
92DQ32	moderate	negative	92DQ56	low	negative
92DQ33	low	negative	92DQ58	low	negative
92DQ34	low	negative	92DQ48	low	negative
92DQ35	low	negative	92DQ49	below low	negative
92DQ42	low	negative	92DQ45	low	negative

92DQ2 had a reovirus not of management significance.

3.2.6: Age Composition and Sex Ratio

Fifty-nine fish were tissue sampled by WDFW for genetic stock identification (GSI).[9] Included were the 25 fish used for broodstock at the hatchery and 34 natural spawning Twisp salmon. Scales were analyzed to learn the age and origin of each fish.[10] Statistical analysis using t-test two samples assuming equal variance showed a significant difference in the means for the POH lengths between the hatchery group and the natural spawning group. However, there was no difference in the mean age composition since the 1992 Twisp salmon were predominantly four years old.

Table 7. Age composition and mean fork length by sex of Twisp spring chinook salmon hatchery broodstock 1992

SEX	Age 3	Age 4	Age 5	Unknown	TOTAL
Male	0	14	2	0	16
		55.7 cm	71.5 cm		57.7 cm
Female	0	6	2	1	9
		60.5 cm	65.5 cm	63.0 cm	61.9 cm
Total	0	20	4	1	25
		57.2 cm	68.5 cm		59.2 cm

Figure 6.

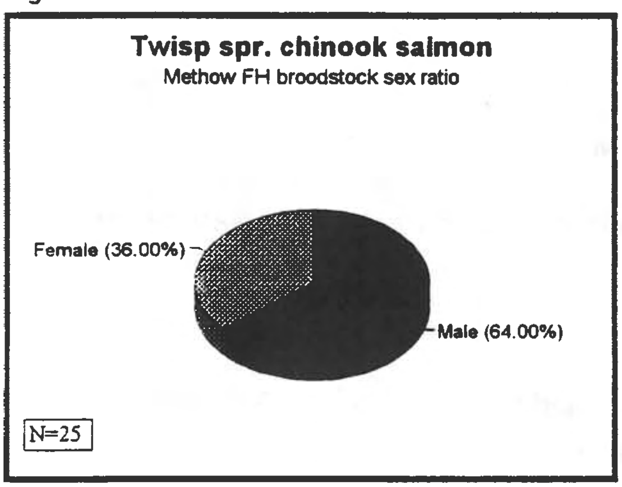
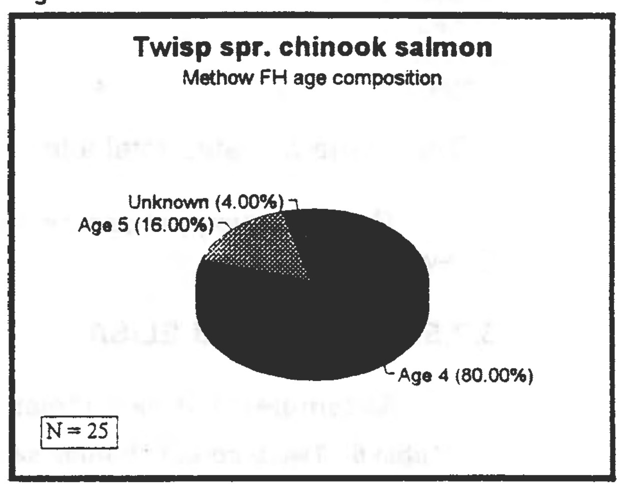


Figure 7.



[9] Sewall Young, Washington Department of Fish and Wildlife, Natural Resource Bdlg., Olympia, Wa. 98504

[10] John Sneva, Washington Department of Fish and Wildlife, Natural Resource Bldg., Olympia, Wa. 98504

Table 8. Age composition and mean fork length by sex of Twisp spring chinook salmon natural spawners 1992

SEX	Age 3	Age 4	Age 5	Unknown	TOTAL
Male	1	23	2	0	26
	48.0 cm	54.3 cm	68.0 cm		55.1 cm
Female	0	6	2	0	8
		59.5 cm	65.0 cm		60.9 cm
Total	1	29	4	0	34
		55.4 cm	66.5 cm		56.5 cm

Figure 8.

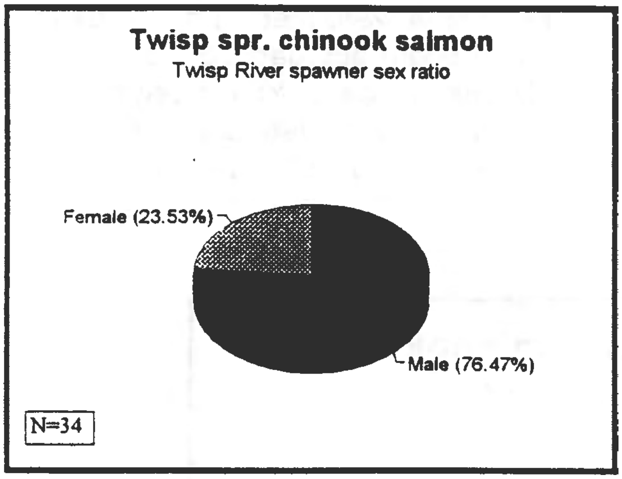
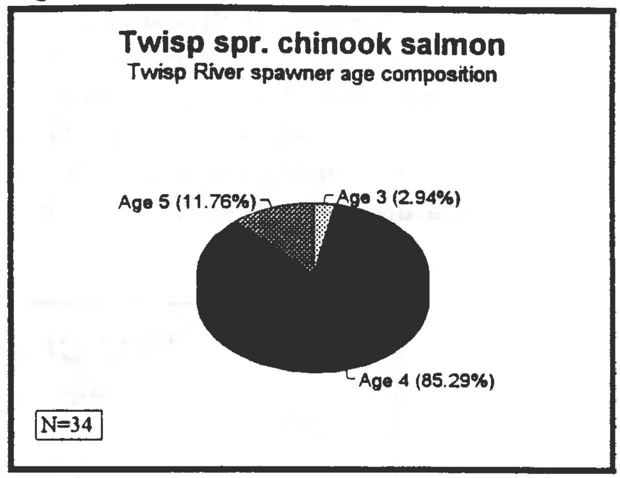


Figure 9.



SECTION 4: JUVENILE REARING

4.1: 1992 Brood Chewuch Spring Chinook Salmon

4.1.1: Incubation

After spawning and disinfection the Chewuch salmon eggs were transferred to vertical incubators (heath stacks) in the Chewuch incubation room. One eight tray heath stack was used per female. Eggs went into alternate trays for easy checking during incubation. Each tray held about 675 eggs. Well water supplied a flow rate of 0.02 cm^3/s and a constant temperature of 9^0C. No formalin treatment was given during egg development.

When the eggs eyed-up or accumulated approximately 500 to 700 temperature units (TU's) they were agitated.[11] Agitation turns the unfertilized or dead eggs white

[11]One temperature unit equals 1^0F above 32^0F for 24 hours. This is a standard measurement.

for easy removal. The remaining live eggs were hand counted to obtain an accurate fecundity. Plastic substrate (vexar) was placed in each tray containing eggs and left until ponding so yolk absorption went toward growth and not movement. This is standard procedure for the Methow FH. Green egg to fry survival for the 1992 Chewuch salmon was 88.2% or 43,032 fry. The three egg lots fertilized by males gaffed off the spawning grounds accounted for 25% of the total egg loss. Specifically, 1,335 eggs were not fertilized or did not hatch, and 63 fry died in the incubators (Appendix B).

4.1.2: Ponding and Early Rearing

Ponding of Chewuch fry began when three criteria were met; 1) KD index (a length/weight measurement that quantifies yolk absorption) approached 1.97, 2) accumulated TU's were above 1,750, and 3) belly slits (visible yolk) showed no more than 1 mm. Ponding began 17 December 1992 and ended 16 January 1993. One start tank was used per family (known female x known male). Each family was kept separate until coded-wire tagging (CWT).

Figure 10.

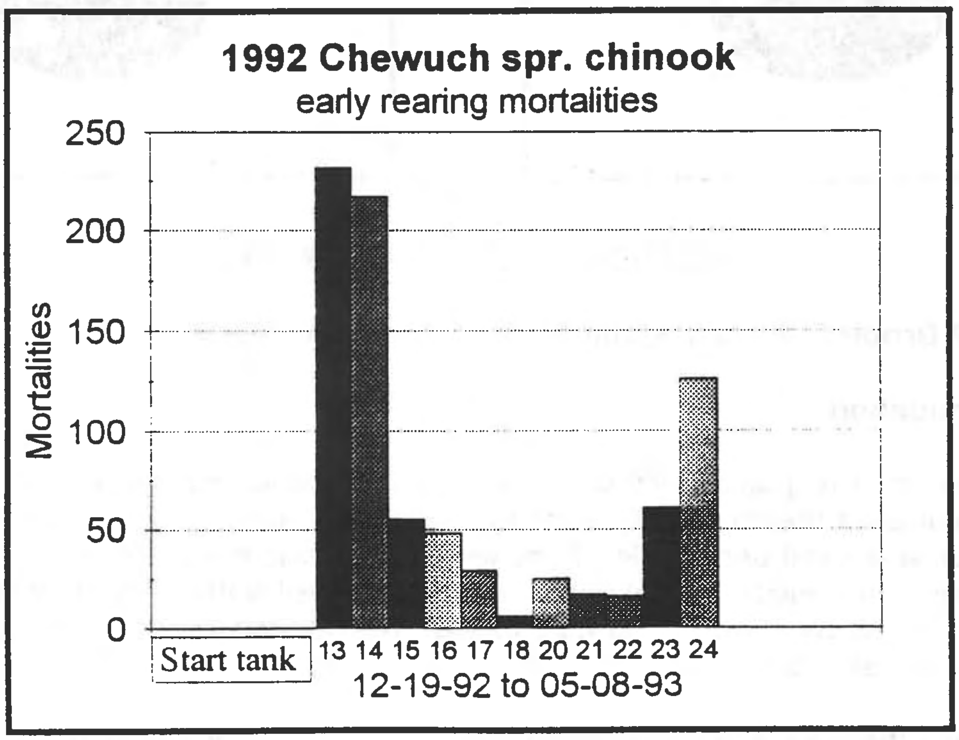
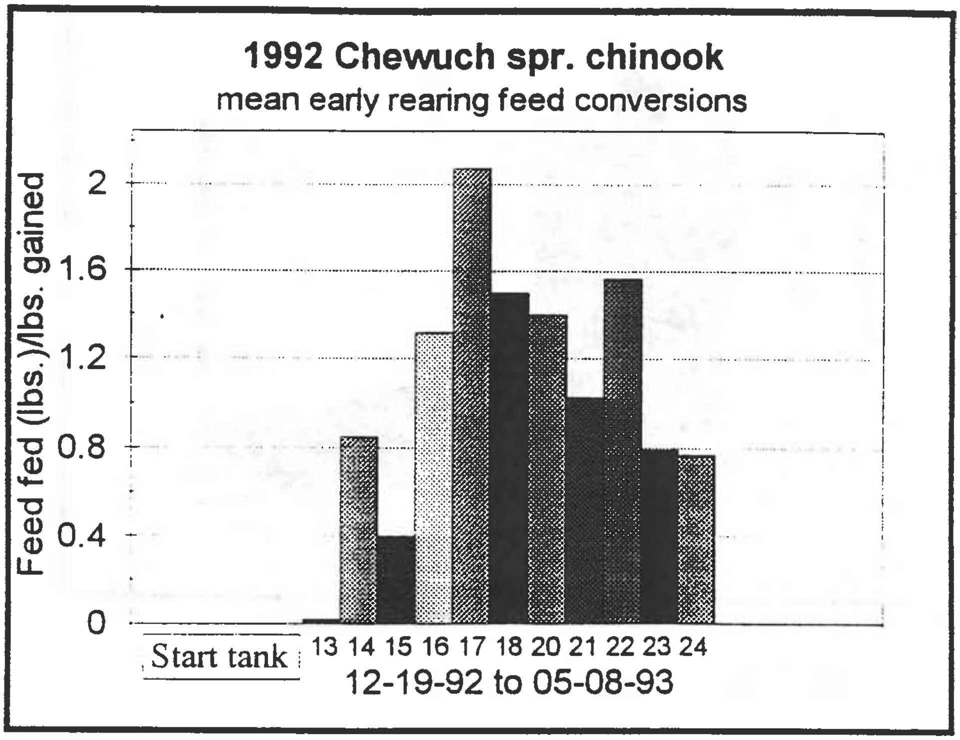


Figure 11.



Weight data was collected weekly through April 1993. Length data was collected monthly, and a condition factor and density index calculated for each family. Due to low rearing numbers the density index remained below the maximum limit of 0.125 lbs. of fish/cu. ft./in. without any splits.

CWT marking began the last week of April when the fish reached approximately 2.7 grams each. Each family unit was given a unique sequence to monitor early rearing and spawning ground contributions in future years. The adjusted total after CWT marking showed a shortage of 1,004 fish. After 100% marking the fish went into three juvenile raceways at the Methow FH. Raceway 1 received 13,733 fish, raceway 2 received 13,863 fish and raceway 3 received 13,587 fish. The respective density indexes were well below the maximum limit of 0.125.

Figure 12.

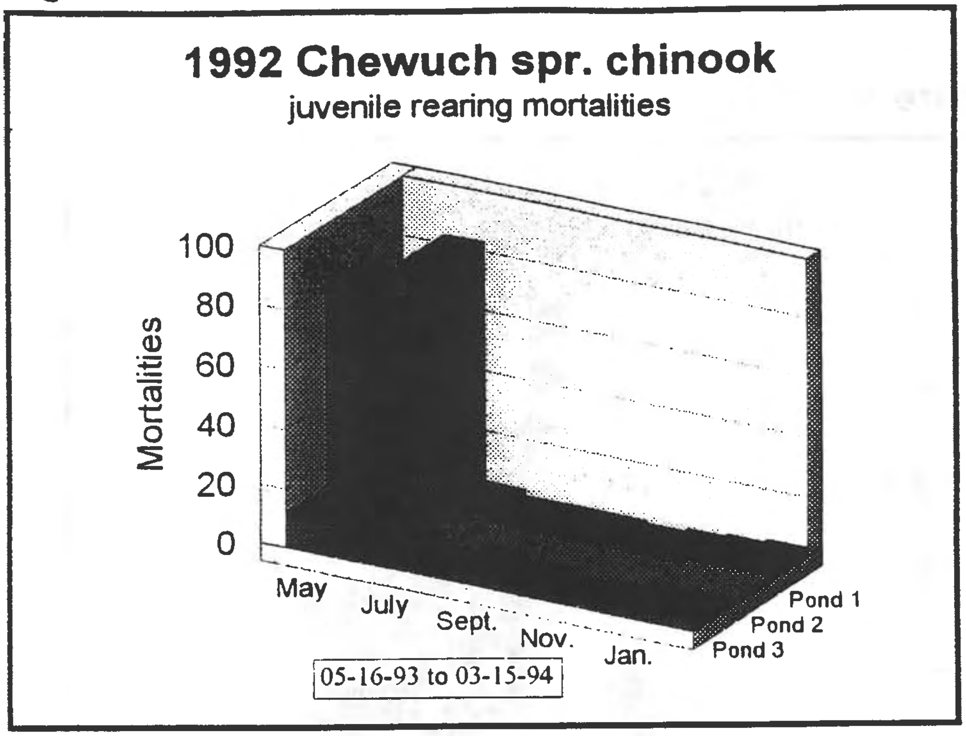
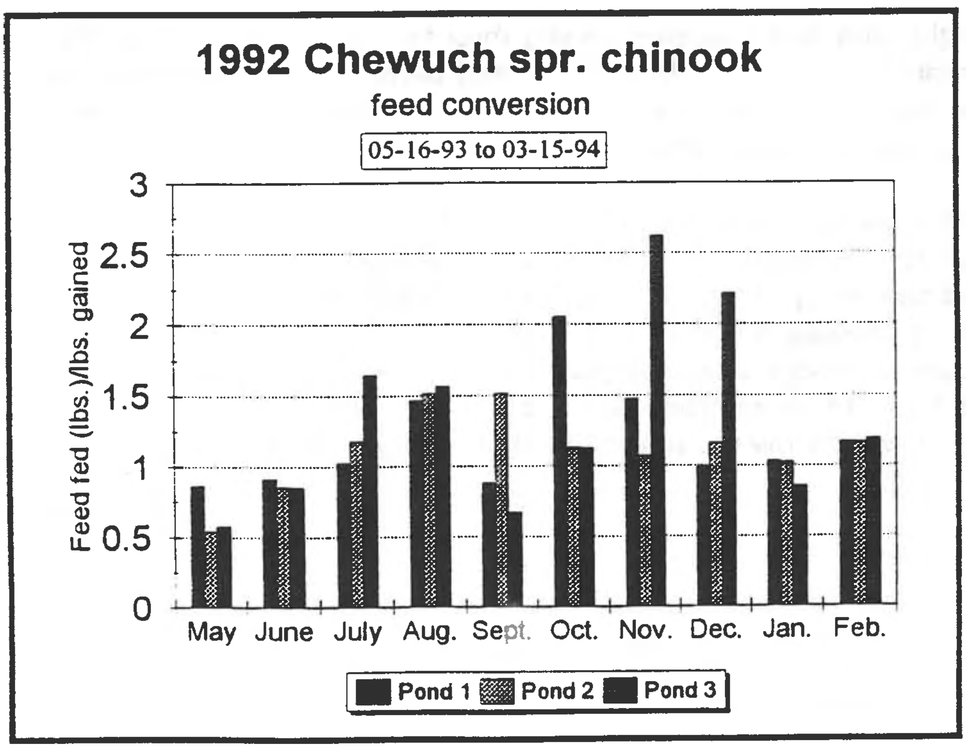


Figure 13.



4.1.3: Fish Health Monitoring

Eleven fish health examinations were done on the 1992 Chewuch stock during hatchery rearing. No major fish health problems occurred. CWT recoveries from pond mortalities showed no bias (Appendix B). A 21-day prophylactic gallimycin treatment began 18 May 1992 on all the fish when they were 3.8 grams each. At treatment completion mortalities were significantly elevated and live fish showed signs of drug toxicity. Percent daily loss in May was 0.002% and in June it was 0.02%. By July, pond mortalities had returned to normal with a percent daily loss of 0.001%.

Table 9. 1992 broodyear Chewuch spring chinook salmon

Date	Life Stage	Size (gr.)	Mean Daily Percent Loss	Water Temp C	Gills	Body	Pathogen	Recommendations
06-Jan-93	fry	0.5	0.01	9	good	clean		T14 high loss because of small eggs...move to BDS #1
23-Feb-93	juvenile	1.5	0.018	9	good	clean		
13-May-93	juvenile	4	0	9	mild hyperplasia	clean		Start 1st Gallimycin treatment in one week
08-Jun-93	juvenile	4.5	0.004	9	good	clean		Gallimycin toxicity...avoid disturbance for three weeks
01-Jul-93	juvenile	6	0	9	mild hyperplasia	clean		Post Gallimycin treatment loss returned to normal
18-Aug-93	juvenile	8	0	9	mild hyperplasia	clean		Move to six week lethal monitoring
14-Oct-93	juvenile	11	0	9	good	smolting		Fat level +2
24-Nov-93	juvenile	13	0	9	very good	perfect		
07-Jan-94	juvenile	19	0	9	excellent	excellent		One fish with pale liver...fish will probably slow down on feeding
28-Jan-94	juvenile	22	0	9	no examine			Recommend tempering in Methow river water no more than two weeks.
18-Feb-94	juvenile	26	0	9	good	smolting		Okay for transfer in early March. Fat level +2
01-Apr-94	smolt	27.5	0	4	good	good		Smolt like activity in pond. Okay to release when permit allows.

4.1.4: Tempering and Acclimation Pond Transfer

Tempering began 23 February 1994 using Methow River water. Tempering adjusts a fish's tolerable temperature range slowly preventing stress. The pathologist recommended tempering two weeks with a 0.6°C drop in temperature per day.[12] At this time the well water temperature was 9°C and the Chewuch River water temperature was 3°C. Because of difficulty in dropping the temperature daily, tempering occurred four weeks using a ratio system. The first week the ratio was 75/25 well water/river water. The next week it was 50/50, the third week it was 25/75 and the fourth week it was 0/100. Transport of the 1992 Chewuch salmon to the Chewuch acclimation pond occurred 14-15 March 1994 in a 500-gallon tank. Loading densities during transport were 0.12 Kg/L of water with oxygen metered to the

[12]Tami Black, Washington Department of Fish and Wildlife, Wenatchee, Wa. 98801

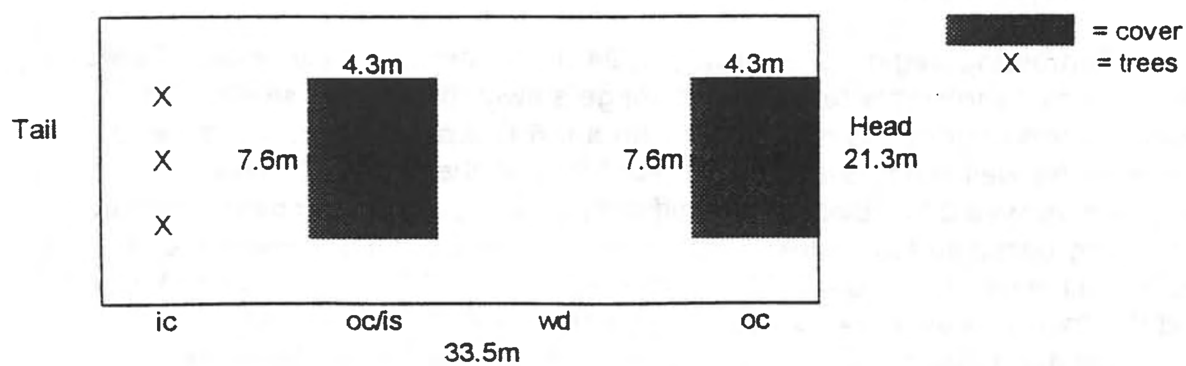
recirculating water. Travel time was 20 minutes. A total of 40,888 fish or 1,092 Kg. were transferred. Mortalities during transport were six fish.

4.1.5: Natural Rearing

Hatchery reared spring chinook salmon spend 14 months in a nourishing and safe environment. The fish produced are large and healthy with minimal mortalities within the hatchery. But exceptional success claimed within a hatchery, can be offset by the undesirably high post-release mortalities (Suboski 1989). Literature indicates that the post-release survival of hatchery-reared fish can be improved by altering the hatchery environment to more reflect the natural environment. The Chewuch and Twisp acclimation ponds are lined with cobble to mimic the river substrate. The sides have large cobble with an average diameter of 25.4 cm and the bottom has small cobble with an average diameter 10 cm. Additionally, in spring 1994 overhead and instream structures were provided in specific areas of the Chewuch acclimation pond to observe and quantify their use by the fish. The pond was divided into four sections starting from head to tail. Camouflage netting provided the overhead cover. Two pond sections had overhead cover dimensions of 7.6 m x 4.3 m. The holes were large enough to let feed and filtered sunlight through. Christmas trees set upright and anchored to the pond bottom provided the instream cover. The pond had a population of 40,888.

Pond sections were as follows head to tail: Overhead cover (oc), water depth only (wd), instream and overhead cover (oc/is), and instream cover only (ic). Approximately 2 surface meters of water depth only separated each section. Two, one cubic foot open frames were placed in the oc, wd and oc/is sections to provide a countable area. Snorkeling and streamside written observations were made for one minute in each section once a week for five weeks.

Figure 14. Chewuch acclimation pond 1992



In the first week of snorkeling approximately 95% of the fish were in the oc and oc/is sections. Fish appeared to pass through the wd section sporadically. No fish were seen in the ic section while snorkeling, but approximately 500 were seen streamside moving from the branches to receive feed.

An estimated 15,000 fish were circling the pond during the second week. This behavior is associated with smolting and migration. Only six fish were counted in the ic section, while the rest of the fish appeared to be in the oc and oc/is sections. The six fish in the ic section maintained position within the branches and did not move until the snorkeler was within 0.6 m. Fish in the oc/is section did not use the instream structures.

In the oc section two random counts of the one cu. ft. frames were made in one minute. The first count yielded 10 fish and the second 12. Spatial distribution appeared consistent throughout the water column. Using the dimensions of the covers (7.6 m x 4.3 m) and a water depth of 1.4 m the estimated number of fish under the head end cover was 19,000. In the wd section four fish and zero fish were counted within the frames to yield an estimate for this section of 6,650 fish. Although fish were in the oc/is section none were in the countable area. The instream structures within this section remained unused.

For verification, a second frame was placed in each section the fourth week. Although no fish were within the frames, the distribution appeared the same as the prior week's. The fifth week yielded a count in the oc section of ten, eight, six and zero. Using a mean of six fish/cu. ft., approximately 10,000 fish were in the oc section. No fish were seen in the wd section. The oc/is section had counts of seven, five, three and four. This corresponds to 8,000 fish. No fish were seen in the ic section. These values do not account for all the fish. It is very likely more fish were in the covered areas than counted.

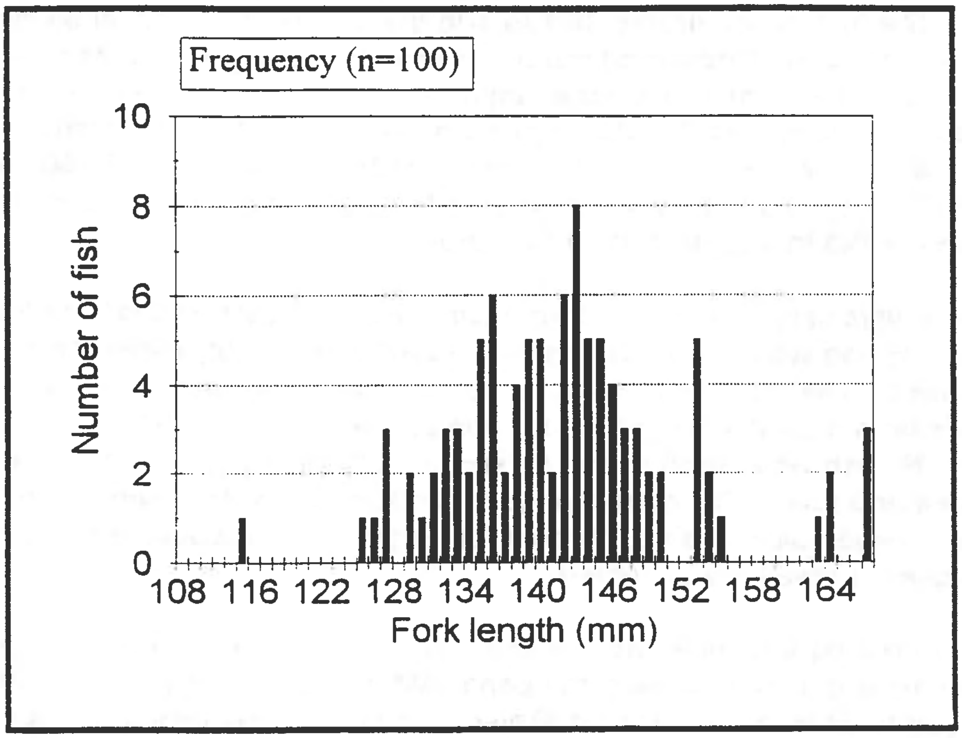
Snorkeling disrupted the fish and quantification was additionally hindered by the sheer number of fish occupying the pond. Within 30 seconds of entering the water fish began to swim around the snorkeler. Albeit, fish maintained position in the overhead covered sections regularly and at a higher density. During all five observations, whether streamside or snorkeling, there were significantly more fish in the overhead covered sections more specifically the head end cover were water entered the pond. On the other hand, fish did not use the instream structures regularly as cover. Fish came out of the overhead covered areas to feed, but the shadow created by the streamside observer did not attract fish.

The fish are reared in covered raceways with very little natural light. Additionally, because of dim lighting no shadows are created, preventing the fish from associating shadows with food. Therefore, the response by the fish in the acclimation pond is consistent with their juvenile rearing environment in the Methow FH. Whether this response is instinctive or conditioned, the outcome is the same; the fish move towards covered areas protecting themselves from terrestrial and aerial predators.

4.1.6: Juvenile Release

Anticipated volitional release date was 15 April. Actual volitional release began 19 April and ended 23 April 1994. After the first 24 hours an estimated 500 fish remained. The fish reared a total of 489 days in the MFHC. At release the Chewuch stock met the goal of 30 gram fish. They had a mean length of 141.8 mm, with a coefficient of variation (CV) of 6.7 and a condition factor (K) of 1.1. Weight of fish planted equaled 1,237 Kg. Fry to smolt survival was 97.2% or 40,862 fish.

Figure 15. Length frequency at release.



4.1.7: Juvenile Sampling

Prior to acclimation pond transfer 74 fish were sampled for genetic stock identification (GSI). Twelve of these fish were from lethal fish health examinations done in January and February 1994. The additional sixty-two were sampled 7 March. Forty were ELISA tested and twenty had gill tissue extracted for ATPase level determination. After transfer six fish were GSI sampled in conjunction with the lethal fish health examination done 1 April 1994. During release twenty fish were sampled for preliberation health assessment (organosomatic indexing, Goede 1988). These twenty fish also provided GSI, ATPase and ELISA samples.

4.2: 1992 Brood Twisp Spring Chinook Salmon

4.2.1: Incubation

Incubation for the Twisp stock followed the same procedures outlined in 4.1.1. Green egg to fry survival for the 1992 Twisp salmon was 94.2% or 36,675 fry.

4.2.2: Ponding and Early Rearing

Ponding criteria was the same as outlined in 4.1.2. Briefly, they were a KD index of 1.97, accumulated TU's of 1,750 and a belly slit of less than 1 mm. Ponding began 11 December 1992 and ended 4 January 1993. One start tank per family was used for early rearing and observations.

Figure 16.

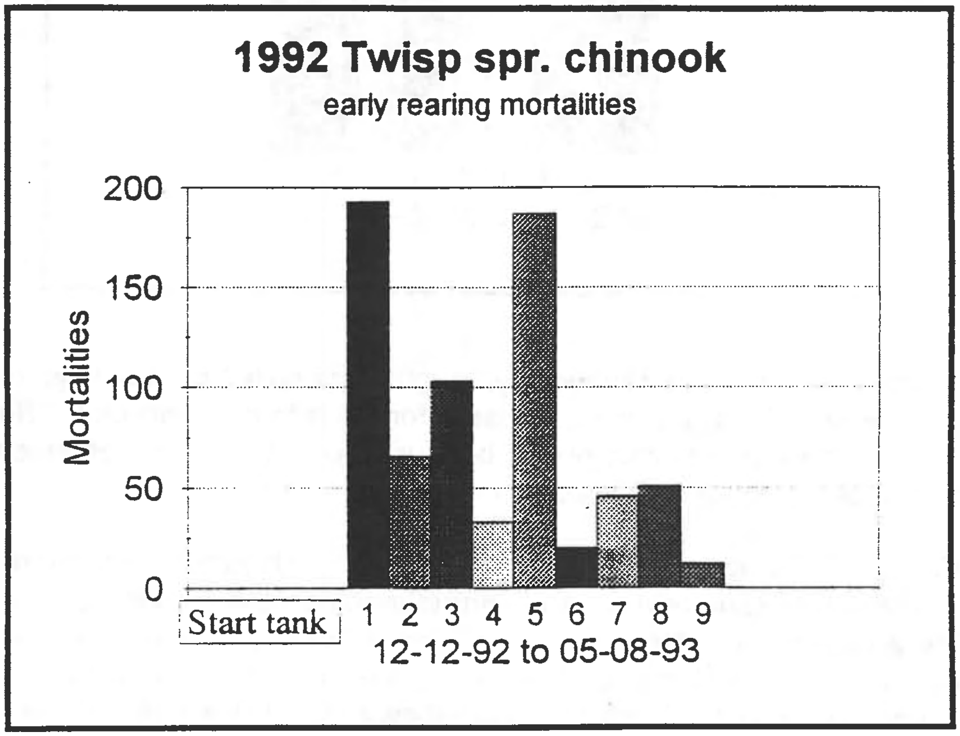
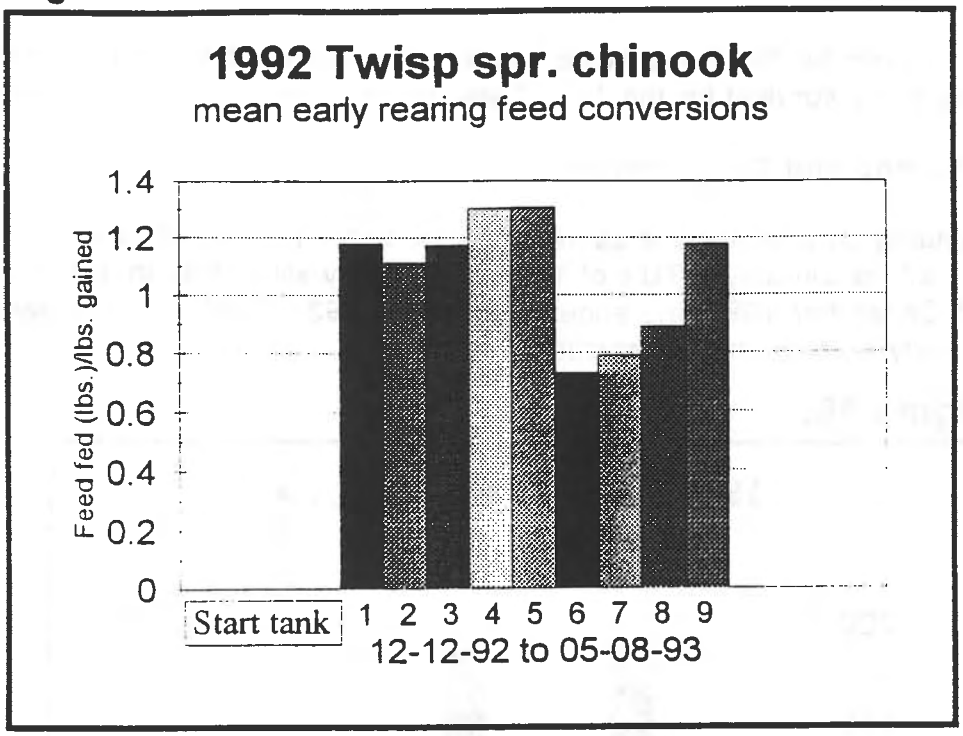


Figure 17.



Weight data was collected weekly, length data collected monthly, and a condition factor and density index calculated for each family start tank. No splits occurred during the early rearing phase because density indexes remained below the maximum limit of 0.125 lbs. of fish/cu ft./in.

CWT marking began the last week of April. Each family was given a unique sequence to monitor early rearing and contributions on the spawning grounds in future years. The adjusted total after tagging showed an overage of 213 fish for the 1992 Twisp salmon. After 100% marking fish went into raceways 5 and 6 at the Methow FH. Raceway 5 received 18,155 fish and raceway 6 received 18,008 fish. The respective density indexes were well below the maximum limit.

Figure 18.

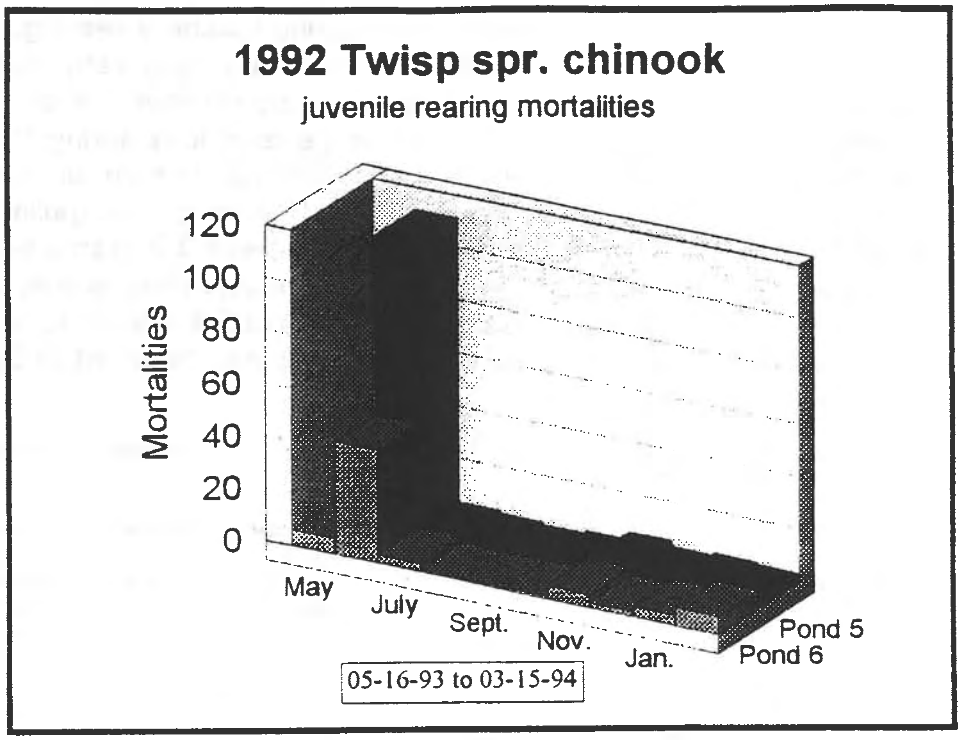
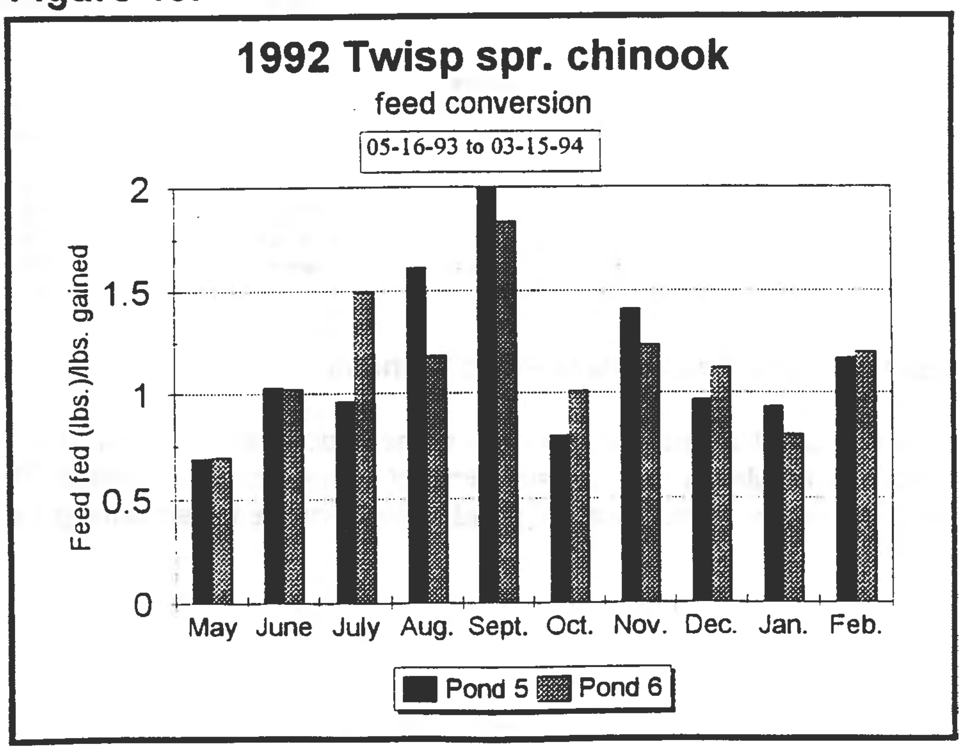


Figure 19.



4.2.3: Fish Health Monitoring

Twelve fish health examinations were done during hatchery rearing. No major fish health problems occurred. CWT recoveries showed a bias in early rearing mortalities for the 1992 Twisp salmon. Progeny of female number 1 accounted for 39.2% of the recovered CWT. This family also had elevated loss during the early rearing period (Appendix B). The progeny of the high ELISA female did not have elevated mortalities during hatchery rearing.[13] A 21-day prophylactic gallimycin treatment began 18 May 1992 for all the fish when they were 3.8 grams each. Upon treatment completion loss in the raceways had increased and drug toxicity was noted in live fish. Specifically, percent daily loss in May was 0.003% and in June it was 0.014%. By the July fish health check percent daily loss had returned to 0.003%.

Table 10. 1992 broodyear Twisp spring chinook salmon

Date	Life Stage	Size (gr.)	Mean Daily Percent Loss	Water Temp C	Gills	Body	Pathogen	Recommendations
06-Jan-93	fry	0.5	0.01	9	excellent	clean		Loss from coagulated yolk.
30-Jan-93	juvenile	0.7	0.02	9	some bacterial gill disease	air bladder fungus	Phoma	Elevated loss in progeny. of female #1.
23-Feb-93	juvenile	1.5	0.04	9	excellent	clean	Phoma	Phoma present in mortalities.
19-Mar-93	juvenile	2	0	9	good	clean		CWT fish while still inside... and begin Gallimycin treatment when fish moved outside.
23-Apr-93	juvenile	2.5	0	9	good	fin clips close		Salt treatment 3 days at 0.75% volume.
01-Jul-93	juvenile	5.5	0.003	9	mild irritation	clean		Gallimycin treatment loss returned to normal. Move to six week lethal sampling.
18-Aug-93	juvenile	7.5	0	9	good	very good		Fat level +2.
14-Oct-93	juvenile	9.5	0.001	9	mild hyperplasia	excellent		Verify that well water is soft... < 50 ppm CaCl2.
24-Nov-93	juvenile	12.5	0	9	very good	perfect		
07-Jan-93	juvenile	19.5	0	9	excellent	excellent		
28-Jan-94	juvenile	21.5	0	9	no examine			Recommend tempering in Methow river water no more than two weeks and dropping the temperature 1-2F/d.
18-Feb-94	juvenile	26	0	9	good	smolting some splits in fins		Okay for transfer in early March. Fat level +2
01-Apr-94	smolt	28.5	0	5	excellent	excellent		Okay to release when permit allows.

4.2.4: Tempering and Acclimation Pond Transfer

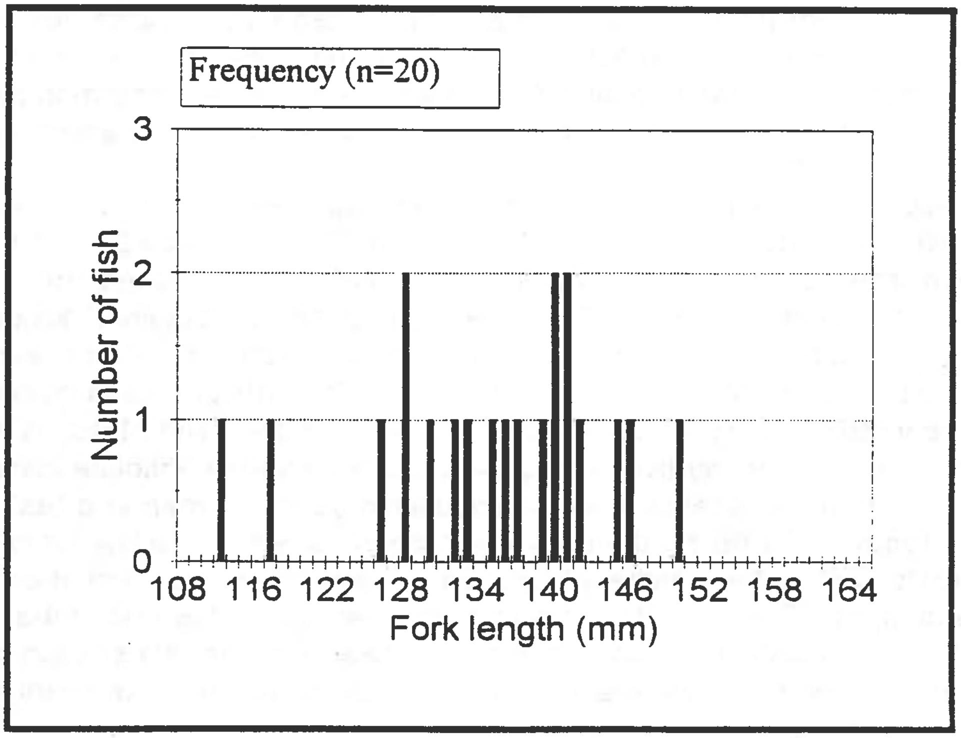
Tempering and transfer followed the same procedure outlined in 4.1.4. Transfer occurred 17 March with a travel time of 25 minutes. A total of 35,889 fish or 958 Kg. went to the Twisp acclimation pond. Only one fish died during transport.

[13]Thirteen pond mortalities out of 171 were from this family.

4.2.5: Juvenile Release

Anticipated volitional release date was 15 April. Actual volitional release began 15 April and ended 19 April 1994. The fish reared a total of 486 days in the MFHC. At release the Twisp stock met the goal of 30 gram fish. They had a mean length of 135.0 mm, with a CV of 6.8 and a K factor of 1.1.[14] Weight of fish planted into the Twisp River in spring 1994 were 1,086 Kg. Fry to smolt survival for the 1992 Twisp salmon was 97.2% or 35,861 fish.

Figure 20. Length frequency at release.



4.2.6: Juvenile Sampling

The same sampling procedure was followed for the Twisp salmon as listed in 4.1.7.

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[14]One hundred fish could not be caught at release, so information is based on a twenty fish sample.

SECTION 5: DISCUSSION

Using current 5 year average spring chinook salmon counts over Wells Dam, the Methow Basin spring chinook salmon appear to be declining.[15] Defining the level of damage is difficult. Approaching supplementation of a moderately damaged stock means collecting for hatchery broodstock less than 50% of the rivers adult escapement. Therefore the safety and escapement of the natural spawning population is a priority.

In 1992, ten adult Twisp River salmon died from stranding on the Twisp River weir. The incorporation of plywood sheets prevented further mortalities on the weir. This style of weir was design for low flow rivers and streams. The Twisp River is a high mountain stream with variable flow and large substrate. The manufacturer is currently working on ways to improve and expand its use (Don Bartlett, pers. comm.).

Trap efficiencies for the 1992 collection year were low. Using redd count expansion, the Chewuch trap collected 10% and the Twisp trap 24% of the respective river escapements. In 1993 the Chewuch trap efficiency improved considerably by increasing the attraction flow.[16] The Twisp trap efficiency remained about the same. Collecting enough fish for broodstock is a guiding principle in determining the success of the traps. Using trap efficiencies obtained in 1993 this collection goal is attainable even in low return years ie. 800 salmon over Wells Dam. The MFHC is in founding population years. Twenty-five mating pairs is a reasonable absolute minimum broodstock collection goal in founding population years (Ryman and Stahl 1980, Shaklee 1983). To reflect the upriver migration pattern and allow for in season adjustments 75% of the hatchery broodstock escapement goal should be collected by the end of June. The final 25% could be collected during the rest of the season. If the early season collection goal is not met, increases in the late season collection goal should not be made. Otherwise the hatchery may create an inadvertent shift in the salmons run timing.

Initial design and production numbers for the MFHC are based upon the volumetric parameter lbs. of fish/cu. ft. Unfortunately the length of fish is not represented in this parameter. Smaller fish have a higher metabolic demand than larger fish, so it is generally accepted that the loading densities must be lower. A parameter that does represent the length of fish is a density index (DI) or lbs. of fish/cu. ft./in. The recommended maximum DI for chinook salmon is 0.125 lbs. of

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[15]1984-1988 Wells Dam count average equaled 3,359, while the period 1989-1993 had an average of 1,518. 1990 and 1991 were the lowest recorded returns since Wells Dam operations began in 1967.

[16]In 1993 the Chewuch trap collected 186. This comprised about 30% of the spawning population.

fish/cu. ft./in. The maximum volumetric density does not exceed the recommended DI in the raceways or acclimation ponds. Twenty-four start tanks can only rear 163,800 fry through mid-March and not exceed a DI of 0.125. Mid-March is when the juvenile raceways are available after transfer of the prior broodyear to the acclimation ponds. Twelve juvenile raceways could rear to acclimation pond transfer 366,000 fish. If raceways are used to start fish this reduces either the prior or the following broodyears' numbers. Fifty mating pairs with a female fecundity of 4,500 would utilize twenty-four start tanks and two raceways for initial ponding. Ten raceways would be necessary to complete the hatchery rearing period for that broodyear. Fifty-two start tanks are necessary to make the early rearing capabilities equal to the latter.

Preliminary information from the 1993 broods' fish health reports suggests erythromycin injection of adult females protects progeny from vertical transmission of BKD. Progeny of non-injected high ELISA females contracted BKD. In contrast, progeny of injected high ELISA females have not had the same propensity.[17] To protect progeny, all adult females used for broodstock should be injected with erythromycin. In addition, the injection should be given with ample time before spawning to ensure protection to the eggs. This may require some minor changes in adult collection at the end of the season to prevent collecting ripe fish.

Eggtake in 1993 was close to program goals. This, coupled with excellent early survival, has shown limitations posed by water availability at the central hatchery.[18] Methow FH operational guidelines call for overwintering the yearlings on Methow River water. If the fish are smolting during this time proper imprinting can be jeopardized. Transportation is stressful on developing juveniles so some acclimation time should be expected (Johnson 1990). If river water rights at the acclimation ponds started in February instead of March, fish could be transferred earlier to give recovery and imprinting time before release. An additional alternative would be to provide a small amount of ground water to the intake to prevent it from freezing during the winter. This would give the opportunity for overwinter juveniles in the acclimation/release sites. Some benefits of a fall transfer would be access, no handling during late winter early spring smolt, plenty of imprint time, natural riverine temperatures, and reduction on water demands at the central hatchery. Volitional release could begin when the rivers thaw, the fish are ready to migrate, and/or the dam spills allow. Opportunities

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[17]1993 progeny of injected Twisp female had 0.0015% loss/day whereas non-injected Twisp females had 0.035% loss/day.

[18]1993 Chewuch, Methow and Twisp egg losses were 2.9(, 2.6% and 2.0% respectively. 1992 Chewuch and Twisp egg losses were 9.8% and 4.4% respectively. The Methow FH crew attributes this excellent survival to spawning the females into buckets on ice. This kept the eggs closer to the females body temperature during fertilization.

exist for scattered and point releases.[19] This increases dispersal and utilization of the habitat, while decreasing the impacts created by a large number of fish migrating from a central location. The MFHC has the ability to be different in its operation and ultimate success as a fish hatchery. To achieve the goals outlined, as natural as possible rearing and release strategies should be followed.

[19]Local residents with year-round spring fed ponds have expressed interest in releasing some 1993 brood fish.

REFERENCES

Allendorf, Fred W. and Nils Ryman. 1987. Genetic Management of Hatchery Stocks. Pages 150-152 in Nils Ryman and Fred Utter, Editors, Population Genetics and Fishery Management. University of Washington.

Bugert, R. 1994. Internal memoranda. Washington Department of Fish and Wildlife.

Goede, Ronald W. 1993. Fish Health/Condition Assessment Procedures. Utah Division of Wildlife Resources.

Johnson, Steven L., M.F. Solazzi, and T.E. Nickelson. 1990. Effects on Survival and Homing of Trucking Hatchery Yearling Coho Salmon to Release Sites. North American Journal of Fisheries Management, 10:427-433.

Meekin, Thomas K. 1993. Spring Chinook Spawning Ground Surveys of the Methow River Basin, 1992. Yakima Indian Nation Fisheries Resource Management. Page 37.

Peck, Larry. 1993. Integrated Hatchery Operations Team. Prepared for the U.S. Department of Energy Bonneville Power Administration, project number 92-043. Pages 125-138.

Suboski, Milton D., and Jennifer J. Templeton. 1989. Life Skills Training for Hatchery Fish: Social Learning and Survival. Fisheries Research, 7:343-352.

APPENDIX A.

Table 1. Chewuch River flow, Wells Dam counts, and adults trapped

Date	Chewuch River CFS	Wells Counts	Trap Count	Date	Chewuch River CFS	Wells Counts	Trap Count	Date	Chewuch River CFS	Wells Counts	Trap Count
01-May-92	655	14		16-Jun-92	586	8		01-Aug-92	246		
02-May-92	618	38		17-Jun-92	532	1		02-Aug-92	229		
03-May-92	618	25		18-Jun-92	473	3		03-Aug-92	215		1
04-May-92	751	47		19-Jun-92	418	16		04-Aug-92	205		
05-May-92	952	6		20-Jun-92	385	11		05-Aug-92	199		
06-May-92	1300	18		21-Jun-92	359	5		06-Aug-92	191		
07-May-92	1580	38		22-Jun-92	336	8		07-Aug-92	198		
08-May-92	1580	154		23-Jun-92	313	10		08-Aug-92	193		
09-May-92	1250	93		24-Jun-92	290	3	2	09-Aug-92	183		
10-May-92	1040	96		25-Jun-92	270	8	1	10-Aug-92	173		
11-May-92	896	38		26-Jun-92	254	9		11-Aug-92	160		
12-May-92	791	44		27-Jun-92	261	15		12-Aug-92	148		
13-May-92	720	49		28-Jun-92	284	27		13-Aug-92	139		
14-May-92	699	44		29-Jun-92	617		3	14-Aug-92	132		1
15-May-92	712	47		30-Jun-92	893			15-Aug-92	120		
16-May-92	661	71		01-Jul-92	570			16-Aug-92	112		2
17-May-92	681	123		02-Jul-92	509			17-Aug-92	104		
18-May-92	729	43	1	03-Jul-92	470			18-Aug-92	96		
19-May-92	750	18		04-Jul-92	439			19-Aug-92	90		
20-May-92	740	51	1	05-Jul-92	508			20-Aug-92	87		
21-May-92	683	21		06-Jul-92	490			21-Aug-92	86		
22-May-92	628	87		07-Jul-92	462			22-Aug-92	97		1
23-May-92	606	103		08-Jul-92	441			23-Aug-92	96		
24-May-92	663	14		09-Jul-92	404			24-Aug-92	92		3
25-May-92	783	24	3	10-Jul-92	378			25-Aug-92	88		1
26-May-92	937	23	1	11-Jul-92	422			26-Aug-92	83		
27-May-92	930	13	5	12-Jul-92	384			27-Aug-92	78		3
28-May-92	817	12		13-Jul-92	344			28-Aug-92	71		
29-May-92	757	18		14-Jul-92	315			29-Aug-92	64		
30-May-92	711	6		15-Jul-92	290			30-Aug-92	61		
31-May-92	656	5		16-Jul-92	271			31-Aug-92	59		
01-Jun-92	638	13		17-Jul-92	254			01-Sep-92	56		
02-Jun-92	611	5		18-Jul-92	236			02-Sep-92	55		
03-Jun-92	556	2		19-Jul-92	222			03-Sep-92	53		
04-Jun-92	507	7	1	20-Jul-92	273			04-Sep-92	50		
05-Jun-92	468	2		21-Jul-92	308			05-Sep-92	49		
06-Jun-92	437	15		22-Jul-92	333			06-Sep-92	50		
07-Jun-92	412	16		23-Jul-92	432			07-Sep-92	52		
08-Jun-92	390	5		24-Jul-92	649			08-Sep-92	54		
09-Jun-92	373	1		25-Jul-92	504			09-Sep-92	57		
10-Jun-92	354	3	1	26-Jul-92	416			10-Sep-92	55		
11-Jun-92	333	5		27-Jul-92	360						
12-Jun-92	378	10		28-Jul-92	325						
13-Jun-92	710	21		29-Jul-92	304						
14-Jun-92	833	7		30-Jul-92	282						
15-Jun-92	645	4		31-Jul-92	264						

APPENDIX A. (cont.)

Table 2. Twisp River flow, Wells Dam counts, and adults trapped

Date	Twisp River CF	Wells Count	Trap Count	Date	Twisp River CFS	Wells Count	Trap Count	Date	Twisp River CFS	Wells Count	Trap Count
01-May-92	596	14		16-Jun-92	596	8	2	01-Aug-92	89		
02-May-92	520	38		17-Jun-92	572	1		02-Aug-92	88		
03-May-92	477	25		18-Jun-92	509	3		03-Aug-92	83		
04-May-92	541	47		19-Jun-92	483	16	4	04-Aug-92	74		
05-May-92	745	6		20-Jun-92	474	11		05-Aug-92	72		
06-May-92	1020	18		21-Jun-92	445	5		06-Aug-92	70		
07-May-92	1240	38		22-Jun-92	421	8	1	07-Aug-92	69		
08-May-92	1220	154		23-Jun-92	384	10	3	08-Aug-92	68		
09-May-92	890	93		24-Jun-92	345	3		09-Aug-92	68		
10-May-92	711	96		25-Jun-92	311	8		10-Aug-92	63		
11-May-92	592	38		26-Jun-92	291	9		11-Aug-92	60		1
12-May-92	513	44		27-Jun-92	280	15		12-Aug-92	58		
13-May-92	457	49		28-Jun-92	251	27		13-Aug-92	53		
14-May-92	426	44		29-Jun-92	465		1	14-Aug-92	52		1
15-May-92	439	47		30-Jun-92	446			15-Aug-92	45		2
16-May-92	430	71		01-Jul-92	305			16-Aug-92	43		
17-May-92	469	123		02-Jul-92	258			17-Aug-92	41		
18-May-92	550	43		03-Jul-92	230			18-Aug-92	41		2
19-May-92	614	18		04-Jul-92	210		1	19-Aug-92	39		
20-May-92	620	51		05-Jul-92	252			20-Aug-92	38		
21-May-92	528	21		06-Jul-92	218			21-Aug-92	38		
22-May-92	472	87		07-Jul-92	200			22-Aug-92	38		
23-May-92	445	103		08-Jul-92	188			23-Aug-92	38		
24-May-92	569	14		09-Jul-92	177			24-Aug-92	36		
25-May-92	812	24		10-Jul-92	170			25-Aug-92	34		
26-May-92	1070	23		11-Jul-92	169			26-Aug-92	32		5
27-May-92	925	13		12-Jul-92	159			27-Aug-92	30		2
28-May-92	767	12		13-Jul-92	150			28-Aug-92	29		
29-May-92	715	18		14-Jul-92	142			29-Aug-92	29		2
30-May-92	705	6		15-Jul-92	140			30-Aug-92	28		5
31-May-92	660	5	16	16-Jul-92	131			31-Aug-92	28		3
01-Jun-92	749	13	1	17-Jul-92	125			01-Sep-92	25		1
02-Jun-92	759	5		18-Jul-92	116			02-Sep-92	23		
03-Jun-92	624	2		19-Jul-92	113		1	03-Sep-92	24		
04-Jun-92	530	7	4	20-Jul-92	120			04-Sep-92	24		
05-Jun-92	466	2		21-Jul-92	128		1	05-Sep-92	22		
06-Jun-92	438	15	1	22-Jul-92	130			06-Sep-92	23		
07-Jun-92	458	16		23-Jul-92	135			07-Sep-92	23		
08-Jun-92	477	5	2	24-Jul-92	156			08-Sep-92	26		
09-Jun-92	464	1		25-Jul-92	142			09-Sep-92	28		
10-Jun-92	431	3		26-Jul-92	131			10-Sep-92	27		
11-Jun-92	385	5		27-Jul-92	117						
12-Jun-92	841	10		28-Jul-92	110						
13-Jun-92	918	21		29-Jul-92	104						
14-Jun-92	674	7	1	30-Jul-92	100						
15-Jun-92	592	4		31-Jul-92	93						

APPENDIX B. 1992 SPRING CHINOOK SALMON METHOW HATCHERY BROODSTOCK CONTRIBUTION

Table 1. Chewuch Spring Chinook Salmon

Spawn Date	Female Number	Primary Male	Total Eggs	Eyed Eggs	Dead Eggs	Dead Fry	Unhatch Eggs	Total Egg Loss	Percent Egg Loss	Eggs per Kg.	Start Tank	Ponded Fry	Start Tank Loss	Adjusted Total After Tagging	Tag Code	Overage/ Shortage	Recovered CWT*	Projected Release	Fry-Smolt Percent Loss
20-Aug-92	92DO1	92DO43/042	5783	5660	123	7	5	135	2.33	4562	13	5648	232	5236	63-51/21	-180	6	5218	4.77
20-Aug-92	92DO2	92DO22/003	5359	3455	1904	5	20	1929	36.00	5793	14	3430	217	3150	63-51/39	-63	19	3119	7.87
26-Aug-92	92DO3	92DO42/147	3025	2699	326	11	60	397	13.12	3330	15	2628	55	2555	63-43/32	-18	16	2529	3.17
26-Aug-92	92DO4	92DO23/144	4515	4488	27	12	14	53	1.17	5165	16	4462	48	4180	63-48/48	-234	4	4165	1.51
26-Aug-92	92DO5	92DO24/167	3737	3582	155	77	51	283	7.57	5344	17	3454	29	3324	63-51/40	-101	12	3296	1.71
26-Aug-92	92DO6	92DO25/160	3638	3594	44	2	6	52	1.43	3595	18	3586	6	3608	63-51/38	28	36	3557	1.58
31-Aug-92	92DO10	92DO7/116	4637	4537	100	14	5	119	2.57	3236	20	4518	25	4511	63-48/50	18	47	4449	1.93
31-Aug-92	92DO11	92DO8/028	5775	4774	1001	7	3	1011	17.51	5066	21	4764	17	4451	63-51/24	-296	2	4438	0.67
31-Aug-92	92DO12	92DO7/015	4144	4123	21	6	3	30	0.72	4148	22	4114	16	4107	63-51/23	9	3	4093	0.73
03-Sep-92	92DO21	92DO18/175	3839	3651	188	42	38	268	6.98	3533	23	3571	61	3467	63-51/33	-43	20	3435	2.68
17-Sep-92	92DO41	92DO43/042	4212	3351	861	181	313	1355	32.17	4200	24	2857	126	2607	63-43/31	-124	21	2563	6.52
			48664	**43914**	**4760**	**364**	**518**	**5632**	**11.57**			**43032**	**832**	**41196**		**-1004**	**186**	**40862**	**2.83**

*pond mortalities only

Average Fecundity = 4,424
Fecundity Range = 3,025 - 5,783
Green Egg to Fry Survival = 88.2%
Fry to Smolt Survival = 97.2%
Egg to Smolt Survival = 85.7%

Table 2. Twisp Spring Chinook Salmon

Spawn Date	Female Number	Primary Male	Total Eggs	Eyed Eggs	Dead Eggs	Dead Fry	Unhatch Eggs	Total Egg Loss	Percent Egg Loss	Eggs per Kg.	Start Tank	Ponded Fry	Start Tank Loss	Adjusted Total After Tagging	Tag Code	Overage/ Shortage	Recovered CWT*	Projected Release	Fry-Smolt Percent Loss
13-Aug-92	92DQ1	92DQ52/072	5481	5439	42	15	9	66	1.20	4099	1	5415	193	5245	63-51/22	23	67	5147	5.55
20-Aug-92	92DQ2	92DQ51/051	4703	4571	132	8	1	141	3.00	4846	2	4562	66	4511	63-51/25	15	11	4485	2.04
20-Aug-92	92DQ3	92DQ61/116	4895	3886	1009	146	132	1287	26.29	4269	3	3608	103	3396	63-48/49	-109	16	3363	4.00
26-Aug-92	92DQ8	92DQ50/054	3951	3897	54	10	13	77	1.95	3639	4	3874	33	3937	63-48/51	96	18	3903	1.70
27-Aug-92	92DQ32	92DQ56/080	4487	4385	102	17	14	133	2.96	3742	5	4354	187	4323	63-51/41	156	20	4288	5.14
27-Aug-92	92DQ33	92DQ58/055	4197	4118	79	28	16	123	2.93	3581	6	4074	20	4089	63-51/34	35	13	4068	1.00
27-Aug-92	92DQ34	92DQ48/050	3263	3248	15	3	3	21	0.64	4335	7	3242	46	3220	63-51/35	24	10	3197	2.14
27-Aug-92	92DQ35	92DQ49/043	3867	3688	179	90	42	311	8.04	4077	8	3556	51	3426	63-51/36	-79	13	3398	2.31
03-Sep-92	92DQ42	92DQ45/131	4107	4022	85	18	14	117	2.85	2925	9	3990	12	4030	63-51/37	52	3	4012	0.74
			38951	**37264**	**1697**	**336**	**244**	**2276**	**5.84**			**36676**	**711**	**36177**		**213**	**171**	**35861**	**2.84**

*pond mortalities only

Average Fecundity = 4,328
Fecundity Range =3,262 - 5,481
Green Egg to Fry Survival = 94.2%
Fry to Smolt Survival = 97.2%
Egg to Smolt Survival = 91.6%

APPENDIX C. RELEASE OF SPRING CHINOOK SALMON FROM METHOW FISH HATCHERY COMPLEX 1994

Table 1. 1992 broodyear Chewuch spring chinook salmon

Stock	Tagcode	Number Tagged	Estimated # at Release	Size at Release	Kilograms	Release Date	Type of Release	Site of Release
Chewuch	63 51/21	5236	5218					
	63 51/39	3150	3119					
	63 43/32	2555	2529					
	63 48/48	4180	4165					
	63 51/40	3324	3296					
	63 51/38	3608	3557					
	63 48/50	4511	4449					
	63 51/24	4451	4438					
	63 51/23	4107	4093					
	63 51/33	3467	3435					
	63 43/31	2607	2563					
		41196	40862	30 grams	1237	19-Apr-94	Volitional	Chewuch River

Table 2. 1992 Broodyear Twisp Spring Chinook Salmon

Stock	Tagcode	Number Tagged	Estimated # at Release	Size at Release	Kilograms	Release Date	Type of Release	Site of Release
Twisp	63 51/22	5245	5147					
	63 51/25	4511	4485					
	63 51/41	3396	3363					
	63 51/34	3937	3903					
	63 48/49	4323	4288					
	63 48/51	4089	4068					
	63 51/35	3220	3197					
	63 51/36	3426	3398					
	63 51/37	4030	4012					
		36177	35861	30 grams	1086	15-Apr-94	Volitional	Twisp River

Notes:

1) Estimated number of release is based on CWT recovered from mortality within the hatchery, and GSI samples taken prior to release.
2) 100% of the population was tagged.
3) Fish transferred to the acclimation ponds 14-17 March 1994.

APPENDIX D. Performance standards for the Methow Fish Hatchery Complex (Peck 1993)

Measures	Stock	Standard Set	Standard Achieved	Constraints
Adult Capture	Chewuch	238	20	
	Twisp	238	30	*A*
Adult Prespawn Survival	Chewuch	80%	85%	
	Twisp	80%	80%	
Egg-Take	Chewuch	350,000	47,660	*B*
	Twisp	350,000	39,164	
Green Egg-to-Fry Survival	Chewuch	85%	88.8%	
	Twisp	85%	94.2%	
Fry-to-Smolt Survival	Chewuch	70%	97.2%	
	Twisp	70%	97.2%	
Fish Releases	Chewuch	250,000	40,862	
	Twisp	250,000	35,861	
Adults Passed Upstream	Chewuch	66%	89.5%	
	Twisp	66%	73%	
Percent Survival	Chewuch	1.0%	N/A	
	Twisp	1.0%	N/A	

A ***An additional 10 fish were killed at the weir from stranding.***

B ***Eggs from the Looking Glass CWT female are not included in this information.***

APPENDIX E. (cont.)

Table 2 . 1992 broodyear Twisp spring chinook salmon

Week/Mon.	BioDiet Starter-grams			BioDiet Grower-Kg.				BioDry 1000-Kg.		Medicated Feed-Kg.
Ending	#1	#2	#3	1.0 mm	1.3 mm	1.5 mm	2.5 mm	2.0 mm	2.5 mm	Gallimycin 1.3 mm
19-Dec-92		454								
26-Dec-92		1816								
02-Jan-93		3450								
09-Jan-93		3587	291							
16-Jan-93		3219	1167							
23-Jan-93		3196	1126							
30-Jan-93		1680	2915							
06-Feb-93		1090	4395							
13-Feb-93		590	2724	1						
20-Feb-93			3437	1.5						
27-Feb-93			1503	4						
06-Mar-93			1158	4						
13-Mar-93			1285	4.5						
20-Mar-93				6						
27-Mar-93				6.5						
03-Apr-93					7					
10-Apr-93					9					
17-Apr-93					9					
24-Apr-93					7.5					
01-May-93					10					
08-May-93					9.5					
15-May-93					9					
22-May-93					6					5.5
29-May-93										10
30-Jun-93					10	30				15
31-Jul-93						56				
31-Aug-93						61				
30-Sep-93						75				
31-Oct-93							86			
30-Nov-93							55		94	
31-Dec-93									157	
31-Jan-94								65	92	
28-Feb-94									119	
31-Mar-94									125	
30-Apr-94									75	

APPENDIX E. FEED USAGE

Table 1. 1992 broodyear Chewuch spring chinook salmon

Week/Mon.	BioDiet Starter-grams			BioDiet Grower-Kg.				BioDry 1000-Kg.		Medicated Feed-Kg.
Ending	#1	#2	#3	1.0 mm	1.3 mm	1.5 mm	2.5 mm	2.0 mm	2.5 mm	Gallimycin 1.3 mm
26-Dec-92		1362								
02-Jan-93		4131								
09-Jan-93		4358								
16-Jan-93	390	4526	386							
23-Jan-93	795	3750	1875							
30-Jan-93	436	3423	2152							
06-Feb-93	32	3369	2751							
13-Feb-93		1544	3786	0.06						
20-Feb-93		363	4145	1.5						
27-Feb-93		123	4213	3						
06-Mar-93			3918	4.5						
13-Mar-93			3664	4						
20-Mar-93				7.5						
27-Mar-93				7						
03-Apr-93					8					
10-Apr-93					9					
17-Apr-93					11					
24-Apr-93					10.5					
01-May-93					9.5					
08-May-93					10.5					
15-May-93					9.5					
22-May-93					6.5					6
29-May-93										11.5
30-Jun-93					11.5	33				18
31-Jul-93						63.5				
31-Aug-93						71.5				
30-Sep-93						85.5				
31-Oct-93							101			
30-Nov-93							55.5		95	
31-Dec-93									173	
31-Jan-94								144.5	84	
28-Feb-94									135	
31-Mar-94									155	
30-Apr-94									96	

METHOW VALLEY SPRING CHINOOK
SUPPLEMENTATION PROJECT
ANNUAL REPORT, 1993
BY
JOEL HUBBLE, YAKAMA INDIAN NATION

APPENDIX - K

METHOW VALLEY SPRING CHINOOK SUPPLEMENTATION PROJECT

ANNUAL REPORT

1993

Prepared by

JOEL HUBBLE

Yakama Indian Nation
Fisheries Resource Management

Prepared for

Douglas County Public Utility District

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1.0 ACKNOWLEDGEMENTS

Special thanks is given to the fisheries technicians Robert Cruz, Sandy Pinkham and Paul Wahpat who oversaw the screw trap operation and to fisheries technicians Vern Bogard, Mike Olney and Jason Rau who conducted the summer parr assessment snorkeling surveys. Special acknowledgement is given to Debbie Azure and Preston Harrison who administered this contract.

2.0 ABSTRACT

An estimated number of 8,908 spring chinook smolts migrated from the Chewuck River and the median date of outmigration was April 19. The mean fork length of outmigrants was 100 mm and the mean condition factor was 1.02. The week of peak outmigration (April 15-24) occurred prior to the week of peak stream discharge (May 15-21).

An estimated number of 828 steelhead/rainbow outmigrated from the Chewuck River, of which 76.4% were identified as steelhead smolts. The median date of outmigration was April 28. The mean fork length and condition factor was 158 mm and 0.918.

An estimated 1,993 spring chinook and 140 steelhead/rainbow parr moved downstream from the Chewuck River during the Fall monitoring period. Parr were still being enumerated when river ice caused termination of trap monitoring on November 18.

The late summer spring chinook parr estimate in the Chewuck River was 8,564 fish with temperature adjustment and 5,838 fish when uncorrected for water temperature. The highest spring chinook parr densities occurred in reaches 2-4 (RM 2.3 to RM 23.3), ranging from 231 to 276 fish per river mile (temperature-unadjusted). The late summer steelhead/rainbow parr estimate was 2,765 fish (temperature-unadjusted) and the highest parr density (626 fish per river mile) occurred from RM 23.3 to RM 24.6 (reach 5).

3.0 INTRODUCTION

The research discussed in this report is part of the Methow Hatchery Complex Evaluation Work Plan (Wells Coordination Committee, 1993). The Methow Valley Spring Chinook Hatchery (MVSCH) is a supplementation program directed towards the enhancement of the wild spring chinook stocks in the Methow River basin. The MVSCH is the result of a mitigation agreement between Douglas PUD and the fisheries co-managers for smolt losses at Wells Dam. The goal of the evaluation work plan is to "**document whether or not the hatchery-based compensation program is producing the Phase I compensation required under the Wells Project Settlement Agreement in a manner that minimizes or eliminates ecological and genetic risks to the natural spawning populations and is consistent with the guidelines and procedures developed under the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program. The Evaluation Plan will also estimate survival of hatchery-produced fish from release to adult**". Specific tasks carried out by the Yakama Indian Nation (YIN) in 1993 included Subtask 2.4.1 ("**Evaluate downstream migrant trapping as an indicator of freshwater production**"), Subtask 2.4.3 ("**Evaluate parr density and standing crop estimation as an indicator of freshwater production**") and Subtask 2.4.4 ("**Begin implementation of a long-term productivity monitoring program**").

4.0 DESCRIPTION OF STUDY AREA

The Methow River Basin is located in north-central Washington on the eastern slope of the Cascade Mountains (Figure 1). The river and its tributaries lie in Okanogan County and drain an area of nearly 1,800 square miles. The headwaters of the Methow River are located near the Cascade Crest at an elevation of more than 6,000 feet At the city of Winthrop, where the Chewuch River joins the Methow River river mile (RM) 50, the river elevation is 1,745 feet The river elevation drops to 779 feet where the Methow and Columbia rivers meet at Pateros, WA.

The upper portion of the Methow basin is heavily forested, predominantly with ponderosa pine. This area is used extensively for recreation and is experiencing significant growth in residential and commercial development.

The lower Methow Valley is a fertile agricultural area. The fruits and other crops grown here place heavy irrigation demands on the Methow River and its tributaries. Water quality in the lower Methow basin nonetheless remains high, with an AA rating from the Department of Ecology.

The Chewuck drainage basin is 530 square miles in size and the anadromous zone for spring chinook extends upstream to river mile 31. The majority of spring chinook spawning (73.6% in 1993) occurs between Eight Mile Ranch RM 10 and Buck Creek RM 22.

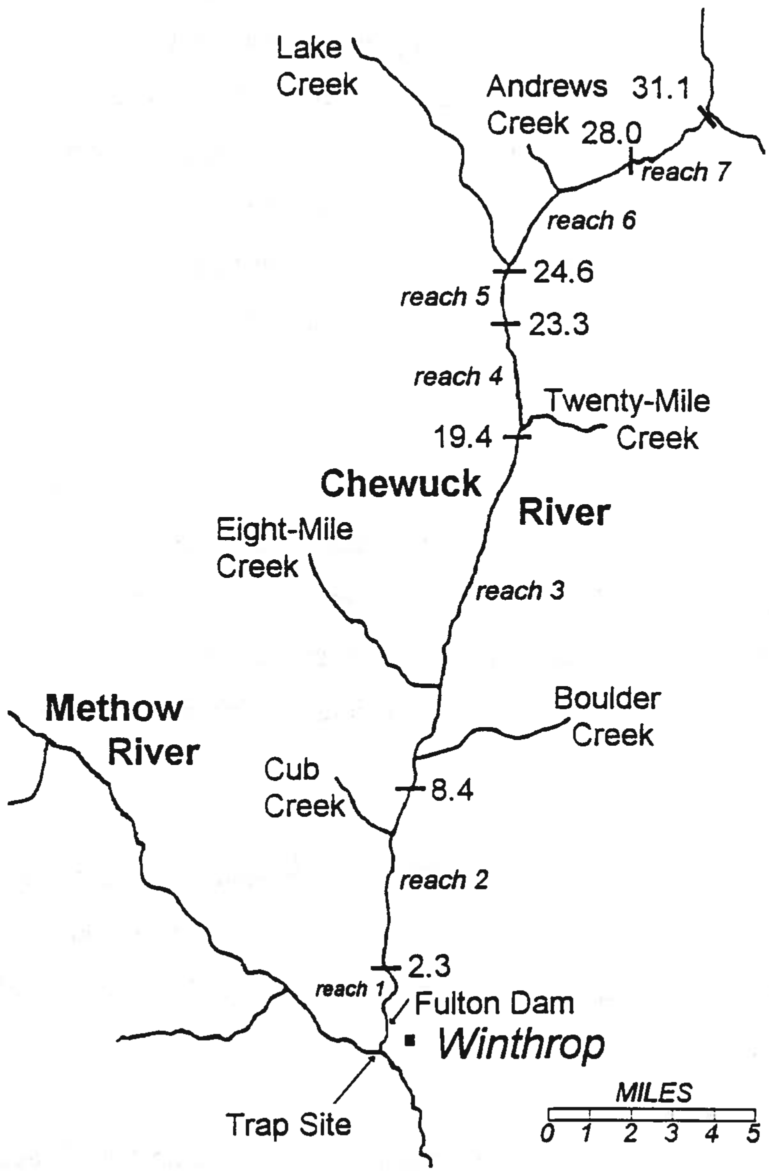

Figure 1. Chewuck basin map.

5.0 MATERIALS AND METHODS

5.1 Outmigration

5.1.1 Spring Season

We monitored spring chinook smolt outmigration at Fulton Dam, RM 0.75 beginning April 8, 1993. Initial monitoring was conducted using a v-weir trap installed in Fulton Ditch. The weir consisted of 1/4 inch hardware cloth panels configured in a "v" in plan view. A four inch PVC pipe at the apex of the weir directed fish into a live box located farther downstream. The weir was used to monitor the smolt outmigration from April 8 through May 12. For the remainder of the smolt monitoring season we deployed an eight foot diameter E.G. Solutions screw trap, fishing along the right bank, immediately upstream from the ditch headgate. Low river discharge precluded operation of the screw trap before May 12. Smolt monitoring was ended for the season on June 9, 1993.

To determine smolt entrainment into Fulton Ditch and thus the smolt trapping efficiency, we released four groups of 50 fish each, at the head of the forebay. Three of the four releases were made in the middle of the river and the fourth at the left bank margin. Fish were marked with a dorsal and/or ventral clip of the caudal fin. Trap efficiency releases could not be conducted for the screw trap due to insufficient numbers of smolts available by the time the screw trap could be used.

We anesthetized trapped fish with MS-222 and recorded fork lengths from most spring chinook and steelhead smolts and other trout species. We weighed a random sample of spring chinook and steelhead smolts, and collected up to 20 random scale samples per week from both species.

Stream temperature was recorded continuously by a Omidata 620 datapod. Mean daily stream discharge was obtained from the USGS gauging station at RM 0.1.

5.1.2 Fall Season

We began monitoring fall-winter outmigrants was initiated September 21 and ceased November 18 when river ice conditions became severe. The eight foot diameter screw trap was fished at RM 0.1 at the town of Winthrop. We made three trap efficiency releases, marking fish as in the Spring and releasing them upstream at RM 0.3.

5.2 Late Summer Parr Densities

We estimated parr density by snorkeling in the Chewuck River from August 16 through September 22. The river was surveyed from its confluence to RM 29. Individual site selections were based upon Hankin and Reeves (1988) methodology where every fifth habitat unit (pool, riffle or glide) was snorkeled.

Snorkelers surveyed habitat units during the day (0900-1630), moving three abreast upstream. Where the stream width was greater than about 75 feet, we made two passes, one on each bank, spacing the three snorkelers between the bank and the thalweg. Water velocity at some sites limited the distance from the bank at which surveyors could operate. The thalweg region of wider sites was usually too fast and deep for snorkelers. The water was clear enough, however, for this region to be visible from the calmer and shallower water. At sites less than about 75 feet wide the three snorkelers conducted a single pass with a single snorkeler in the thalweg region and the other two snorkelers next to the bank.

6.0 RESULTS AND DISCUSSION

6.1 Outmigration

6.1.1 Spring Season

6.1.1.1 Spring chinook

Smolt outmigration presumably began before April 8, as 19 fish were captured on the first day of monitoring. The dates of 25%, 50% and 75% cumulative outmigration were April 15, April 19 and April 24, respectively (Figure 2). The estimated smolt outmigration for the season was 8,908 fish.

Smolts ranged in length from 65 mm to 123 mm, with a mean length of 100 mm (Figure 3). There was no significant change in the mean length averaged by week, throughout the outmigration period.

The mean smolt condition factor was 1.02, and there was no significant change in the mean weekly condition factor throughout the outmigration period. The length-to-weight relationship was described by the linear regression equation-
WEIGHT = LENGTH * 0.30 - 19.9, $r^2 = 0.86$; (Figure 4) where fork length is in millimeters and weight is in grams.

The mean daily stream temperature in April was 8.4° C, and ranged from 7.5° C to 8.5° C. In May the mean daily stream temperature was 8.7° C, and ranged from 8.0° C to 10.0° C. The mean daily stream temperature in June was 11.4° C, and ranged from 9.5° C to 12.0° C.

Figure 5 presents the mean daily stream discharge for the Chewuck River during the smolt outmigration period. Stream flow did not change significantly until May 6 (the mean daily discharge prior to this was 92 cfs) when the mean daily discharge increased to 178 cfs from 117 cfs on May 5. The period of peak discharge occurred from May 15 through May 21, when the mean daily discharge reached a high of 2,780 cfs on May 20.

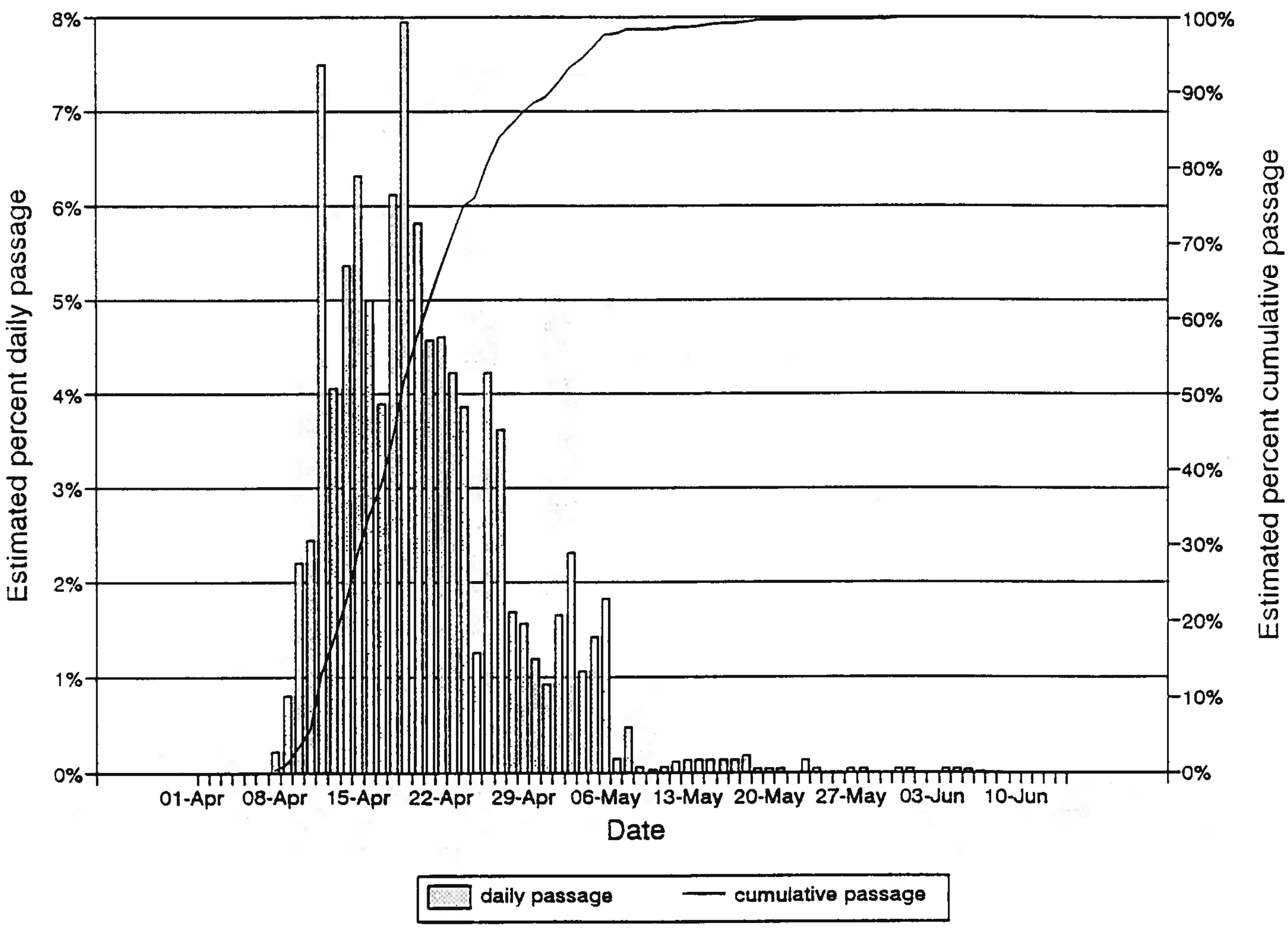

Figure 2. Estimated daily and cumulative spring chinook smolt out-migration from the Chewuck River, Spring 1993.

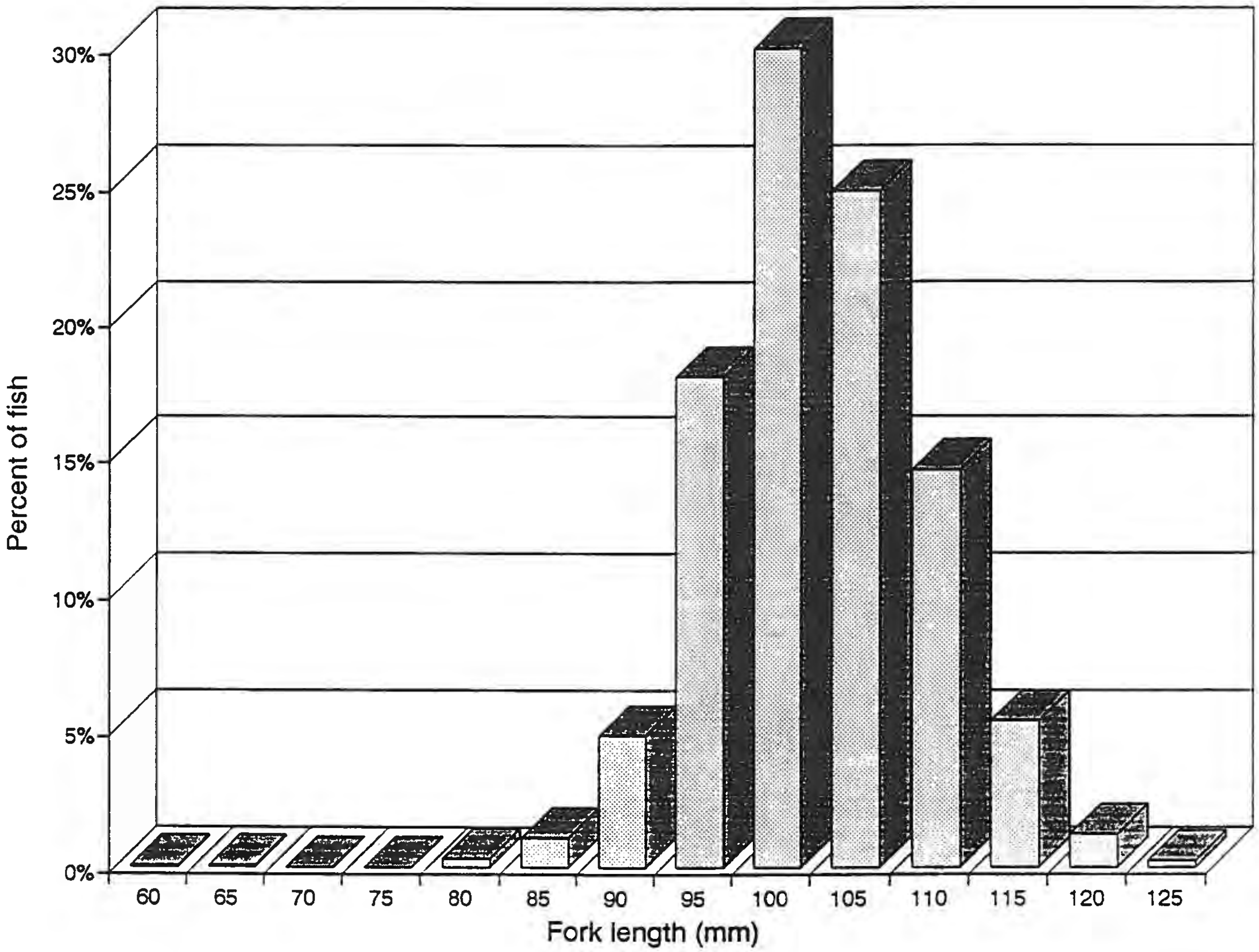

Figure 3. Length frequency distribution of Chewuck River spring chinook smolts, 1993.

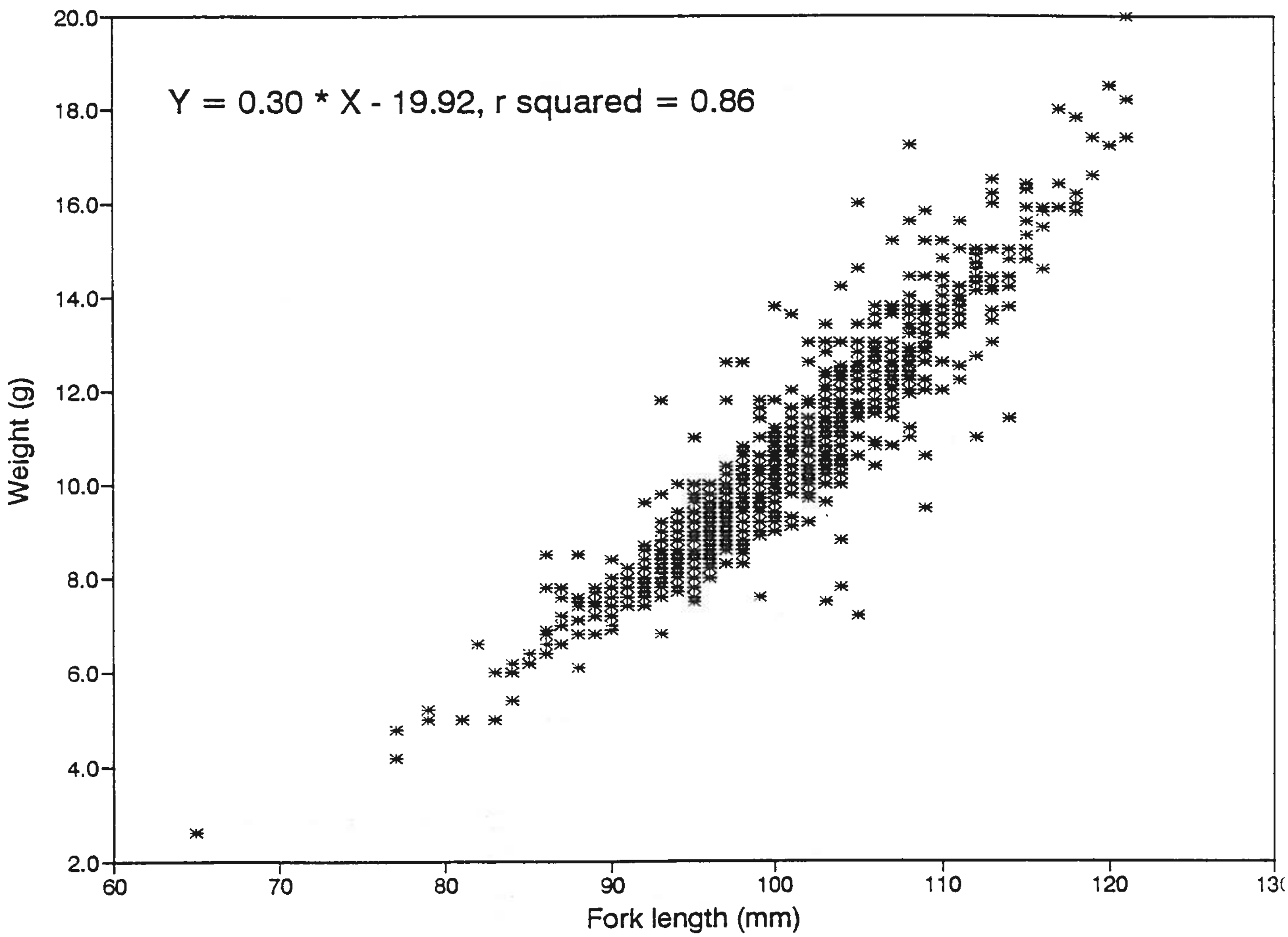

Figure 4. Length to weight relationship of Chewuck River spring chinook smolts, 1993.

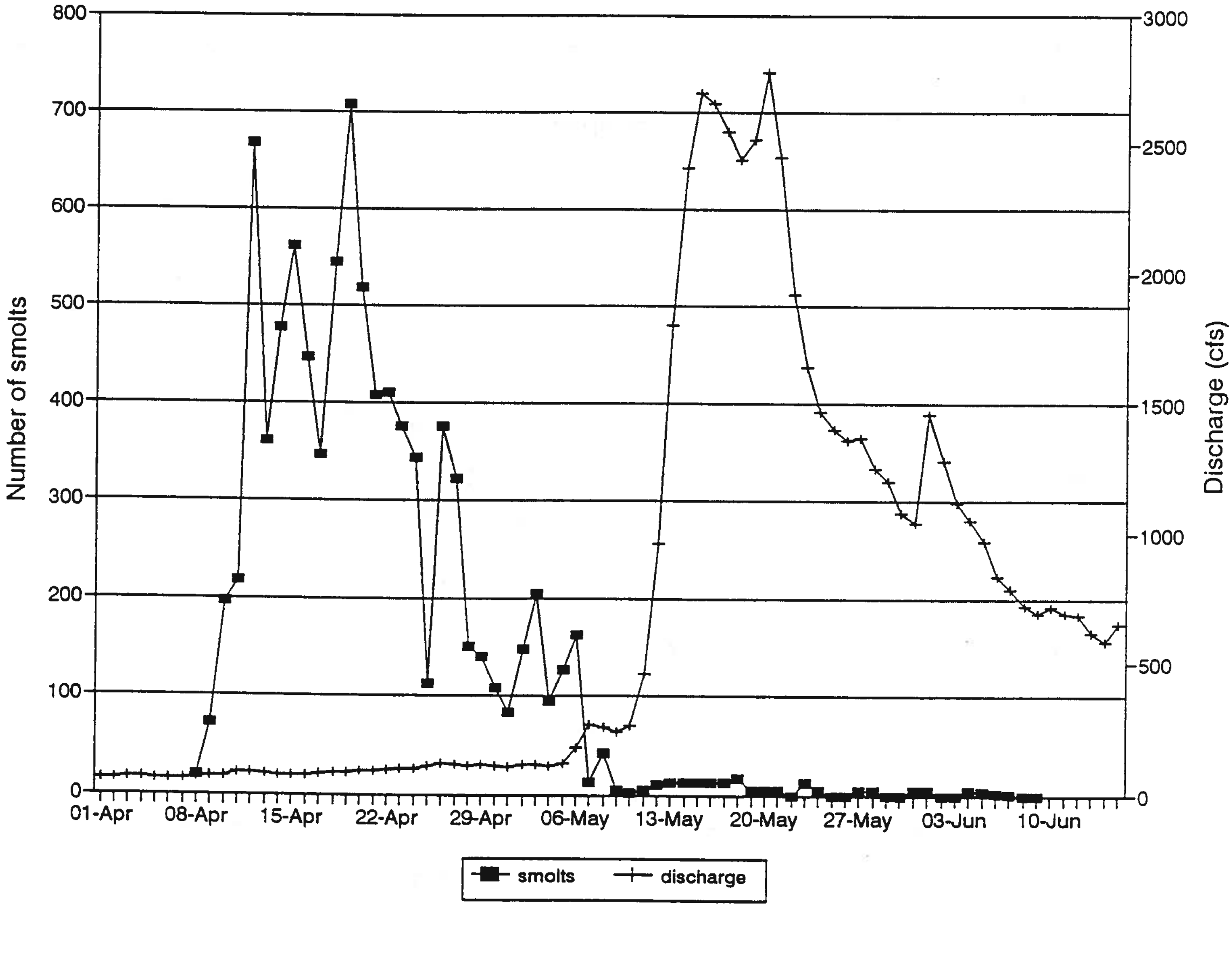

Figure 5. Estimated daily spring chinook smolt outmigration and mean daily discharge (cfs) for the Chewuck River, Spring 1993.

Prior to discussing specifics of the spring chinook smolt outmigration, it may be beneficial to briefly discuss key factors in the smolt transformation process. Smolt transformation is a complex and interactive process involving both endogenous and exogenous factors (Hoar, 1976). Iwamoto (1982) found photoperiod to be the most important exogenous cue affecting the smolt transformation process. Wedemeyer et al. (1980) concluded that the stimulatory affect of photoperiod on smolt transformation was the direction (increasing or decreasing) and rate of change of the day length, and not simply the length of day. Both Iwamoto (1982) and Clarke et al. (1978) determined that stream temperature regulates the response to photoperiod, but does not act as an exogenous cue. Knutsson and Grav (1976) examined the interaction between photoperiod and temperature, and their resultant effect on smoltification (measured by seawater survival) in Atlantic salmon. At 7° C, they found no significant differences among three different photoperiod treatments; however, at 11° C there were significant differences in seawater survival. The smolt transformation process, however, is not simply a function of exogenous cues. Ericksson and Lundqvist (1982), working with Baltic salmon parr, observed a cyclic endogenous smoltification process under a constant water temperature and photoperiod. Wagner (1971) demonstrated that salmonid parr would undergo smolt transformation in total darkness, indicating there was an inherent endogenous process involved separate from the effects of exogenous cues. Ericksson and Lundqvist (1982) and Hoar (1965) have suggested that photoperiod may act more as a synchronizing cue, rather than a stimulating cue. They concluded that photoperiod synchronizes the endogenous process of smolt transformation to the environment.

High or increasing stream discharge does not stimulate smoltification, but it provides a favorable environmental condition to enhance in-river smolt survival. The lack of correlation between smolt outmigration timing and Chewuck River discharge (Figure 2) is rather interesting. By the time there was a significant increase in discharge (May 6), 97.7% of the smolts had left the Chewuck River. Half the total outmigration of smolts left from April 15 through April 24, well ahead of the May 15-21 peak discharge period. The median outmigration date (April 19) is similar to that observed in the Yakima River basin, where the average median date of spring chinook outmigration is April 25 (Fast et al., 1991).

For the past two years the same annual discharge pattern has been observed in the Chewuck River (Figure 6). Highest stream flows were sustained in May and June (USGS, 1992 and 1993). A similar annual discharge pattern is observed in the Methow River at Twisp (Figure 7) for water years 1919-62 (Rhodus, 1988). It appears, therefore, that the Chewuck River discharge pattern observed for the past two years is typical of that for the entire Methow River Basin.

Since smolt transformation occurs within a specific biological window that is largely regulated by photoperiod and water temperature, the opportunity for smolts originating from the Chewuck River to take advantage of the annual high water period appears minimal. The biological window for smoltification, at least in 1993, occurred earlier than the high flow period.

Within the context of long-term adaptation to the watershed, there are undoubtedly other important factors that influence when smoltification occurs. For example, the lack of synchronization between an early smolt outmigration and a late peak discharge period in the Chewuck River, may be outweighed by the increased travel distance to the ocean and the increased likelihood of encountering higher stream discharge further downstream in the lower Columbia River. Overall travel time may actually be reduced if smolts leave the Methow River basin before the relatively late spring runoff period.

6.1.1.2 Steelhead

An estimated 828 steelhead/rainbow outmigrated past the Chewuck screw trap. Of these, 76.4% were identified as steelhead smolts based on the presence of external smolt characteristics, i.e., absence of parr marks, silver body color and black fins. The daily and cumulative outmigration for steelhead smolts is presented in Figure 8. The dates of 25%, 50% and 75% cumulative outmigration were April 23, April 28 and May 7, respectively. The mean length

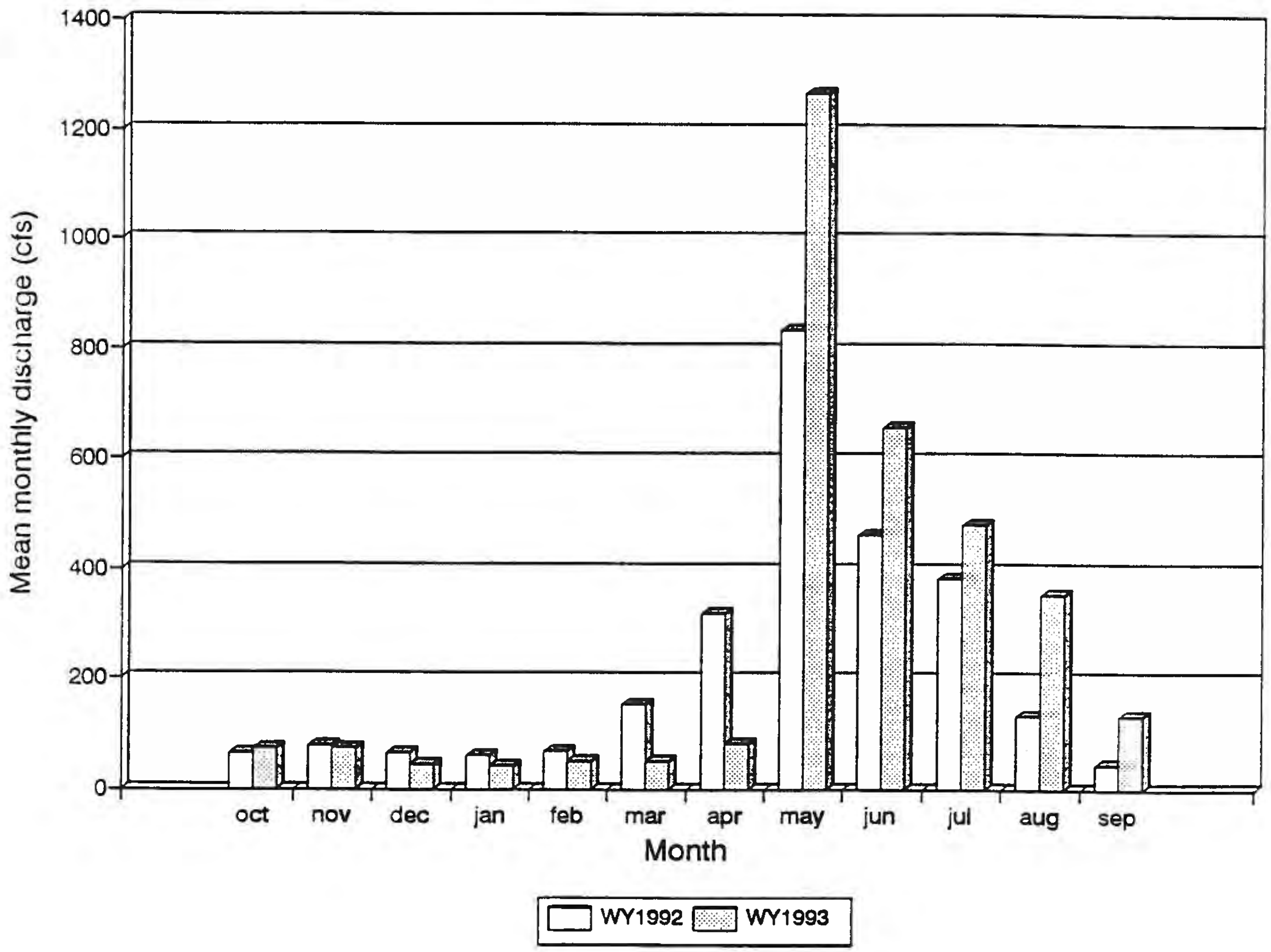

Figure 6. Mean monthly discharge (cfs) for the Chewuck River for water years 1992 and 1993.

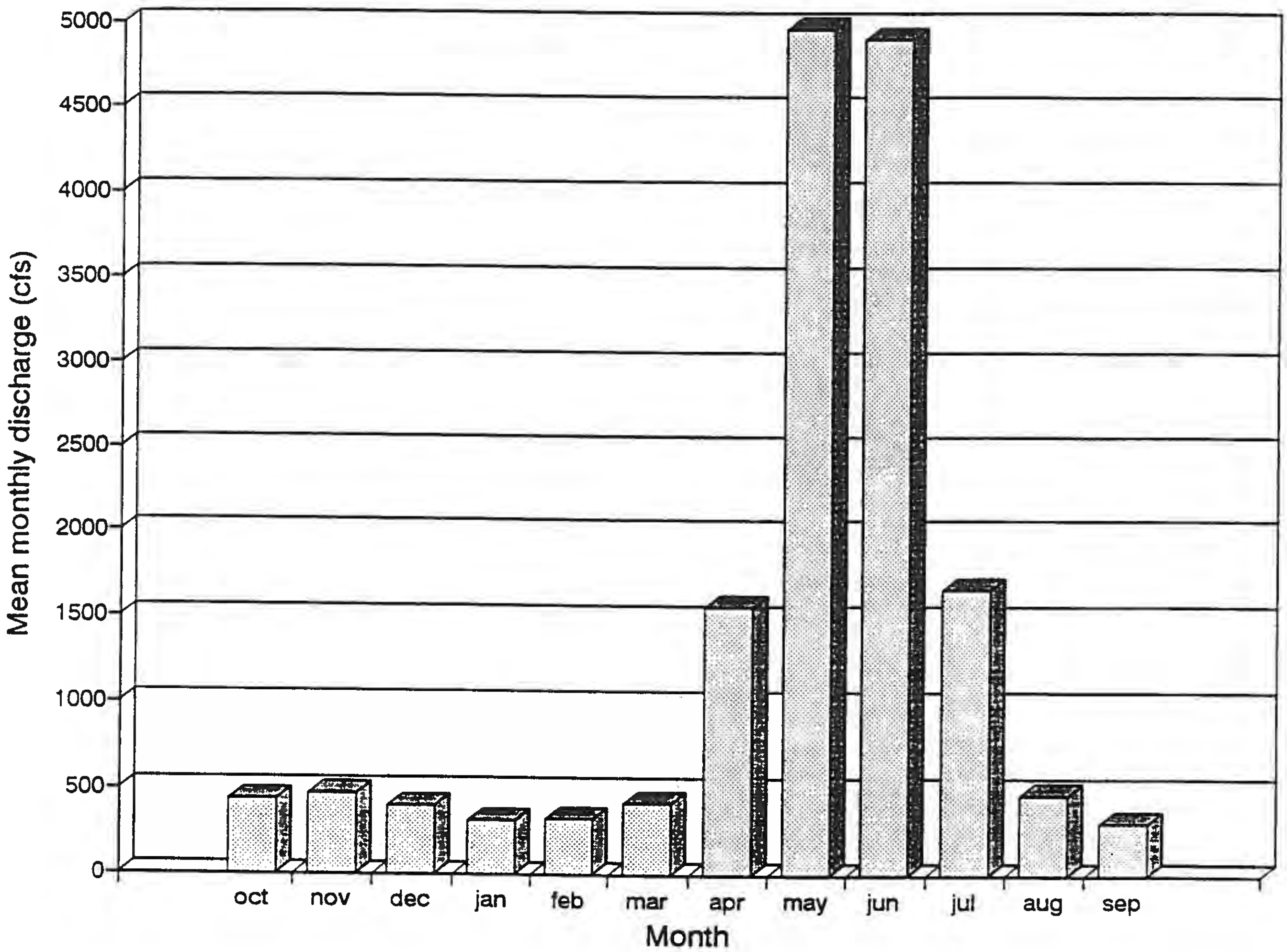

Figure 7. Mean monthly discharge (cfs) for the Methow River at Twisp for water years 1919-62.

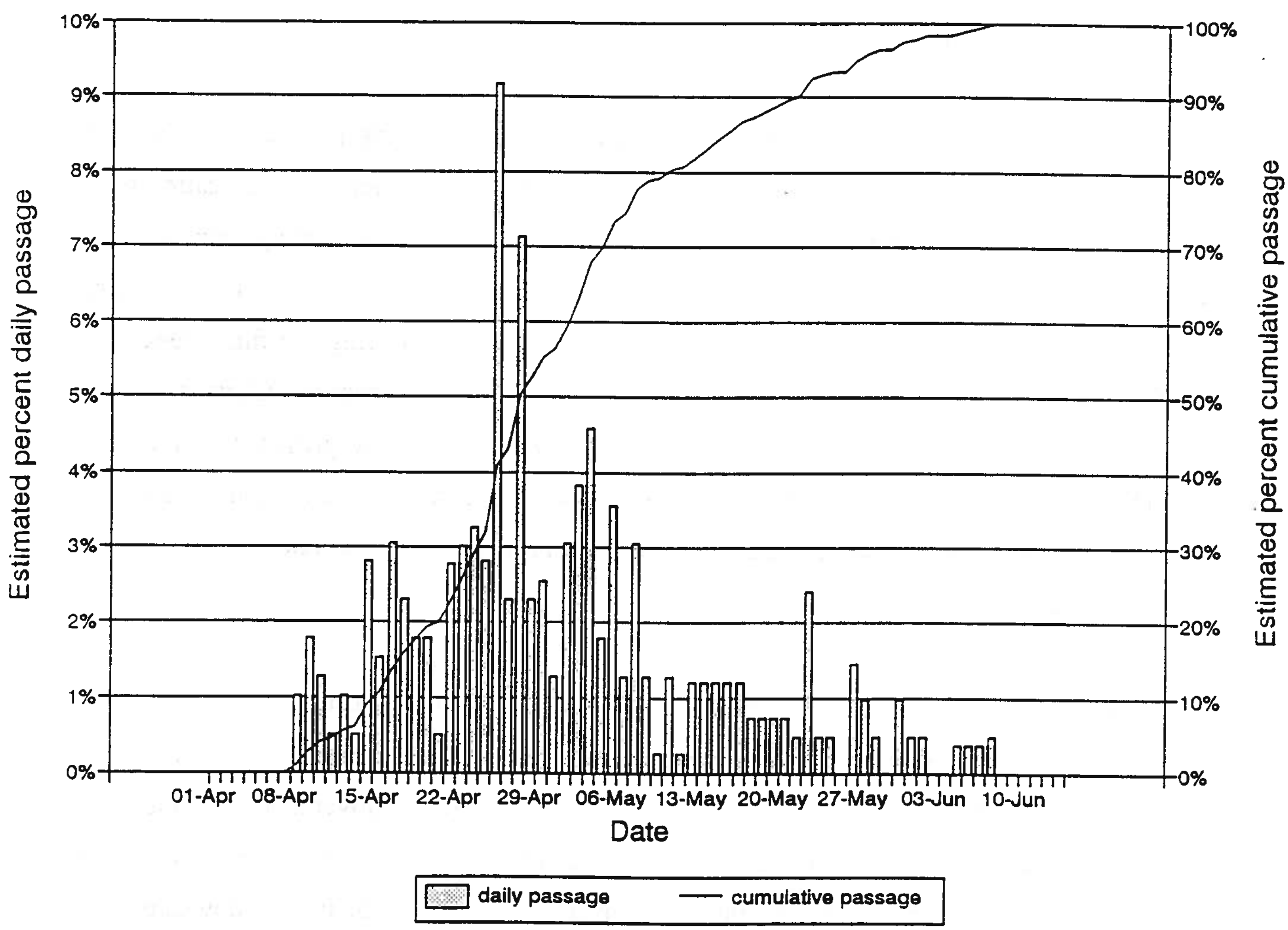

Figure 8. Estimated daily and cumulative steelhead smolt outmigration from the Chewuck River, Spring 1993.

of steelhead outmigrants was 158 mm and they ranged in length from 89 mm to 457 mm (Figure 9). Their mean condition factor was 0.918.

The mean fork length of nonsmolt steelhead/rainbow was 100 mm. These fish could either be resident rainbow trout or steelhead parr that would smolt later in the year or the following spring.

6.1.2 Fall Season

6.1.2.1 Spring chinook

An estimated 1,993 spring chinook outmigrated during the monitoring period from September 21 through November 18. Fish were captured on the first day of operation, indicating that downstream movement began before this date. The greatest number of spring chinook were captured November 6-18, which accounted for 38.4% of the total estimated passage (Figure 10). An estimated 69 fish per day were still passing the trap site during the final week of operation, and it is likely that parr continued to move downstream from the Chewuck River into the Methow River after monitoring ceased on November 18. The presence of a distinct fall/winter parr downstream movement in the Chewuck River basin is consistent with what is observed in other basins as well, e.g., Yakima, WA (Fast el. al., 1991) and the Salmon, ID (Chapman and Bjornn, 1969).

There was no apparent correlation between discharge and downstream movement, although, the period of greatest outmigration coincided with a significant decrease in stream temperature (Figure 10). Chapman and Bjornn (1969) observed a downstream movement of spring chinook parr that corresponded to a decrease in water temperature in the Lemhi River, Idaho. They reasoned that parr were seeking out better over wintering habitat farther downstream. The scarcity of large woody debris (LWD) is the most likely the limiting factor for over-wintering in the Chewuck basin both directly as cover, and indirectly by creating pools. The density of LWD in the Chewuck River ranged from 1.9 pieces (reach 1) to 54.7 pieces (reach 2) per river mile, based on a 1993 habitat inventory (Molesworth, pers. comm., 1993). The

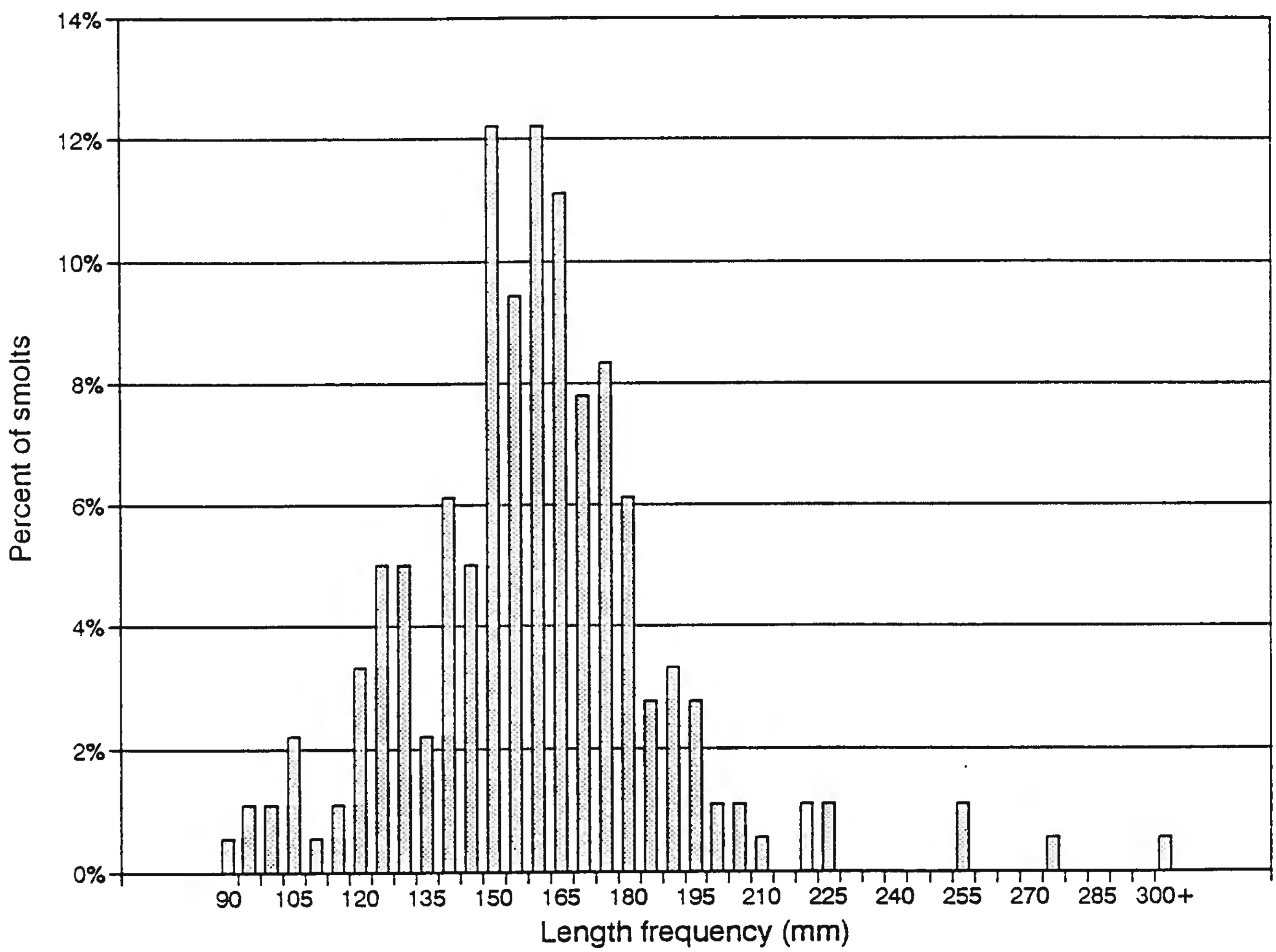

Figure 9. Length frequency distribution of Chewuck River steelhead smolts, 1993.

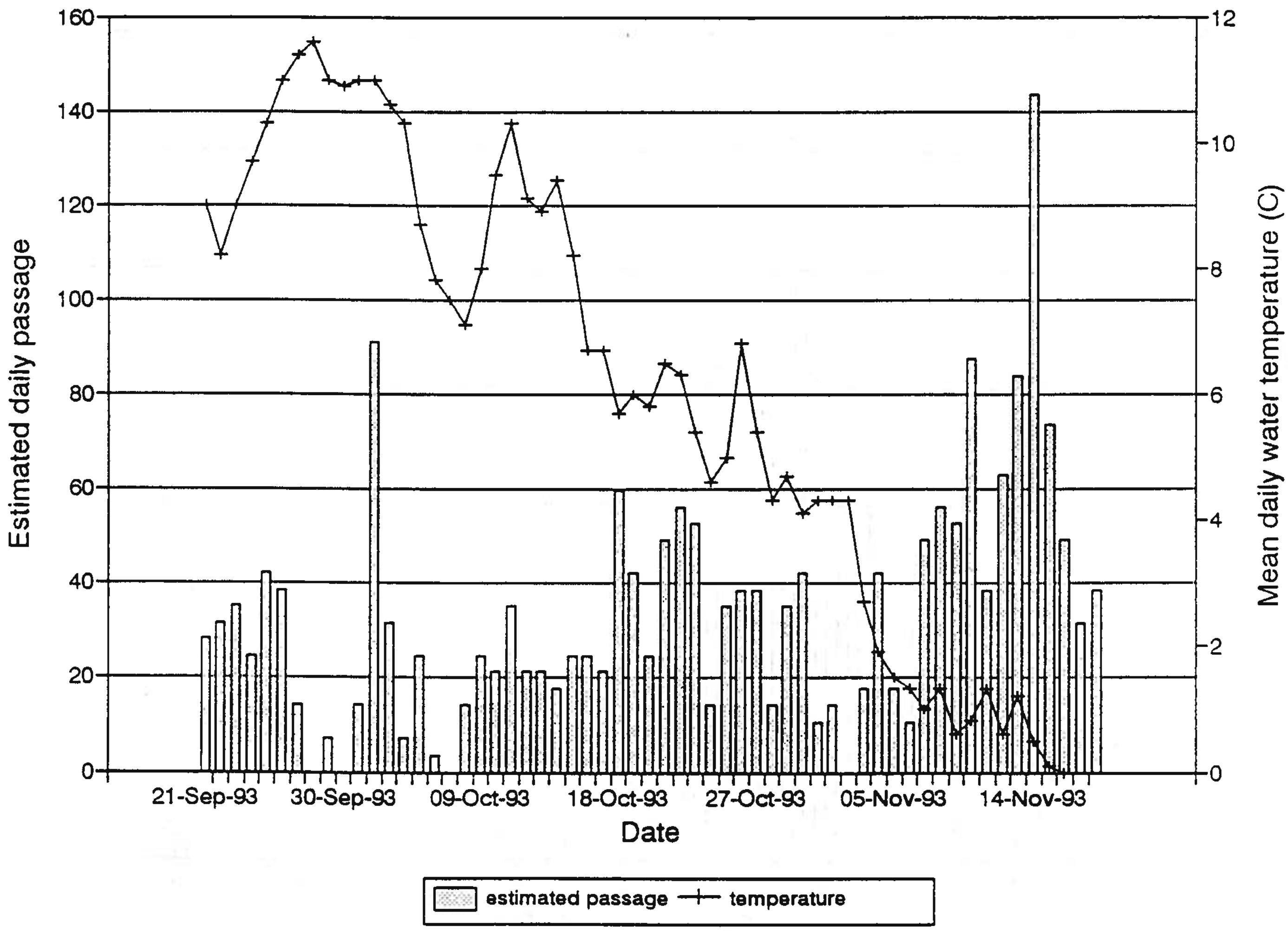

Figure 10. Estimated daily downstream movement of spring chinook parr and the mean daily water temperature in the Chewuck River, Fall 1993.

situation is exacerbated by decreasing stream flows during the winter months; mean monthly discharges reach lows of 60-70 cfs.

6.1.2.2 Steelhead/rainbow

An estimated 140 steelhead/rainbow moved downstream past the screw trap and the their mean fork length was 160 mm.

6.2 Late Summer Parr Densities

6.2.1 Spring chinook

Hilman and Miller (1993) found that the number of spring chinook parr observed by snorkeling was dependent upon factors such as water temperature and light intensity. They could explain 79% of the variability in chinook parr counts by stream temperature. Hilman and Miller calculated population estimates for spring chinook parr and for steelhead parr less than 200 mm in length, taking into consideration the effect of temperature on fish behavior (their degree of activity in the water column). Since Hilman and Miller's data were collected in the Methow and Wenatchee basins, we believe that these equations could be applied to our Chewuck River snorkeling data.

Our temperature-adjusted population estimate for spring chinook parr was 8,564 fish, which was 31.8% higher than the temperature-unadjusted population estimate of 5,838 fish. The temperature-adjusted population estimate is presented to give the reader an indication of what the actual parr estimate may have been. Our temperature-unadjusted parr estimates could be low since it is unlikely we were seeing one-hundred percent of the fish present. However, the relative abundance estimates between reaches are felt to be accurate, and these figures will be used in the remaining discussion.

Parr density was highest between RM 2.3 and RM 23.3 (Figure 11 and Appendix Table 1). Parr density (fish per river mile) was 262 fish in reach 2, 276 fish in reach 3 and 231 fish in

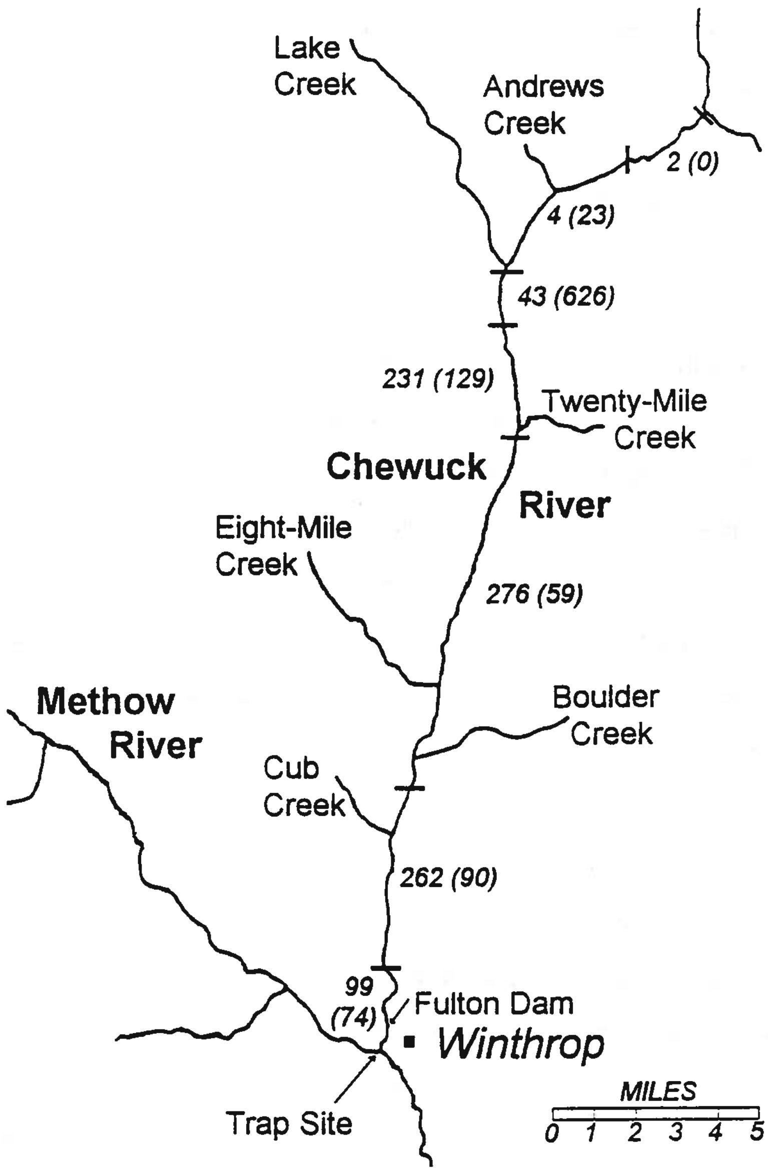

Figure 11. Estimated spring chinook and steelhead/rainbow (in parentheses) parr densities (fish/RM) by reach in the Chewuck River, Summer 1993.

reach 4. In reach 1 the parr density was 99 fish. In the uppermost part of the basin, reaches 5, 6 and 7, the parr density was 43 fish, 23 fish and 0 fish respectively.

Meekin (1992) found the most spring chinook redds (70.4%) in reach 3 in 1992, which coincided where the highest parr density (276 fish per river mile) was found. The high parr density (262 fish per river mile) in reach 2, where only 5.4% of the redds were located, suggests fry moved downstream to rear in this reach. The lower parr density (99 fish per river mile) in reach 1 is probably due to lower-quality rearing habitat in this reach. Excluding the pool behind Fulton Dam, there are no pools, and riffle habitat comprises 97.6% of this reach. The stream channel in reach 1 is also more confined than in reach 2. The low numbers of parr that rear in the upper reaches of the Chewuck River (reaches 5, 6 and 7) is consistent with the limited spawning and rearing habitat in these reaches. Redds upstream to reach 4 comprised only 6.5% of the basin total in 1992 (Meekin, 1992). The presence of parr in reach 5 (43 fish per river mile), where no spawning occurred in 1992, suggests that young-of-the-year originating from redds located in reach 7 move downstream and rear in this reach.

It should not be assumed that the majority of Chewuck River spring chinook parr rear within the basin. The exact temporal and spatial rearing pattern of Chewuck River spring chinook juveniles is not well understood. The presence of newly emergent fry in the screw trap in the spring indicates that some Chewuck River juveniles rear elsewhere. Post-emergent fry began to appear at Fulton Dam on April 10 and a total of 128 fry were captured through the spring season. In the Yakima River a large portion of the spring chinook young-of-the-year move downstream continuously throughout the spring and summer from spawning reaches and rear in lower reaches of the river (Fast et al., 1991).

It appears that the late summer parr population accounts for a small portion of parr from the Chewuck basin. There were a total of 185 redds deposited in 1992 (Meekin, 1992) and the mean fecundity was 4,411 eggs per female (Bartlett, pers. comm., 1993). Applying the mean egg-to-fry survival rate for Yakima basin spring chinook of 59.6% (Fast et al., 1991), to our egg deposition estimate of 816,035 an estimated 486,356 fry emerged in the Chewuck basin.

There are no data on the fry-to-parr survival rate, in the Methow basin. A Beverton and Holt model (National Marine Fisheries Service, 1993) taken from the literature was used to estimate a range in the late summer parr population in the Chewuck River. This model takes into account percent seeding level and sets the low density survival rate at 0.5. The model predicts fry-to-parr survival rates to range between 13% and 32% depending on the basin's percent seeding level. This equates to a late summer parr population of 63,226 up to 155,634 fish. Compared with an temperature-unadjusted population estimate of 5,838 parr and an temperature-adjusted population estimate of 8,514 parr, it suggests the bulk of the population is rearing out of basin.

6.2.2 Steelhead/rainbow

The estimated number of steelhead/rainbow parr was 2,765. The highest parr density (626 fish per river mile) was observed in reach 5, followed by 129 fish per river mile in reach 4. In reaches 1-3 the number of fish per river mile ranged from 59 to 90. Parr density in reach 6 was 23 and no steelhead/rainbow were observed in reach 7.

The estimated number of steelhead/rainbow young-of-the-year was 587 and the highest young-of-the-year density was found in reach 1 (154 fish per river mile). However, this is most likely an underestimate. We had difficulty in snorkeling the shallow water (<30 cm) where the majority of steelhead/rainbow young-of-the-year were observed. Hilman and Miller (1993) also reported difficulty in enumerating fry under 40 mm in length because of the inability of snorkelers to reach the shallow waters (less than 15 cm) in which fry normally were found.

7.0 RECOMMENDATIONS

Screw trap operations were re-located from Fulton Dam in the spring to the Highway 20 Bridge (RM 0.1) in the fall. The site provides an entrainment efficiency of about 20 % and the trap is easy to operate logistically and should provide a good long term monitoring site. However, at this site two monitoring locations, one for low river stage (<5.0 ft) and one for high river stage (>5.0 ft), are required. At a river stage above 5.0 feet the flow changes from laminar to turbulent flow at location 1, and the trap does not operate well. A second location downstream 30 meters and towards the right bank from location 1 is used for trapping when the river stage exceeds 5.0 feet. This will require developing an entrainment relationship for each location. The exact trap locations have been surveyed to allow exact placement each time the trap is re-deployed. It is evident that the limited number of available wild smolts will require development of the entrainment relationships over several years.

It will not be possible to estimate the Chewuck basin spring chinook egg-to-smolt survival rate since apparently a large percentage of juveniles move out of the basin before smolting, based on the snorkeling data. At best, an estimate of the percent composition of young-of-the-year migrants, fall migrants and smolts could be determined. It may be possible to estimate egg-to-smolt for the Methow Basin by conducting smolt monitoring near the Methow River confluence. This would be successful only if pre-smolts reared within the basin upstream to the trap.

A supplementation objective is to minimize the interaction between wild and hatchery smolts. Fifty percent (25% to 75% cumulative outmigration) of the 1993 wild smolts outmigrated from the Chewuck River in a nine day period (April 15-24). Thus it appears there is a minimal period for wild and hatchery smolts to interact within the Chewuck basin. For the 1994 wild smolt outmigrants it appears a similar outmigration trend occurred, although it occurred earlier in time. Thus it appears that the smolt outmigration period in the Chewuck basin is short in duration, but may peak at different times depending on annual weather conditions, etc. The ability to control the release date of the hatchery smolts is limited, since the same factors that control smoltification in wild fish apply as well in hatchery fish. In terms of fish health it is better to release them earlier than later in the smoltification process. There seems to be only a minimal amount of manipulation that can be done with the hatchery smolt release to minimize interaction with wild smolts. For the 1994 hatchery smolt release it appears that they smolted (as a whole) after the peak wild smolt outmigration period and that they outmigrated rapidly from the Chewuck River. An option to minimize potential wild-hatchery smolt interactions might be to allow the hatchery smolts to volitionally release shortly after being "ponded", opposed to keeping them in the acclimation pond for several weeks before allowing them the opportunity to outmigrate. This may protract the outmigration period and thus reduce the actual numbers of hatchery smolts in the river to potentially interact with the wild smolts.

LITERATURE CITED

Chapman, D.W. and T.C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. In T.C. Northcote [ed.], Symposium on salmon and trout in streams. H.R. MacMillian Lectures in Fisheries. Univ. British Columbia, Vancouver, B.C.

Clark, W.C., J.E. Shelbourn and J.R. Brett. 1978. Growth and adaptation to seawater in underyearling sockeye (*Oncorhynchus nerka*) and coho (*O. kisutch*) salmon subjected to regimes of constant or changing temperature and daylength. Can. J. Zool. 56:2413-2421.

Ericksson, L.-O. and H. Lundqvist. 1982. Circannual rhythums and photoperiod regulation of growth and smolting in Baltic salmon (*Salmo Salar L.*). Aquaculture 28:113-121.

Fast, D.E., J.D. Hubble, M. Kohn and B. Watson. 1991. Yakima River spring chinook enhancement study. 1991 Final Report to Bonneville Power Administration. Project No. 82-16.

Hankin, D.G. and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45:834-844.

Hilman, T.W. and M.D. Miller. 1993. Estimated abundance and total numbers of chinook salmon and trout in the Chiwawa River, Washington 1992. Report to Chelan Public Utility District.

Hoar, W.S. 1965. The endocrine system as a chemical link between the organism and its environment. Trans. R. Soc. Can. Ser. IV, 3:175-200.

Hoar, W.S. 1976. Smolt transformation: evolution, behavior, and physiology. J. Fish. Res. Board Can. 33:1234-1252.

Iwamoto, R.N. 1982. Strain-photoperiod-temperature interactions in coho salmon: freshwater growth, smoltification, and seawater adaptation. Ph. D. Thesis, Univ. of Washington.

Knutsson, S. and T. Grav. 1976. Seawater adaptation in Atlantic salmon (*Salmo salar L.*) at different experimental temperatures and photoperiods. Aquaculture 8:169-187.

Meekin, M.K. 1993. Final report spring chinook spawning surveys of the Methow River Basin, 1992. Yakima Indian Nation, Fisheries Resource Management. Prepared for Douglas County Public Utility District.

National Marine Fisheries Service. 1993. Draft Snake River salmon recovery plan recommendations for peer review. Prepared by the Snake River Salmon Recovery Team.

Rhodus, G. 1988. Runoff characteristics of the upper Methow River above Winthrop, Washington. United States Geological Survey. June 1988.

Wagner, H.H. 1971. The parr-smolt metamorphotosis in steelhead trout as affected by photoperiod and temperature. Ph. D. Thesis, Oregon State Univ.

Wagner, H.H. 1974a. Photoperiod and temperature regulation of smolting in steelhead trout (*Salmo gairdneri*). Can. J. Zool. 52:219-234.

United States Geological Survey. 1992. Provisional data, 1992 for the Chewuck River at Winthrop. Station number 12448000.

United States Geological Survey. 1993. Provisional data, 1993 for the Chewuck River at Winthrop. Station number 12448000.

Wedemeyer, G.A., R.L. Saunders and W.C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Marine Fisheries Review, June 1980.

Appendix Table 1. Estimated number of spring chinook and ages 0+ and 1+ years old rainbow trout/steelhead parr in the Chewuck River, Summer 1993.

		Pool				Riffle				Glide			
Reach	Rivermiles	Chinook	RBT/ST 0+	RBT/ST 1+	% of reach	Chinook	RBT/ST 0+	RBT/ST 1+	% of reach	Chinook	RBT/ST 0+	RBT/ST 1+	% of reach
1	2.3	--	--	--	0.0	227	355	170	97.6	0	0	0	2.4
2	6.1	2	13	7	8.9	1,595	79	545	91.1	--	--	--	0.0
3	11.0	1,737	7	201	29.0	1,124	23	432	55.8	180	0	16	15.1
4	3.9	553	0	125	15.6	346	38	377	81.8	--	--	--	2.6
5	1.3	11	0	112	11.5	45	66	702	88.5	--	--	--	0.0
6	3.4	0	0	24	12.9	12	6	55	87.1	--	--	--	0.0
7	3.1	0	0	0	88.9	6	0	0	6.4	0	0	0	4.7

FIRST ANNUAL REPORT
WATER QUALITY AND SOCKEYE SALMON
ENHANCEMENT IN LAKE OSOYOOS DURING 1994
BY
JACK RENSEL, Ph.D.

APPENDIX - L

FIRST ANNUAL REPORT

WATER QUALITY AND SOCKEYE SALMON ENHANCEMENT IN LAKE OSOYOOS DURING 1994

PREPARED FOR THE

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Acknowledgement

The author wishes to thank a number of individuals for their participation in the data collection, analyses and funding for this work. Field sampling was conducted with the assistance of Shane Bickford, Rick Kligne or Wayne Marsh. Maribeth Gibbons of WATER Environmental Services provided expert taxonomic analyses and Aquatic Research, Inc. of Seattle provided some of the laboratory analyses. All other laboratory analysis were performed by Kathy Krogslund of the Routine Chemistry Laboratory at the University of Washington. This report was produced with funding from Public Utility District No. 1 of Douglas County. The project manager was Rick Klinge.

EXECUTIVE SUMMARY

1994 marked the first year of native sockeye salmon enhancement in Lake Osoyoos with net pens. The Wells Dam Settlement Agreement discusses the use of net pens in Lake Osoyoos to increase the native run of sockeye, as a temporary measure while habitat restoration in the subbasin is planned. Pen operation was funded by the Douglas County Public Utility District; the Colville Confederated Tribes provided fish cultural personnel. The pen program was operated on a pilot scale and was successful by most measures. However, fish size at release should be increased to insure the successful ocean survival of the fish.

The program included April to late September monthly sampling of water quality, phytoplankton and zooplankton and related factors to determine the trophic (nutrient) status of the south basin of the lake. A before and after assessment of the total organic carbon content of the lake bottom under and near the pens was also conducted. Although this is primarily a data report, several tentative conclusions may be reached regarding trophic status, nutrient sources, trends in the physical habitat, and prospects for long-term health of the sockeye salmon population as follows:

Indicators of Trophic State of Lake Osoyoos

Several indicators of trophic state, shown numbered below, were evaluated in 1994. The data suggest that the possibility that the lake is very slightly more eutrophic than in the early 1970s. However, the lake remains within the range of conditions known as mesotrophic, or moderately enriched. The trend portion of this conclusion must be qualified as tentative because of the patchwork of comparison data that must be used that varied over time (1970's and 80's), place (north or south basin), investigators (Canadian and American) and probably differing techniques. No firm conclusions should be assumed based on only one year's results as interannual variability may be significant.

The first three trophic indicators are physical or chemical parameters. Collectively they are known as Carlson's (1977) trophic state index (TSI) and are often used to summarize and quantitatively characterize the degree of eutrophication of lakes. The average TSI for these factors is 46.8, based on April to October surface water results. The result indicates the lake to be mid-way in the range of conditions known as mesotrophy or moderately enriched.

The fourth indicator, total nitrogen is another chemical indicator that is less often used, but useful in the present context. The fifth and sixth indicators, phytoplankton and zooplankton species composition and biomass, are qualitative measures. They can be considered as very important for sockeye salmon ecology because they are direct biological measurements of the food web in the lake that supports the fish. Some biologists believe that direct biological measurements of such systems are often more useful than indirect physical and chemical indicators.

Each indicator is summarized here with 1994 data compared to prior results:

1) Average summer Secchi disk water transparency was essentially unchanged, averaging 3.1 m in the south basin during 1994 compared to 3.3 m in 1971 from an unknown location, but probably the north basin. The 1994 transparency data are also similar to other recent data and suggest that water transparency has not changed for several years.

2) Average summer chlorophyll *a* concentration of surface water in the south basin of Lake Osoyoos was 5.4 µg/L, significantly less than 23 µg/L that was recorded in the early 1970s. Such a large difference (about 4x) was somewhat surprising, given that water transparency was unchanged and total phosphorus in 1994 was relatively high. However, the 1994 results are corroborated by more recent data from the north and south basin.

3) Total phosphorus (total P) in surface waters of the south basin in the summer of 1994 averaged 23.4 µg/L; this was considerably greater than a limited number of summer observations from the mid-1970's and later that averaged from about 12 to 16 µg/L. Nevertheless, the 1994 total P results are still within the range of values expected for mesotrophic lakes.

Total P in surface waters during summer was mostly composed of forms other than orthophosphate, probably organic P due to phytoplankton biomass. It is unclear why this did not show up as higher concentrations of chlorophyll *a*, although both total P and chlorophyll *a* yielded similar TSI indices.

4) Total nitrogen (total N) in surface waters of the south basin in the summer of 1994 averaged 616.6 µg/L, much higher than comparison data from both the 1980s that averaged about 400 µg/L. There is also some evidence that total N during the spring months was higher than in the early 1970s, but the comparison is potentially bias because the prior samples were taken in the north basin. Total N is a less often used indicator of trophic condition compared to total P, but the high concentrations found in Lake Osoyoos suggest that this be closely watched in the future.

5) Phytoplankton (i.e., microalgae) density, biomass and species composition was assessed in 1994. A shift from beneficial diatoms in the spring to undesirable, inedible or in some cases harmful blue-green in the summer was observed. While this general relationship also occurred in the early 1970s in the lake, there are no reliable density (other than chlorophyll *a*), biomass or species composition data from the prior data. Species composition can be highly important to the food web and sockeye salmon ecology, and I will attempt to get some unpublished Canadian technical reports that may have this information.

6) Zooplankton (i.e., predators of phytoplankton and other organisms) density, biomass and species composition were also evaluated in 1994. I was able to compare density results to prior studies, but there were no prior data on biomass including the more recent Canadian work. Dominant zooplankton excluding rotifers during 1972-73 surveys by Allen and Meekin (1980) were copepods (*Cyclops* spp. and *Diaptomus* spp.), immature copepod nauplii, and the cladoceran *Daphnia* spp. Total density without the rotifers was similar in the south basin some 23 years later, although calanoids were more abundant than cyclopoids in 1994. The similarity may be superficial, however, because there are few species composition data from the earlier study and as for the phytoplankton, this is of paramount importance to the food web and sockeye salmon survival.

In 1994 the biomass of desirable fish prey known as cladocerans (crustacean zooplankton) was relatively constant through the sampling period until late September. An approximate 50% decrease in their biomass at that time was concurrent with the increased dominance of blue-green algae. Two possible explanations include a) the unsuitability of blue greens as zooplankton food and/or b) the increasing anoxia of the hypolimnion (deep layer) that would have forced these zooplankton out of dark refuges during the day and resulted in increased predation.

Evaluation of the plankton data is more difficult, but of great interest. With regard to trophic state trends, however, no firm conclusions may be reached because the prior data lacked biomass information (for phytoplankton) and biomass and density information (for zooplankton). The numerical dominance of potentially harmful blue-green algae in Lake Osoyoos throughout the spring to fall sampling period of 1994 is cause for concern. Blue green algae became volumetrically dominant in the late summer, i.e., they were the largest biomass component of the phytoplankton. Concurrently, the biomass of desirable cladoceran zooplankton decreased by 50% as previously mentioned. If development in the watershed continues to increase, nutrient loading could lead to increased dominance of these harmful algae. Sockeye salmon and other fish populations could be negatively affected by reduction of desirable prey (e.g., cladoceran zooplankton), toxin production by the blue-green algae, and low dissolved oxygen conditions that accompany eutrophication.

Another possible trophic state indicator, degree of dissolved oxygen depletion in the hypolimnion, did not indicate change compared to the early 1970s. However, there were inadequate data to place much emphasis on it at this time. Additional dissolved oxygen measurements will be taken in 1995 using automated equipment discussed below.

Applying equal weighting to the four physical and chemical factors described above (i.e., total P, total N, summer chlorophyll *a* concentration, secchi disk transparency) , it appears that there has been a slight increase in the trophic state of Lake Osoyoos since the early 1970s. The increased total N and P is partly offset by chlorophyll *a* concentrations that have apparently declined. The last indicator was essentially neutral; secchi disk transparency remain unchanged. These indicators are obviously not all in agreement, resulting in a slightly equivocal situation. Additional data from 1995 will help establish the present trophic state by accounting for inter-annual variability.

Internal Loading and Other Nutrient Dynamics

Patterns of phosphorus concentration in surface and bottom water suggest that internal phosphorus loading may be a significant nutrient source to the lake. Internal loading may be defined as the release of orthophosphate from bottom sediments during periods of low or no dissolved oxygen in the hypolimnion (bottom water) that involves shifts in iron binding properties. A prior study suggested that another important and probably dominant source of nutrient flux through the lake is the inflowing Okanogan River, although internal loading was not discussed.

The ratio of surface water dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (orthophosphate) suggest that nitrogen could be limiting to some forms of phytoplankton growth in surface waters at times during the summer. Many blue-green algae have the capability to fix nitrogen; they may also adjust their buoyancy to move vertically in the water column. This allows them to access deep water reserves of nutrients that may exclude them from being limited by N or P supply rates in surface waters. Other conditions found in the summer in Lake Osoyoos promote blue green algal dominance including warm surface waters, periods of calm weather with no wind mixing, and possibly low CO_2 content of the surface water, although this was not measured in 1994.

Physical Habitat Suitability for Sockeye Salmon

Regarding the physical suitability of the habitat for sockeye fry, the situation remains similar to that reported 20 years ago. Fry inhabiting the south basin must be sandwiched in a narrow layer near the thermocline (i.e., the metalimnion: warm to cool transition depth), avoiding low dissolved oxygen concentrations below and high water temperatures above. It is possible that sockeye fry do not utilize the south basin during the mid to late summer in some years, depending on water temperature and dissolved oxygen. The data presented here show that there was only a 1 or 2 meter wide depth in the south basin during July that would have allowed their survival. Before and after that period, however, conditions were more suitable. A comparison of the south and north basins in August of 1994 show that the surface water was slightly cooler in the north basin (<1°C), but the hypolimnion (deep water) was 6 to 7 °C cooler in the north basin.

Long-Term Risks of Lake Habitat Degradation for Sockeye Salmon

At present there is little evidence that the mesotrophic state of Lake Osoyoos is an immediate threat to the survival of the sockeye population. Certainly other factors may be more important to the fish stock such as the thermal block to migration of adult spawners that occurs in some years in the lower Okanogan River and the apparent lack of spawning area and fry recruitment. There is no evidence that food or space is limiting to sockeye production in the lake, and in fact the large size of the smolts suggests no density dependence at present. However, Lake Osoyoos is fundamentally much more enriched than all other sockeye salmon nursery lakes in North America and that differences raises some important questions that previously have not been posed. The minor degradation of trophic status in the past 23 years certainly must not be used to conclude that there have been no significant or adverse changes in the food web that supports the sockeye salmon.

Other sockeye lakes are essentially oligotrophic (low nutrient flux, clear water, cooler, higher dissolved oxygen at depth) and are not dominated by potentially harmful blue-green algae in the clement weather months. In many sockeye lakes, blue-green algae are normally not present at all or are confined to late summer and fall. As eutrophication of any lake proceeds, blue-green algae can become dominant in the spring or any time of year regardless of water temperature. The numerical dominance of blue-greens in Lake Osoyoos throughout the spring to fall sampling period of 1994, and the volumetric dominance in late summer is cause for concern that they may become dominant by both measures in future years.

Experience with trout lakes that are more similar to Osoyoos has shown that populations of desirable zooplankton prey can "crash" due to eutrophication and increased predation by introduced species such as mysid shrimp or increased forage fish populations. Examples of these types of "trophic cascade" problems in lakes are briefly discussed in the report. At present there is no safety net or adequate base of knowledge about Lake Osoyoos to insure that subtle but adverse changes to the lake's food web do not cause serious problems with the survival of the sockeye. Lake Osoyoos carrying capacity estimates for sockeye based on euphotic zone volume and smolt production in Alaskan lakes must be seriously questioned because of the blue-green algal dominance and inappropriately warm epilimnion of Lake Osoyoos during summer. Certainly, there are no sockeye salmon lakes in Alaska with conditions that approach those found in Lake Osoyoos.

The hypoxic or anoxic conditions in the hypolimnion of Lake Osoyoos are severe and could become worse as development increases in the watershed. Not all human land use activities cause increased nutrient loading of aquatic systems, but in some cases agriculture, urban development and even treated municipal waste discharge may produce serious adverse effects. For example, there are now some well documented long-term studies that show near order of magnitude increases in nitrate loading to water sheds after some types of logging.

To improve long-term suitability of the lake for rearing sockeye fry during the summer months, it may be beneficial if trophic conditions were lowered to a condition less than mesotrophy. This would allow adequate food-web resources, but over a period of decades it could also reduce the problem of dissolved oxygen depletion in the deep waters that have more suitable water temperatures than the surface waters. It would also eventually result in a reduction in blue-green algae, that are relatively useless as prey for desirable zooplankton. Development and land area in the Canadian portion of the watershed far surpasses that in the American side, so the issue becomes complicated when lake restoration is considered. It may not be technically or economically feasible to achieve an improvement in trophic status of Lake Osoyoos, but that decision should hinge on the results of a nutrient budget for the lake.

Fish Cultural Results and Impacts

Temporary net pens were stocked with 12,500 fish averaging 2.3 grams in early April of 1994. A larger proportion of the fry were kept at the Cassimer Bar Hatchery until release as smolts. The fish transferred to the net pens did very well, with little mortality (0.5%) and good growth in the 34 days that they were cultured, tripling their weight to about 7 grams at release. Although this size is acceptable for an experimental zero-aged smolt production program of this nature, ocean survival of the fish will undoubtedly be improved if they were larger at release. The Lake Osoyoos program is rather ambitious in that it is attempting to produce a large size smolt in only six months after hatching compared to the wild smolts that have had one and one-half years in the lake.

A limited number of stomach samples at the time of release showed the fish to be actively feeding on naturally occurring zooplankton. Feed conversion ratio (i.e., feed used to fish biomass gained) approached 1.1, which is good for this type of program. However, the fish were reared at a very low density and natural feed may have been in part responsible for the good food conversion ratio.

The bottom beneath and near the net pens was sampled for carbon content prior to and after operation of the pens and no increase was detected. Macrophyte species and areal coverage was estimated along the nearest shoreline during August. The lack of impacts to the bottom could be attributed to the very small amount of feed used and the pilot scale fish production. No impact to macrophytes along the distant shoreline is projected even during full operation of the pens as solids from the pens will not travel that far and macrophytes acquire most of their nutrients from bottom sediments.

Recommendations for 1995 program

Much of the 1994 program of net pen rearing, impact assessment and lake monitoring could be operated with little change from 1994. Some fine tuning and program modification may, however, be in order that would increase the power of the program in determining the true condition of fish habitat conditions in Lake Osoyoos.

Fish Culture Practices

Accelerated growth of the hatchery and net-pen sockeye fry may be obtained through increasing the length of the feeding period that was too short in 1994. The use of recently-developed high energy feeds that have proven to nearly double trout growth rates may also be necessary. It is also important to try to increase the size of the hatchery fish being produced by the hatchery through any means available.

Fish Distribution Study: South Basin

There have been no population assessments (hydroacoustic soundings or nettings) of Lake Osoyoos sockeye fry in the late summer, although it was recommended by a prior study. Gillnet sampling was conducted only on one night in the south basin on August 10, 1972, but no fish were captured. If sockeye fry do not inhabit the south basin during the late summer, what happens to fish that are there prior to that time? Vertical gill net sampling could be conducted in the south basin late July or early August, concurrent with water quality monitoring to shed more light on this issue.

Instrumentation, Additional Monitoring Stations and Other Changes

In 1995 I will be using a computerized Hydrolab multiprobe (H20) unit that allows concurrent collection of water temperature, depth, conductivity, pH, redox and dissolved oxygen. The unit has a constant velocity water pump, but unlike the completely submersible CTD unit used in 1994, continuous monitoring of the results can be provided to a surface display/datalogger. In this manner, we can review the data as it is logged and provide quality control and assessment *in situ*. The unit should further improve the accuracy of the data and allow us to collect more data within the same time limitations, and especially for dissolved oxygen in the hypolimnion.

Given the importance of total phosphorus, chlorophyll *a* and Secchi disk transparency in assessing trophic index, I propose that three separate stations be utilized for collecting these specific data in the south basin in 1995 during the summer months. The Boundary Point station would remain the main station with full profiles over depth, but two other stations, the south central basin station near the net pen location and one new station half-way between the two existing stations would be used only for the collection of the above mentioned parameters in surface waters.

Another possible change in 1995 would be the addition of a station in the north basin for collection of water quality data. This would allow the comparison of north and south basin conditions, and provide better use of much of the historical data that has been collected in Canadian waters. It is possible that most of the sockeye fry use the north basin only during late summer, so the conditions there are relatively more important than in the south basin. Other minor changes in the program are discussed in the *Recommendations* section.

INTRODUCTION

1994 marked the first year of native sockeye salmon enhancement in Lake Osoyoos with net pens. The Wells Dam Settlement Agreement discusses the use of net pens in Lake Osoyoos to increase the native run of sockeye, as a temporary measure while habitat restoration in the subbasin is planned. Pen operation was funded by the Douglas County Public Utility District; the Colville Confederated Tribes provided fish cultural personnel. The pen program was operated on a pilot scale and was successful by most measures. However, fish size at release should be increased to insure the successful ocean survival of the fish.

The program included April to late September monthly sampling of water quality, phytoplankton and zooplankton and related factors to determine the trophic (nutrient) status of the south basin of the lake. See Rensel (1993) for a description of prior water quality studies in the lake, the net-pen program and background information on limnology and nutrients. A before and after assessment of the total organic carbon content of the lake bottom under and near the pens was also conducted. Although this is primarily a data report, several tentative conclusions may be reached regarding trophic status, nutrient sources, trends in the physical habitat, and prospects for long-term health of the sockeye salmon population as follows:

The extent of water quality sampling in Lake Osoyoos reported here goes far beyond that necessary to determine the effects of the net pens. As previously shown by Rensel (1993), the net pens are probably an insignificant source of nutrients to the water column and sediments of the lake and due to their timing of operation will not have a measurable effect on the biota. Accordingly, the sampling described herein is mostly to describe and characterize the trophic state of the lake and associated conditions for the sake of water quality maintenance and sockeye salmon perpetuation.

This report also includes a summary of water quality and fish culture data collected at the sockeye salmon net pens by staff of the Colville Confederated Tribes that were responsible for operation of the net-pen system.

METHODS

Routine water quality data was collected monthly from April through late September. Two sampling locations were selected in the south basin of the lake, in mid channel at Boundary Point (the international border with Canada) and in mid channel along the same latitude as the salmon net pen location (Fig. 1). The two stations were designated as Boundary Point and South Central Basin, respectively.

A variety of instruments and analytical techniques were used to sample water quality (Table 1). Although a Seabird conductivity, temperature and depth (CTD) automatic datalogging probe (SEACAT SBE-19) was used at both locations and some back-up

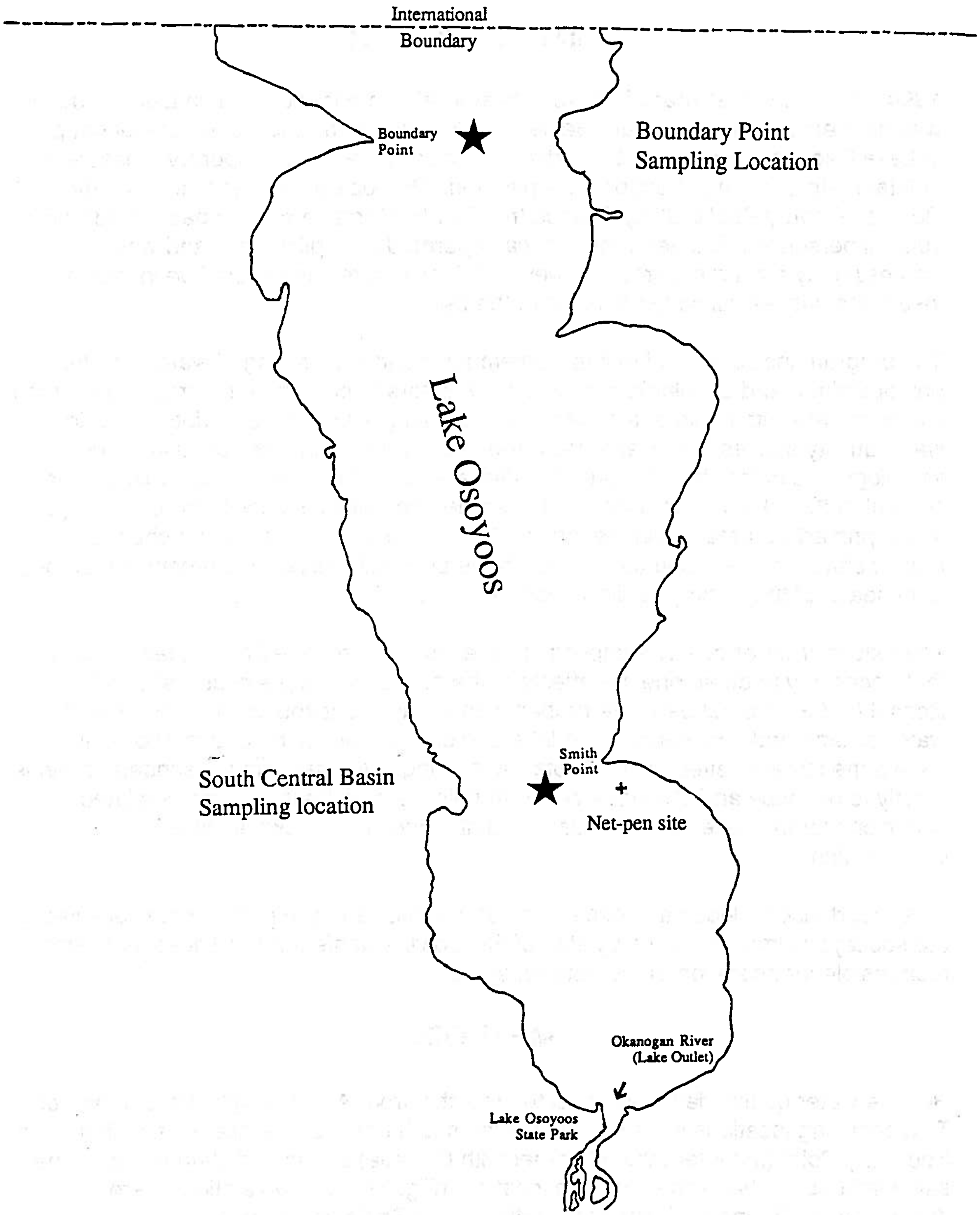


Figure 1. Map of the southern basin of Lake Osoyoos showing two sampling locations used in 1994.

data were collected using other instrumentation in case of a CTD malfunction. A Scott water bottle was used to retrieve subsurface samples and a depth finder was used to locate the boat over the deepest part of the lake at each location. Time of sampling, sky conditions, wind speed and direction, wave conditions and air temperature were also recorded for each location and sampling session. Dissolved oxygen and pH meters were calibrated immediately before use, and the Seabird CTD has been calibrated in the spring by it's manufacturers. Nutrient samples and replicates were collected from the same water bottle or mixture of water bottle casts and placed in acid-rinsed poly bottles. The bottle were iced and frozen within a day for processing by the Routine Chemistry Laboratory at the School of Oceanography.

Zooplankton and phytoplankton samples were analyzed by Water Environmental Services, Inc. of Bainbridge Island, Washington as follows: Phytoplankton enumeration, identification, and cell volume determinations were made on preserved water samples collected from Lake Osoyoos. The samples were from composite depths of 1, 3 and 6 meters. Average counts for each species were computed from the sample. Algal cell densities were reported as numbers per ml. For each sample, cell dimensions of at least 10 organisms of each species were computed to obtain average cell volume per species. Determination of cell volumes and identifications were made at 400X using a nannoplankton counting cell and calibrated whipple disc. Cell volumes were reported as cubic microns per ml, and also converted to cubic millimeters per liter (mm^3/l). Species identifications were made primarily according to Prescott (1975, 1980) and Patrick and Reimer (1966, 1975).

Zooplankton determinations were made on samples collected by making a vertical tow with a plankton net from the 5 meter depth to surface. In the laboratory, aliquots of each zooplankton sample were examined in an open chamber under a binocular dissecting microscope as outlined in Edmondson and Winberg (1971) and Downing and Rigler 1984). The entire volume of each sample was inspected for dipteran immatures (*Chaoborus)*. Organisms were identified to species wherever possible according to Brooks (1957), Edmondson (1959), Stermberger (1979), Pennak (1989), and Thorp and Covich (1991). Calanoid and cyclopoid nauplii were treated as one group. Organism densities were reported in numbers per cubic meter of water volume. Zooplankton biomass (micrograms per cubic meter) was estimated for each organism according to literature values of average dry weight per organism (summarized in Downing and Rigler, 1984). Linear dimensions of each lake organism for use in the length-dry weight relations were calculated using a calibrated ocular micrometer under 100 to 400X magnification.

Sediment samples were collected for total carbon analysis at the net pen site after pen installation in mid-April, but before the fish were stocked. The same locations were sampled again in mid-May after the fish were released. See Rensel (1993) for an explanation of techniques.

Table 1. Location, depths, and equipment for sampling in Lake Osoyoos.

Parameter	----- LOCATION/DEPTHS ----- International Boundary	South Central Basin	Methods
Water Temperature	computerize CTD probe and manual meter for appropriate depths	Same as other location	Seabird CTD-19 & YSI SCT 33
Conductivity	same as above	Same as other location	Seabird CTD-19 & YSI SCT 33
Secchi Disk	Collect in consistent manner and time of day	same as other location	Standard 20 cm white disk
Dissolved Oxygen	same as above, use probe or winkler titration	same as above	Corning Checkmate or Winkler titration
pH	discrete: 2 m from surface & 2m below thermocline	same as other location	VWR Mini meter
Total Nitrogen & Phosphorus	composite samples: 1 above/1 below thermocline with one triplicate set for QA/QC	same as other location	Water bottle, freeze & persulfate oxidation method
Dissolved Inorganic N and P (water)	same as above	same as above	GF/F filter/freeze and autoanalysis
Chlorophyll *a* (and phaeophytin)	Composite of water bottle collection of 3 near surface depths: 1, 3 and 6 m	same as other location and at pen site during fish rearing	GF/F filter/freeze/ Turner fluorometer
Phytoplankton	Composite of water bottle collection of 3 near surface depths: 1, 3 and 6 m	Collect and archive	Sedimentation/dico -tomous key
Zooplankton	net tow from 5m to surface using a 64 μm mesh net	Collect and archive	visual inspection and dissection for species ID
Sediment Carbon	N/A	cores from Van Veen grab samples and at reference sites	See Rensel 1993

RESULTS AND DISCUSSION

Basic Water Quality Data

In general, water quality conditions were similar at both sampling locations in the south basin, as can be seen through comparison of Tables 2 and 3 that are based on replicate values shown in appendix 1 and 2. CTD profiles were also similar between sampling locations (see appendix figures). Accordingly, the discussion will focus mainly on the international boundary location, where more data was collected and there is greater depth.

Vertical profiles of temperature and other parameters suggest that the lake was not vertically stratified in April, but gradually became stratified thereafter (Tables 2 and 3, see figures in appendix 3). In most cases, it is adequate to simply refer to the surface samples (epilimnion) or the bottom samples (hypolimnion), although the former was often a composite of 1, 3, and 6 meter depth samples.

Water Temperature

Maximum water temperature was 27.5°C in surface waters of the south basin during late July, which was similar to the bimonthly average for late July in the Washington Department of Ecology (WDOE) volunteer-collected data from 1989 to 1992 (See Fig. 6 of Rensel 1993). On all sampling dates, water temperature gradually declined with depth, except in late July, when it was constant from about 0 to 8 m in both the CTD and the backup data shown in Tables 2 and 3. This may have been due to mixing caused by strong afternoon winds that were noted during this period of time. The winds were at least 15 kts when we completed sampling on this date.

Comparison of automated probe data that shows continuous profiles of water temperature and conductivity versus depth show that the south basin was considerably warmer at and below the thermocline than the north basin in late August 1994 (about 6 - 7°C, see appendix 3, August 30th profiles for both locations). The surface layer (epilimnion) of the south basin at that time was near 21°C and well oxygenated. The deep water (hypolimnion) was about 14°C, but virtually without measurable oxygen. In comparison deep water in the north basin was 7 - 8°C, but no dissolved oxygen data were collected.

Conductivity

Conductivity in surface waters had no apparent trend, with maximum values in late July of 265 µS. Overall, conductivity values in-lake in 1994 were less than those measured in the Okanogan River station just below the outlet from Lake Osoyoos. CTD profiles (appendix 3) show a slight increase in conductivity with depth in the summer that in part could be attributed to increased phosphorus in the hypolimnion. This was pronounced in the one CTD cast from the north basin in August.

Table 2. Summary of water quality data from Boundary Point, Lake Osoyoos, 1994.
Station: Boundary Point

1994 Date	Time	Wind Dir.	Velocity kts	Wave Height Feet	Depth m	Water Temp. °C	Conductivity µS	pH	Secchi disk m	D. Oxygen mg/L	Chlorophyll a µg/L	Phaeophytin µg/L	C/P Ratio	Nitrate µg/L	Nitrite µg/L	Ammonium +Ammonia	Ammonia µg/L	DIN µg/L	Ortho-P. µg/L	N:P ratio DIN/PO4	Total N µg/L	Total P µg/L
April 13	820	S	5	0.2	0.5	9.3		8.4	3.7	10.6	4.63	0.98	4.7	8.40	0.33	6.02	0.25	14.75	38.82	0.4	429.01	55.75
					15			8.3		9.8				0.65	0.05	11.62	0.49	12.32	34.58	0.4	401.01	40.26
May 16	1200	S	5	0.2	0.5	15.5		8.3	2.5	11.3	4.24	0.85	5.0	0.37	0.09	5.23	0.28	5.69	61.94	0.1	365.91	75.77
					15	10.2		7.9		7.3				0.14	0.56	10.31	0.15	11.01	1.55	7.1	330.59	13.83
June 16	1200	N	3	0.2	0.5	19.0	210	8.4	3.5	8.4	2.74	0.55	5.0	3.08	0.28	14.56	1.23	17.92	3.41	5.3	527.94	32.21
					1	19.0	210															
					3	18.5	215															
					6	18.0	220															
					10	16.0	220															
					15	13.0	210	7.6		4.1				2.66	0.70	13.58	0.13	16.94	1.55	10.9	358.54	13.32
July 25	1120	S	3 -15	0 - 1.5	0.5	27.5	265	8.7	4.0	8.5	2.56	0.74	3.5	0.00	0.14	6.58	1.38	6.72	1.86	3.6	578.76	20.44
					1	27.0	262															
					3	24.9	249			8.1												
					6	23.0	240			8.3												
					8	20.3	233			6.1												
					10	17.5	231			3.5												
					12	15.0	230															
					15	13.5	225	7.5		0.1												
					20					0				2.94	1.68	119.91	0.92	124.53	18.12	6.9	544.88	41.81
August 30	830	N	2	0	0.5	21.1	239	8.7	2.5	8.2	6.53	0.07	93.3	0.84	0.07	4.97	0.87	5.88	7.43	0.8	659.96	380.47
					1	21.1	241															
					3	21.1	243															
					4	21.1	243			7.3												
					6	21	242			7.4												
					8	21	243															
					10	20.5	249															
					15	14	237	7.6		0												
					20					0				0.91	0.00	208.74	2.09	209.65	38.56	5.4	676.90	69.22
Sept. 29	1020	S	1	0	0.5	19.8	231	8.9	2.6	9.5	9.93	0.10	99.3	2.71	0.23	8.21	1.85	11.15	5.37	2.1	741.39	20.13
					1	19.6	231			9.5												
					3	19.5	231			9.5												
					6	19.1	232			8.4												
					8	19	233			6.9												
					10	18.8	234			6.7												
					15	14.9	239	7.5		0												
					20					0				2.38	0.14	374.50	3.18	377.02	62.46	6.0	883.68	95.28

Chlorophyll a and Phaeophytin values are from composite of surface depths, usually 1, 3 and 6 m

Table 3. Summary of water quality data from South Central Basin, Lake Osoyoos, 1994.
Station: South Central Basin

1994 Date	Time	Wind Dir.	Velocity kts	Wave Height Feet	Depth m	Water Temp. °C	Conductivity µS	pH	Secchi disk m	D. Oxygen mg/L	Chlorophyll µg/L	Phaeophytin µg/L	C/P Ratio	Nitrate µg/L	Nitrite µg/L	Ammonium +Ammonia	Ammonia µg/L	DIN µg/L	Ortho-P. µg/L	N:P ratio DIN/PO4	Total N µg/L	Total P µM
---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------	---------
April 13	1130	S	10	0.2	0.5	9.0		8.5		10.6	5.29	1.925	2.7	0.37	0.00	1.73	0.10	2.1	0.83	2.5	381.45	19.30
					15			8.7		9.7				0.09	0.00	4.62	0.27	4.7	5.78	0.8	326.85	50.58
May 16	1445	S	5	0.2	0.5	15.5		8.4	3.5	10.4	3.18	1.37	2.3	0.00	0.28	6.44	0.43	6.7	0.62	10.8	304.22	13.32
					15			7.9		7.3				0.00	0.28	2.80	0.18	3.1	0.62	5.0	332.78	10.22
June 16	1200	N	3	0.2	0.5	19.0	220	8.4	3.5	10.1	2.22	0.74	3.0	0.00	0.28	1.26	0.11	1.5	0.31	5.0	420.00	12.70
					1	19.0	220															
					3	19.0	220															
					6	19.0	220															
					10	16.0	215															
					15	13.0	215	7.4		4.3				1.82	0.70	20.86	0.12	23.4	2.17	10.8	643.86	88.26
July 25	1255	S	12	0.5	0.5			8.6	4.0		1.75	0.54	3.2	2.38	0.14	21.56	(a)	24.1	3.10	7.8	905.24	25.71
					1																	
					3																	
					6																	
					8																	
					10					4.8												
					12																	
					15																	
					20									0.84	0	8.54	(a)	9.4	1.24		380.80	11.15
August 30	1254	N	0	0	0.5			8.8	2.5	8.3	4.49	0.05	89.8	1.26	0	16.38	(a)	17.6	27.56	0.6	659.96	20.75
					1																	
					3																	
					4																	
					6																	
					8																	
					10																	
					15			8.6		6.5												
					20									1.12	0	6.02	(a)	7.1	4.34	1.6	676.90	28.49
Sept. 29	1200	S	3	0	0.5			8.8	2.8	8.4	8.07	0.88	9.2	2.38	0.14	7	(a)	9.5	3.72	2.6	681.52	18.27
					1																	
					3					9.2												
					6					8.5												
					8					6.9												
					10					6.4												
					15			7.8		0												
					20									2.38	0.14	61.6	(a)	64.1	8.05	8.0	512.4	25.09

a/ calculated ammonia not possible without temp. and pH from same depth *pH*

pH values in surface waters varied from 8.3 to 8.9 with maximum values occurring later in the year. Increased phytoplankton activity was probably responsible for this, due to bicarbonate uptake that reduces the available hydrogen ion content. Bottom water pH varied from 7.5 to 8.3, with the minimum occurring in late September, concurrent with minimum levels of dissolved oxygen.

Water Transparency

Secchi disk transparency averaged 3.13 m for all months sampled, but if an October value similar to September is added, then the average for 1994 would have been 3.06 m. This compares similarly to a same time period of 1971 when secchi disk depth averaged 3.3 m, probably in the north basin (Stockner and Northcote 1974). The variance between years certainly is not outside of expected interannual variation. Secchi disk depth averaged 2.6 m from mid-May to October 1 of the WDOE volunteer-collected data from 1989 through 1992 at the Boundary Point station, which again is not a notable difference.

Dissolved Oxygen and Fish Distribution History

The rate of dissolved oxygen depletion below the thermocline in seasonally stratified lakes is a general measure of the state of eutrophication. Lakes that rapidly lose dissolved oxygen in the deep layer (hypolimnion) are usually more eutrophic than those that slowly become anoxic or hypoxic (no or low oxygen, respectively). The available data shows that dissolved oxygen is lost from the deep layers of Lake Osoyoos during the summer, but only at a moderate rate. This fits with the findings that the lake is still mesotrophic, to be discussed later.

Dissolved oxygen was 4.1 mg/L in bottom (hypolimnetic) water in mid-June, however zero oxygen (anoxic) conditions were noted at 20 m during July and at 15 m during the August and afterwards (Table 2). During the July visit there was only a 1 or 2 meter wide depth in the south basin during July that would have allowed for sockeye salmon survival (compare temp. and DO in Table 2 for July) . I estimate that range of depth to center at about 9 m deep. Before and after that period, however, conditions were more suitable for the fish.

It could be useful to compare the 1994 results with those of Allen and Meekin (1980, Table 4) who collected vertical profiles of water temperature and dissolved oxygen (DO) in 1972 while gillnetting juvenile sockeye (see their figures 9-13, reproduced as figures 12-16 in Rensel 1993).

Table 4 shows a similar trend in dissolved oxygen concentrations over depth and month with the exception of the final samples. The lake turned over prior to the October 2, 1972 sample, resulting in high DO concentration at the 15 m depth compared to the 1994 sample when the lake was still stratified. This is most likely due to interannual variability in wind and weather that affects vertical stratification of the water column.

Table 4. Comparison of dissolved oxygen concentrations (mg/L) from 1972 (Allen and Meekin 1980) and 1994 (present study) at the Boundary Point station in Lake Osoyoos. Some interpolation was necessary.

Sampling Dates	7 m	15 m	20 m
July 12, 1972	8.0		1.5
July 25, 1994	7.1	0.1	
August 9-11, 1972	6.5	0.9	0.8
August 30, 1994	7.4	0.9	0.8
Sept. 11-12, 1972	8.0	0.8	
(no comparison)			
Oct. 2, 1972	8.4	8.1	
Sept. 29, 1994	7.6	0.0	

Judging from the available data, it is entirely possible that sockeye fry do not utilize the south basin at all during the mid to late summer until vertical stratification is lost during lake turnover. There have been no hydroacoustic soundings at that time, although prior studies have recommended that it be done (Biosonics 1983). Gillnet sampling was conducted only on one night in 1972 with no fish captured in the south basin (Allen and Meekin 1980).

Nutrients

Total Nitrogen and Total Phosphorus

Total phosphorus ("total P") is a measure of the trophic or nutrient status of a lake and is best collected over the summer months in surface waters (Welch 1992). The mean summer 1994 (June to Sept.) total P of surface water in Lake Osoyoos was 113.3 µg/L, which is extremely high relative to prior data and what was expected. This average was influenced strongly by one monthly measurement that occurred in late August (Table 2).

Although the August total P value was replicated by a duplicate sample collected at that station, I will conservatively discard it as a probable outlier because the duplicate came from the same water bottle collection. It is possible that macroalgal fragments or other debris influenced the sample. A sample collected the same day from the south central basin station yielded a total P concentration of 20.75 µg/L. This result will be substituted for the Boundary Point sample (Table 2), resulting in a mean summer total P of 23.4 µg/L (SD = 5.9, N = 4, Fig. 2). Figure 2 shows the monthly trend, decreasing from high concentrations earlier in the year as expected. Total N was very high, as discussed later.

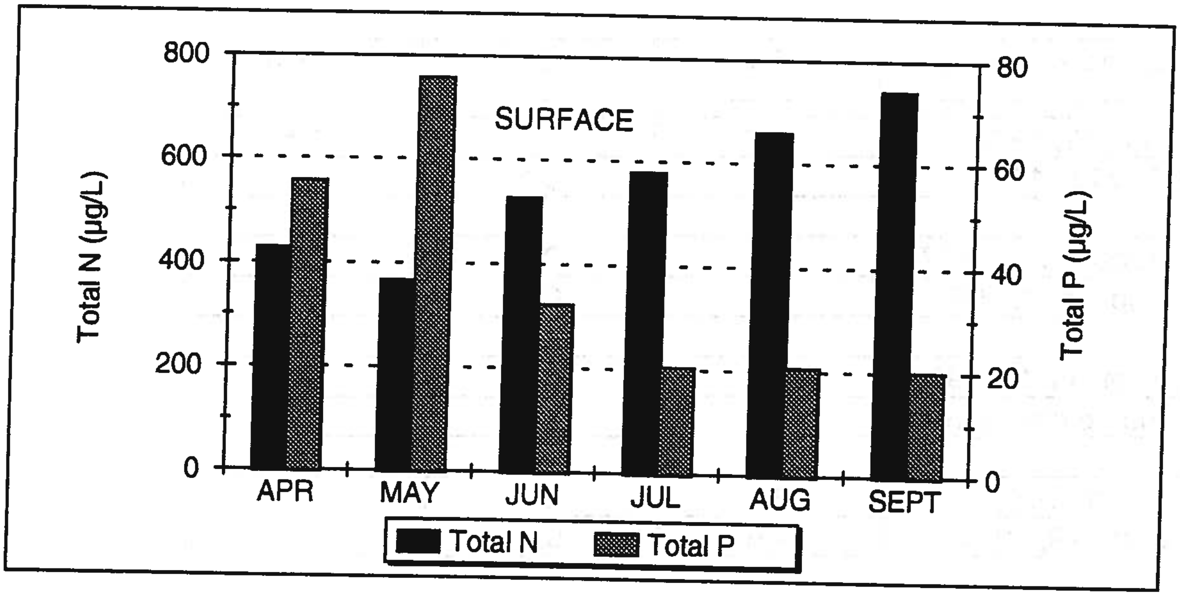


Figure 2. Monthly total nitrogen and total phosphorus for surface water in the south basin of Lake Osoyoos during 1994 (Boundary Point location except for S. Central Basin for August.

The following is a review of all historical total P results in the lake for comparison to the 1994 data or other available data.

Collection of total P only during spring turnover of lakes that have summer time vertical stratification is of interest because there is often (but not always) a direct relationship between total P concentration and algal biomass, measured as chlorophyll *a*. The Canadians (B.C. Environment) have been sampling in late February to early April, but anytime after turnover but before phytoplankton production increases in the spring should be sufficient.

In 1970-71 a spring turnover timing mean of 76.5 µg/L total P was reported by Stockner and Northcote (1974). Comparison data collected by B.C. Environment in the 1980s is shown in figure 3, that averaged 26.4 µg/L total P (SD = 5.2, N = 10, no data from 1989).

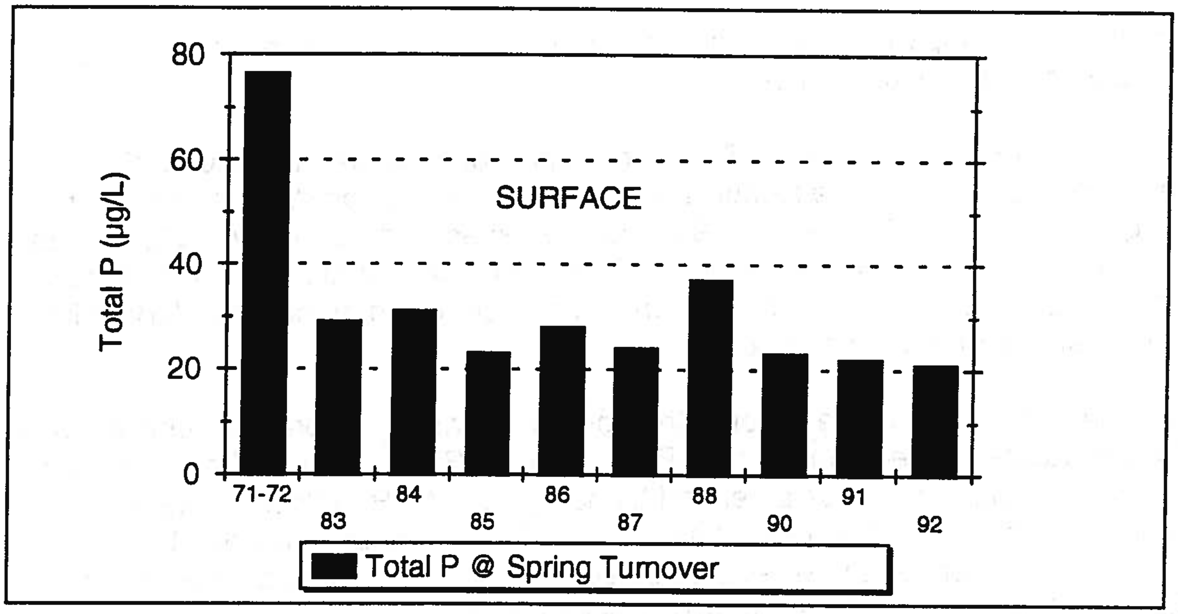


Figure 3. Total phosphorus from the surface water of the north basin of Lake Osoyoos during or directly after spring turnover. 1971-1972 data from Stockner and Northcote (1974) and 1983-1992 data from data provided by E.V. Jensen, B.C. Environment.

The decline of spring turnover total P concentration of over 50% in ten years between 1971-72 and years from 1983 on is very dramatic but possible under some extreme circumstances. I would suggest that the lake was either 1) much more eutrophic in the early 1970s than later or 2) there is a problem in comparability of data due to varying analytical techniques or other problems. Because chlorophyll *a* data, discussed below, was also much higher in the 1971-72 data, it may be argued that the total P data was indeed correct. However, there has been no apparent change in water transparency; a change that would be expected if both total P and chlorophyll *a* concentrations decreased. This results in an ambiguous situation that I am unable to resolve with the limited data at hand. I will attempt to reach John Stockner or other experts in British Columbia to see if they have any comments on this. It would also be useful to obtain the technical reports that Stockner and Northcote used for their analyses.

The USGS collected 3 samples for total P analysis from two locations in July of 1974, 1 from the surface and two from near the bottom (Dion et al. 1976). I assume the locations were in the south basin due to the shallow depth of the deeper samples (<50'). The results were 12 µg/L for the surface and 14 and 17 µg/L for the deeper samples.

Mean summer total P in the Okanogan River below the outlet of Lake Osoyoos ranged from about 10 to 30 µg/L from 1976 to 1991, but in most recent years of 1987-1991, the trend was down from 20 µg/L to about 12 µg/L (Rensel 1993). As I discussed in that previous report, sampling in the river is a poor substitute for in-lake data collection, and comparisons are tenuous at best until some concurrent sampling and correlative analysis is performed.

The 1994 total P results from the Boundary Point station were much higher than infrequently collected in-lake samples taken during summer by Washington Dept. of Ecology (WDOE) in 1974, 1981,1989 (2 samples averaged here), and 1992 (mean = 15.6 µg/L, SD = 4.2, N= 4, Rector 1993). The most recent total P data from August 31, 1992 was 12 µg/L from the epilimnion of the south basin at the Boundary Point station near the international border.

Data collected in the surface water of the north basin during September only of 1983-91 by Canadians yielded a mean total P = 14.2 µg/L (SD = 4.0, N = 9) as discussed by Rensel (1993). There was a general tendency for total P to decline later in that data set, with the 1989-91 average being only 9.3. Comparison between basins must be done with caution, as there never has been concurrent nutrient data collected to show if conditions are similar (see recommendations).

A total P value of 24 µg/L was found in early October of 1992 at two locations in the south basin by Rensel (1993). This compares similarly to the late September 1994 value of 20.1 µg/L total P (Table 2).

Based solely on the 1994 summer mean of 23.4 µg/L total P, a trophic rating for the south basin of Lake Osoyoos would be just at the threshold of "eutrophic", using the definitions of Porcella et al. (1980) or Carlson (1977). Moreover, comparison to other data collected in the summer suggest an increase in eutrophication in Lake Osoyoos. However, the lake must be evaluated with all available data, which is done below in the section *Trophic State Determination.*

Total N values from the summer of 1994 averaged 716.6 µg/L, a value also quite high due to the August sample (Table 2, Fig. 2). After deleting that value, a mean of 616.0 µg/L was noted, also very high compared to limited prior data. Figure 2 shows that total N increased nearly in a linear fashion over the summer while total P declined in step fashion. The WDOE sampling mentioned above also included 4 summer samples of total N taken over 3 years: 1981, 1989 and 1991 that yielded a mean of 397.5 µg/L. Stockner and Northcote's (1974) much older data had a mean total N of 272 µg/L, at spring turnover. Comparing that data with our April data (TN = 429.01 µg/L, Table 2), I note about a 58% increase in 1994, although our data was collected into the spring bloom period. Porcella et al. (1980) suggest that an average total N greater than 180 µg/L in summer months is indicative of eutrophic conditions. Total N is a seldom used indicator of trophic condition compared to total P, but the high concentrations found in Lake Osoyoos suggest that future sampling continue for this parameter.

It is interesting to note the inverse relationship of surface waters in Figure 4, with total P declining and total N increasing over the sampling interval. Apparently the pool of available organic and inorganic P declined in the surface waters, but the pool of total N increased. In part this may be due to the buildup of blue-green algae with nitrogen-fixing ability in the surface layer. Due to thermal-induced vertical stratification, the surface layer (epilimnion) is somewhat isolated from the oxygen poor, cold and nutrient rich bottom layer (hypolimnion). Within the surface layer, chemical and physical conditions were probably homogeneous due to wind mixing, which at times is very strong in Lake Osoyoos.

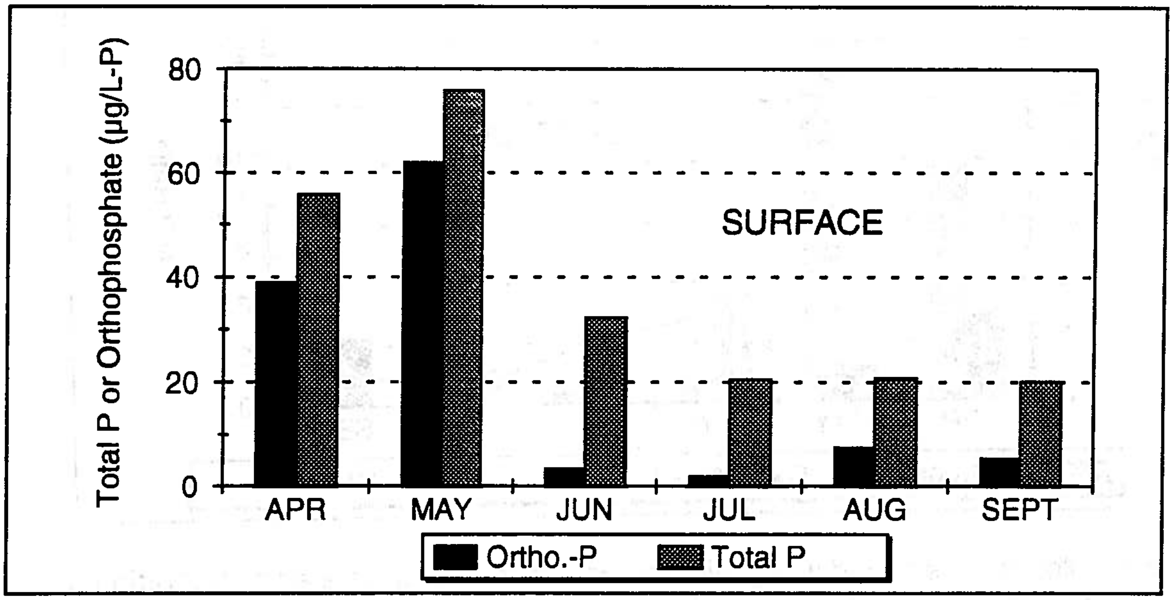


Figure. 4. Monthly orthophosphate and total phosphorus for surface water in the south basin of Lake Osoyoos during 1994, Boundary Point sampling station.

The decrease in surface total P to about 20 -30 µg/L in summer was accompanied by a decline in orthophosphate (a form of dissolved inorganic phosphorus generally available to plant growth) to very low concentrations near detection limits in June and July (Fig. 4). Because orthophosphate cycles relatively fast from organic to inorganic forms, relative to nitrogen, the possibility of phosphorus limitation of phytoplankton can not be determined from these measurements, but must be determined experimentally through ^{14}C uptake experiments or other means.

Dissolved Inorganic Nitrogen and Orthophosphate

Although dissolved N and P fractions are less useful in determining the trophic status of a lake, they are useful for determining which, if either dissolved nutrient was possibly limiting to algal growth. The monthly pattern of dissolved inorganic nitrogen (DIN = nitrate+nitrite+ammonium+ ammonia) and orthophosphate concentration in the south basin of Lake Osoyoos during 1994 is shown in Figure 5. A ratio of N to P of 7:1 is considered neutral with regard to the physiological requirements of algae. Note that the ratio was always less than 7:1, suggesting that nitrogen was always proportionately less available than phosphorus. This would be expected in a eutrophic lake, whereas phosphorus is often less available in oligotrophic or mesotrophic lakes. The July and August samples are of special interest, as the low ratio was accompanied by very low concentrations of phosphorus in surface waters and may have been limiting to some forms of plant growth.

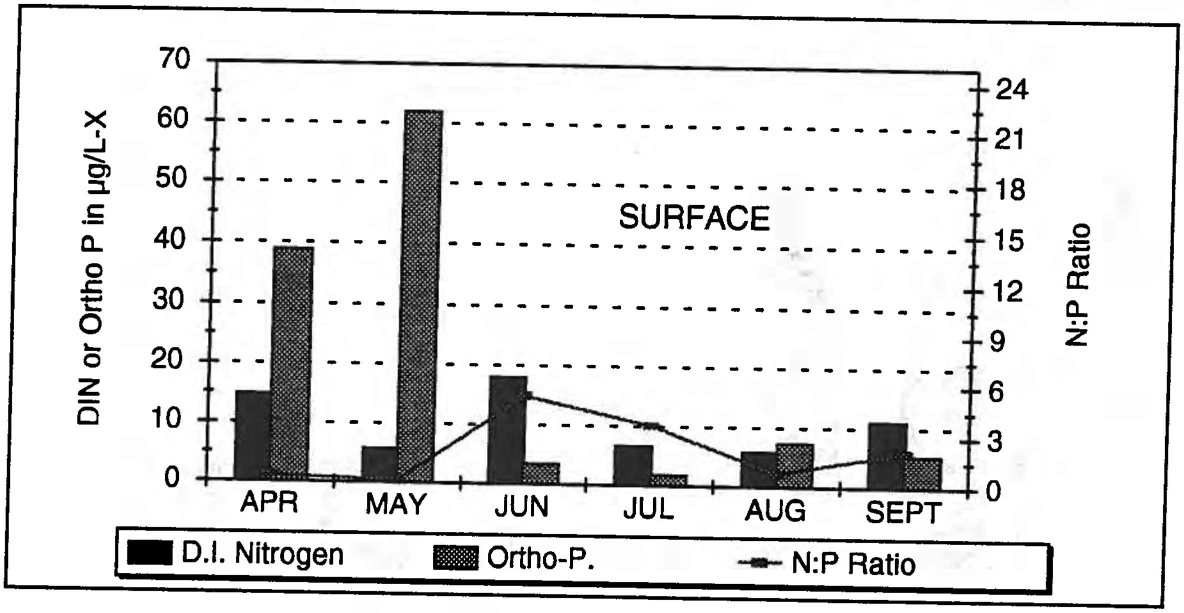


Figure 5. Monthly dissolved inorganic nitrogen, orthophosphate and their ratio for surface water in the south basin of Lake Osoyoos during 1994.

A comparison of the forms of dissolved inorganic nitrogen from surface and bottom water are shown in figures 6 and 7. Examination of the raw data (Tables 2 and 3) show that ammonium+ammonia was the majority of the DIN of surface waters. Normally ammonium+ammonia is usually rapidly taken up by algae or oxidized to nitrate by bacteria in oxygenated environments so it was somewhat surprising to find it dominating the DIN pool although it's concentration only averaged 7.6 µg/L-N (SD = 3.6, N = 6). A prior study of the Okanogan River data downstream of the lake outlet showed that average summer ammonium+ ammonia was about 35 µg/L-N (Rensel 1993). Because concentrations in hypolimnetic water of the lake (mean = 123.1 µg/L-N, SD = 146.8, N = 6) were much higher, there must be some advection of deep water out of the lake into the river during the summer to result in values near 35 µg/L.

Data from the north basin collected by Canadians from September only in 1983-1991 showed average ammonium+ammonia concentrations around 5 µg/L-N. However, the data is subject to a detection limit of 5 µg/L-N in 5 of the 9 years, suggesting that the actual mean concentration could have been less. In all of these surface and bottom water data the percent unionized ammonia which is toxic to fish was only a few percent of the "total" ammonium+ammonia concentration, and therefore not a problem for fish life.

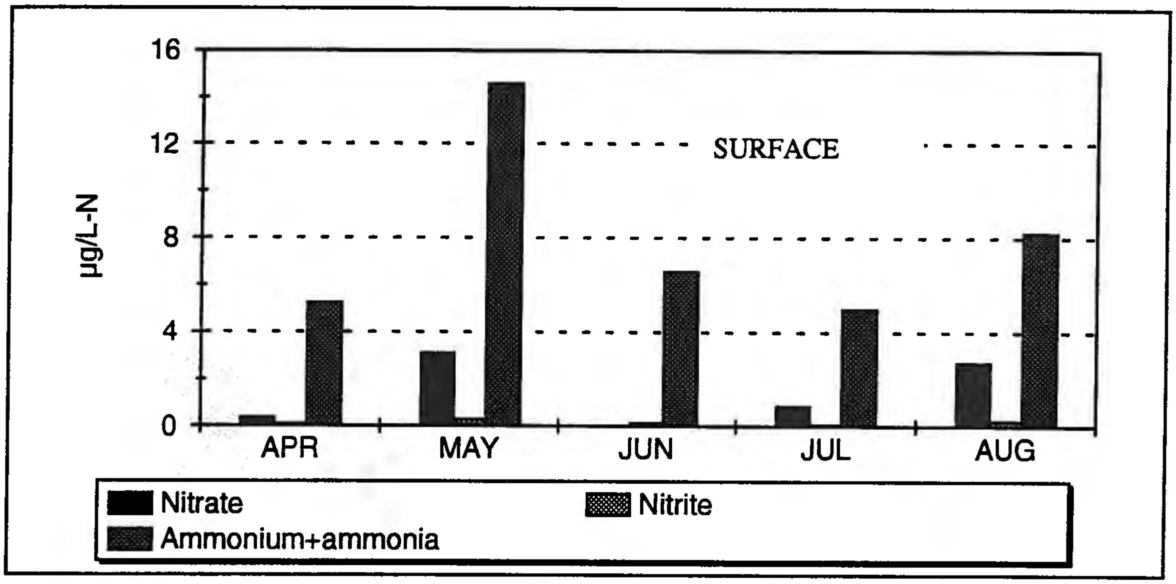


Figure 6. Monthly nitrate, nitrite and ammonium+ammonia for composite surface water samples in the south basin of Lake Osoyoos during 1994.

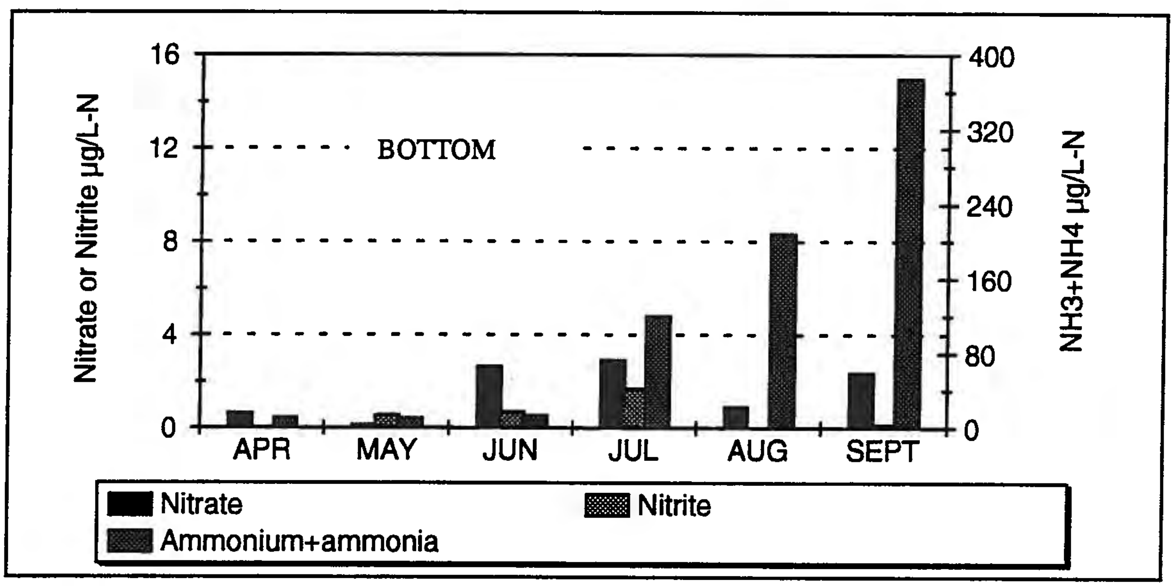


Figure 7. Monthly nitrate, nitrite and ammonium+ammonia for bottom water in the south basin of Lake Osoyoos during 1994.

Orthophosphate increased concurrently with total phosphorus in bottom water during the summer of 1994 (Fig. 8), most-likely due to release of orthophosphate from sediments in the anoxic conditions that prevailed. The reaction occurs because of changes in the valence state of iron that releases adsorbed phosphorus when oxygen is unavailable. This process, termed "internal loading" can be validated through various forms of experimentation, and the data shown here does not prove cause and effect. A large proportion of the total P was accounted for by orthophosphate, but there are many other forms of P that could possibly exist. Implications of this finding are discussed later with regard to the sockeye salmon population.

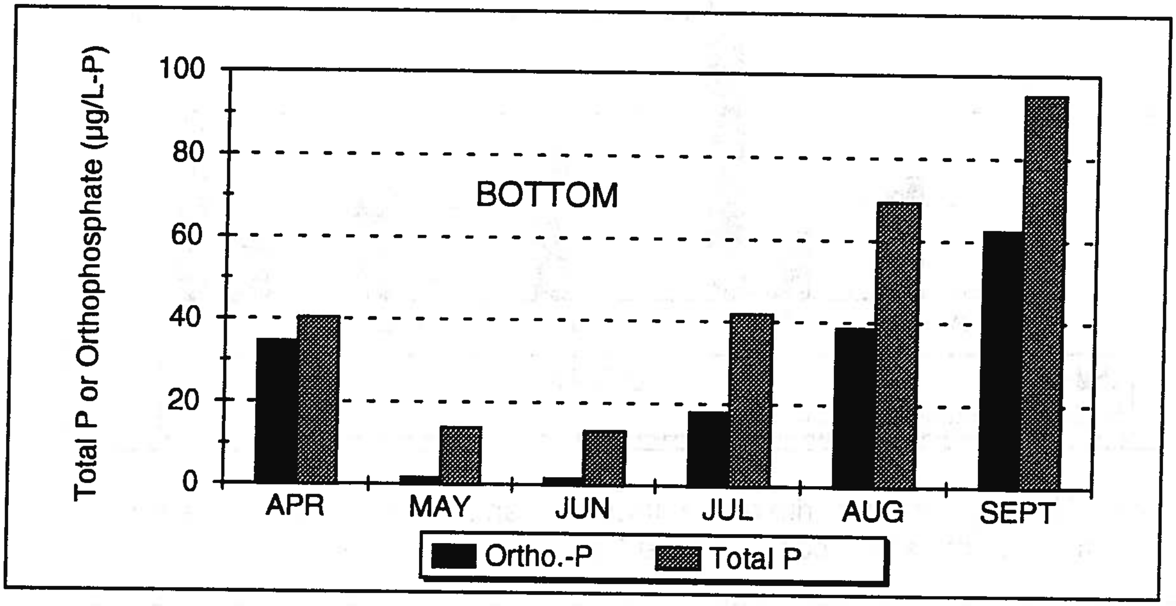


Figure 8. Monthly orthophosphate and total phosphorus for near bottom water in the south basin of Lake Osoyoos during 1994.

Phytoplankton: Chlorophyll *a* and Species Dynamics

Chlorophyll a

Chlorophyll *a* had an irregular but approximately bimodal distribution, with peaks of 4.6 µg/L in April and 9.9 µg/L in late September (Fig. 8). The distribution corresponds with a seasonal shift from diatoms in the spring to blue-green algae later in the summer, as will be discussed below. Minimal chlorophyll *a* values were seen in June and July. This corresponds to the minimal orthophosphate concentration measurements (Fig. 5) and may be inter-related.

Figure 9 compares Secchi disk depth (transparency) to chlorophyll *a* because lakes often exhibit an inverse relationship between the two parameters, when algal stocks are responsible for changes in transparency. The correlation coefficient in this case, however, was only 0.67, not particularly high. This suggests that some factor other than phytoplankton may in part be influencing transparency in Lake Osoyoos. The variance could be due, in part, to the presence of blue-green algae that may be patchy in their distribution both vertically and horizontally. Additional secchi disk measurements are planned in 1995 to help account for this factor (see Recommendations).

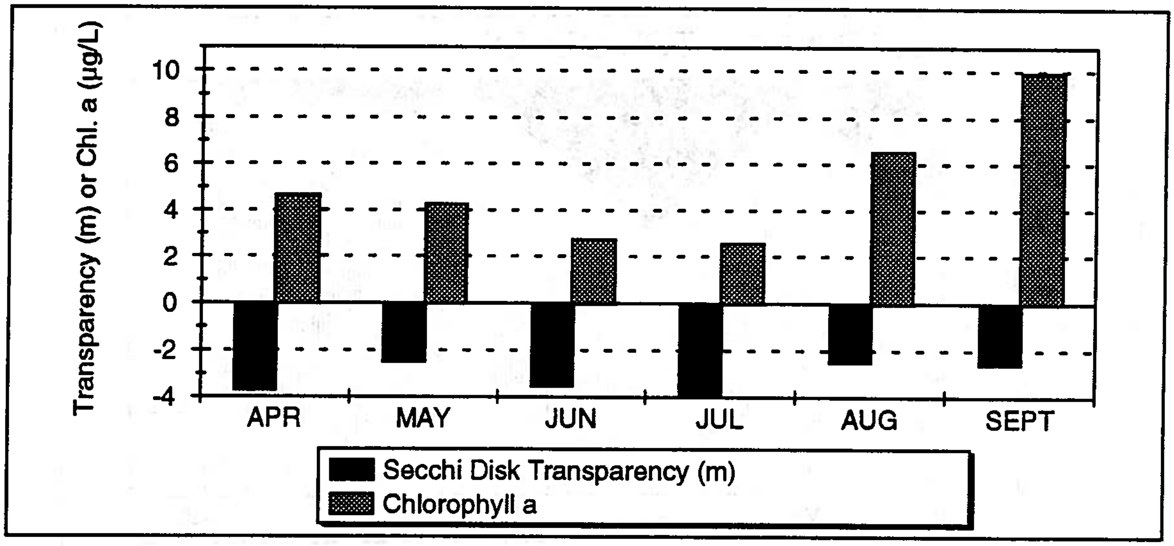


Figure 9. Monthly Secchi disk transparency and near surface water chlorophyll *a* pigment concentration in the south basin of Lake Osoyoos during 1994.

The general transparency to chlorophyll *a* relationship for many lakes in its simplest form is reported by Carlson (1977) to be:

$$Secchi\ (meters) = 7.7\ Chl.\ a\ (\mu g/L)^{-0.68} \qquad \text{Equation 1.}$$

Average summer chlorophyll *a* concentration of surface water was 5.4 µg/L in 1994 (Table 2). Using equation 1 with this data, a secchi disk transparency of 2.45 is predicted. The average summer (June - Sept.) secchi disk transparency was 3.15 m (SD = 0.7, N = 4), 22% greater than expected.

Phytoplankton: Species Dynamics

The species composition of phytoplankton are of particular interest because they are an important base level of the food web. The presence or absence of various taxa and species are powerful tools to analyze the suitability of lakes for various types of fish populations. Species succession of phytoplankton are shown in figures 10 and 11 for density and biomass, respectively based on the raw data shown in appendix 4 and 5.

In terms of density (numbers per ml), blue-green algae dominated the lake throughout the sampling period, with diatoms being a far second in April and June. A few green algae were seen later in the summer. However, in terms of biomass (Figure 11), diatoms dominated in late spring and early summer with a gradual shift to blue-green dominance (80%) by late summer accompanied by a lesser showing of green algae.

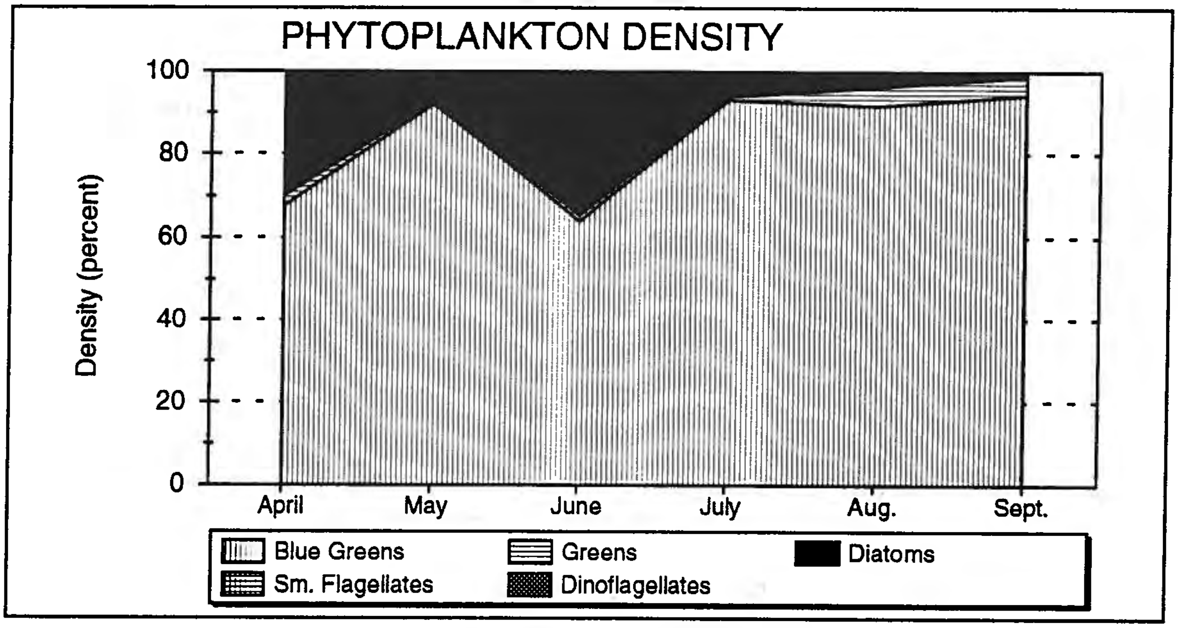


Figure 10. Percent distribution for density of major taxa of phytoplankton in the south basin of Lake Osoyoos during 1994.

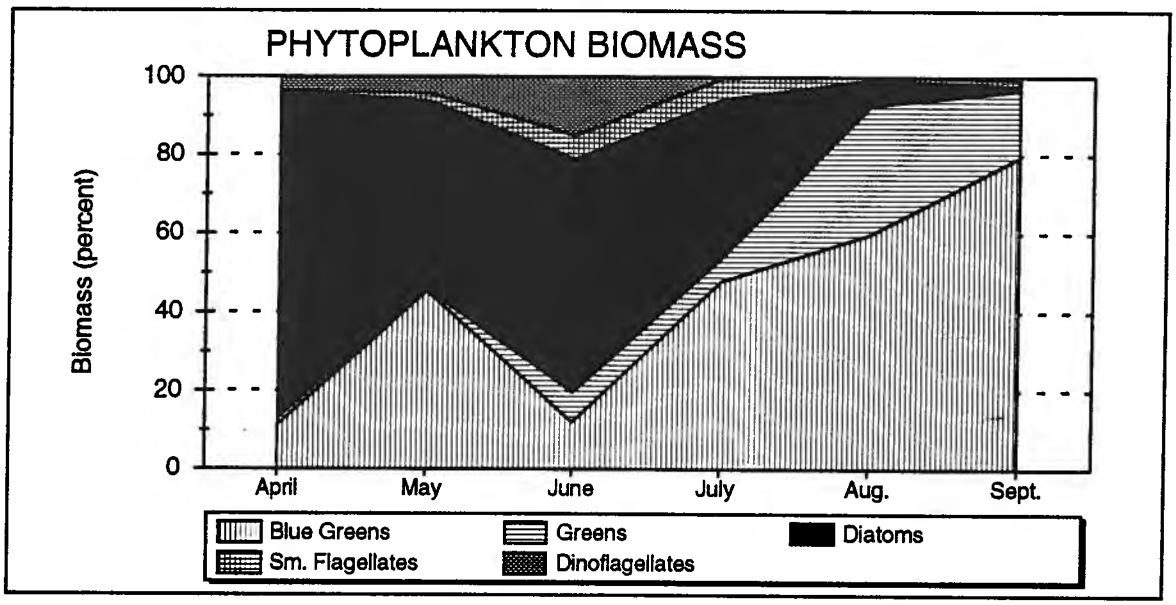


Figure 11. Percent distribution for biomass of major taxa of phytoplankton in the south basin of Lake Osoyoos during 1994.

The species lists (Appendix 4) show that more species of diatoms were present before July, and more species of blue-greens (Cyanophytes) were present after July. However, even as early as April, the blue-green alga *Oscillatoria tenuis* was the most dominant single species, both numerically and in terms of biomass. By May the blue-green alga *Aphanizomenon flos-aquae* was similarly dominant in both categories.

Semi-dominant diatoms by volume included *Tabellaria fenestrata*, *Melosira italica* and *Stephanodiscus niagarae.* Later in the summer there was no single dominant blue-green alga, but a mixture of species including the above two mentioned species, several species of *Anabaena*, *Aphanocapsa* sp., *Chroococcus* sp., *Gomphosphaeria lacustris*, Lyngbya sp., *Microcystis aeruginosa*, *Aphanothece* sp., and *Coelosphaerium naegelianum*. Some of these species may produce toxins, but there is no data for Lake Osoyoos specifically. The importance of these findings are discussed later with regard to sockeye salmon.

There are no reliable density or biomass data (other than chlorophyll *a*) from the 1970s to compare the present data. This is unfortunate because shifts in species composition can be highly important to the food web and sockeye salmon ecology. However, the general shift from beneficial diatoms in the spring to undesirable, inedible or in some cases harmful blue-green in the later summer is still the same for the two time periods (Stein and Coulthard 1971). I will attempt to contact Canadian authorities to obtain more information from the unpublished technical reports or the 1970s that may have species composition and other data.

Because of the prevalence of blue-green algae in Lake Osoyoos, It would be interesting to sample Lake Osoyoos sockeye livers for the microcystins, a class of hepatotoxins known to accumulate in salmon under certain circumstances (Kent 1990). Dr. Wayne Carmichael of Wayne State University is a world authority on this issue and he may agree to process samples for me, as he has in the past. However, I am not aware of any blue-green algal blooms in Lake Osoyoos having been toxic to domestic animals or pets, as has occurred in many other lakes throughout eastern and western Washington.

Zooplankton: Species Dynamics

Zooplankton are the animal plankton that are the primary consumers of phytoplankton in many aquatic environments; they may be highly important as sockeye fry prey. Zooplankton normally include crustaceans and rotifers as major categories in lakes. A fundamental relationship between eutrophication and the size of zooplankton has been noted throughout many eutrophic lakes of the world. The more eutrophic a lake, the smaller the average size of the zooplankton and less importance of these zooplankton in controlling the phytoplankton populations. This relationship is driven by a change in the size and palatability of the phytoplankton for consumption by large-bodied zooplankton as well as a shift in the energy flow to the microbial loop (organic matter and bacteria). In highly eutrophic lakes microbial recycling of nutrients dominates over the more desirable food web that involve several different levels of consumers and prey.

The major categories of zooplankton discussed here include generally desirable crustaceans such as the calanoid and cyclopoid copepods, especially cladocerans such as *Daphnia* sp. Not all of these are desirable as sockeye prey, generally just the larger ones. Rotifers are less desirable non-crustaceans and indicative of trophic shifts to undesirable small or large, inedible phytoplankton species. In eutrophic lakes there are more filamentous forms of phytoplankton that are less susceptible to predation by zooplankton.

The best example of desirable zooplankton is the larger-bodied cladoceran *Daphnia magna* or *D. pulex.* These forms are able to prosper in many eutrophic lakes, unless blue-greens dominate the phytoplankton or predation by forage fish crops too many of them (Welch 1992).

In general, juvenile sockeye are well known for initially feeding in nearshore areas of lakes on insects and their larvae before moving offshore to feed on pelagic zooplankton including cladocerans, copepods and amphipods (Hart 1973). Although optimum spawning escapement and carrying capacity of the lake for juvenile sockeye salmon is not known with certainty, the relatively large smolts migrating out of Lake Osoyoos indicates that existing rearing habitat is underutilized (Pratt et al. 1991) and accordingly prey does not appear to be limiting.

Several studies have shown that the introduction of trout into lakes having forage fish can lead to improved water quality (i.e., increased water transparency, normal oxygen values and lower phytoplankton populations) because the forage fish may be eating the *Daphnia* and the larger trout will reduce the forage fish populations (Benndorf et al. 1984 and Scholz et al. 1985 and others). A simplified schematic of this type of "top down" biomanipulation is shown in Figure 12. It may be stated that large zooplankton like *Daphnia* are more desirable than smaller species in this regard, which was discussed previously. In Lake Osoyoos, the sockeye fry, smolts and kokanee may be considered "forage fish" in this scheme. However, it is unknown if the above scenario applies to Lake Osoyoos at present; little is known regarding the population sizes of the very diverse non-sockeye/kokanee fish populations, and their potential interactions (see Allen and Meekin 1980 and Carl et al. 1959).

With regard to the 1994 sampling results, zooplankton data from Lake Osoyoos must be considered in terms of density (numbers per unit volume of water, Fig. 13) as well as biomass (total volume, Fig. 14). If only evaluated for the former, the situation looks fairly bleak with the clear dominance of less desirable rotifers and only a minor trend toward increasing cladocerans by the end of the summer. However, the biomass results (Fig. 14, appendix 4 and 6) show that rotifers were only a small fraction of the total, and that on cladocerans were dominant. Calanoid copepods, although smaller in size, were subdominant and increased in biomass later in summer.

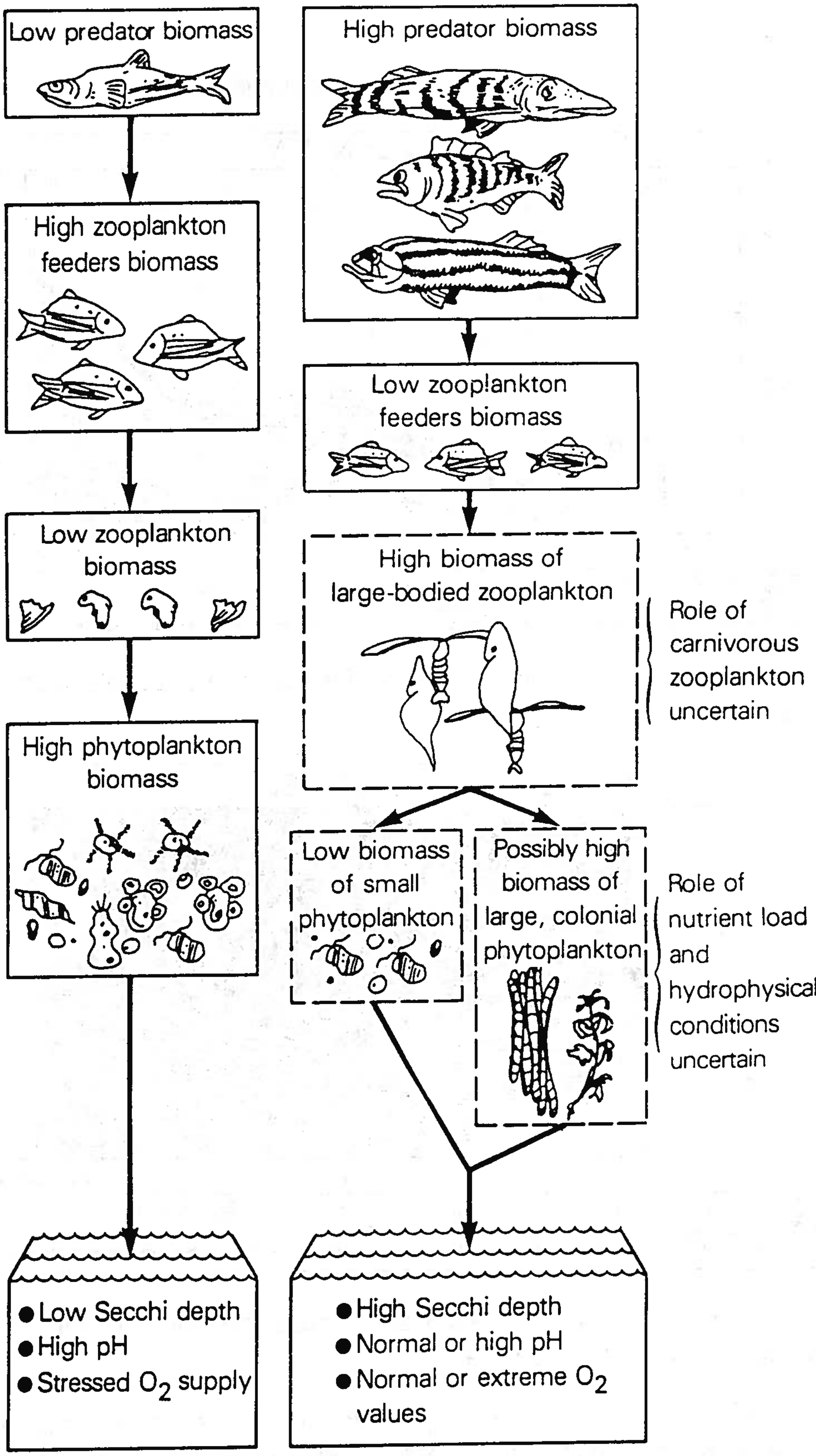


Figure 12. Comparison of two alternative paths of "top down" biomanipulation. The right path prevails in well-balanced systems with moderate or less trophic levels. The right path is common in eutrophic lakes. Lake Osoyoos probably is a mixture of these and the high zooplankton feeder biomass could be sockeye fry, kokanee, or forage fish but other factors do not all point to the left path. From EPA (1990).

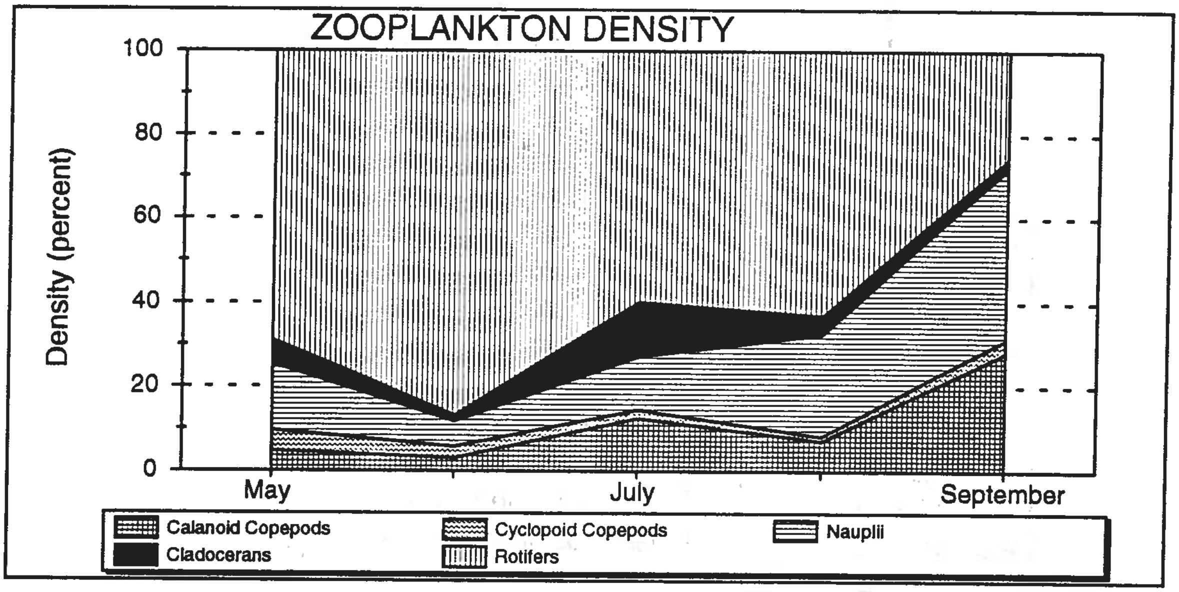


Figure 13. Percent distribution for density of major taxa of zooplankton in the south basin of Lake Osoyoos during 1994.

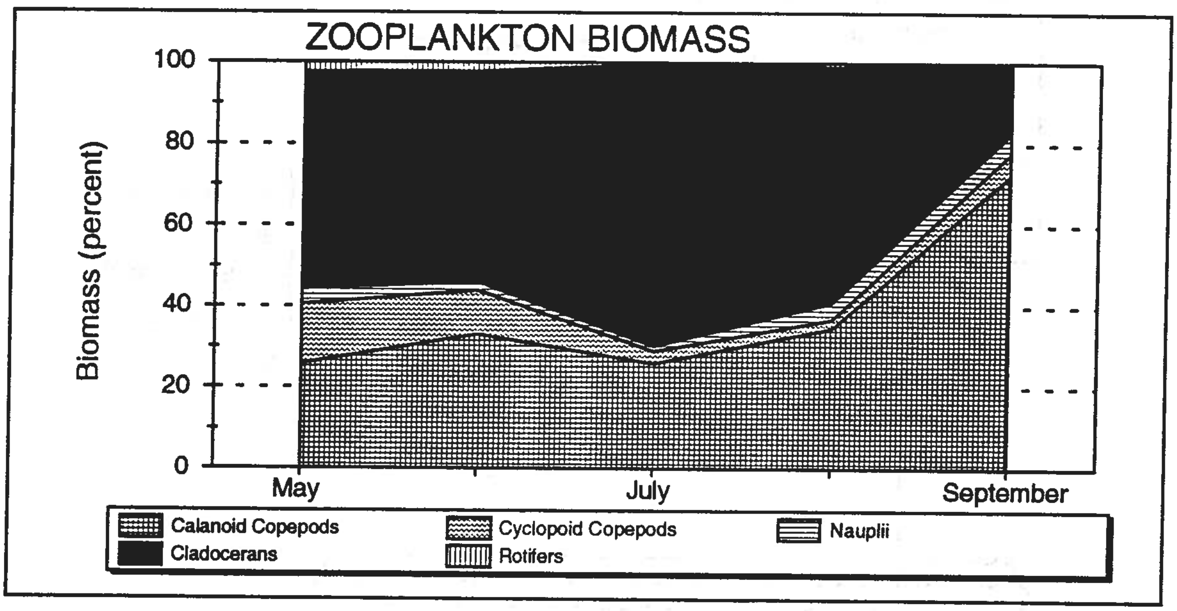


Figure 14. Percent distribution for biomass of major taxa of zooplankton in the south basin of Lake Osoyoos during 1994.

There are few previous studies to compare zooplankton species composition or abundance in the south basin. None of the prior studies, including samples from the north basin collected by the Canadian government include biomass estimates, i.e., only density (numbers of plankters per ml) has been reported.

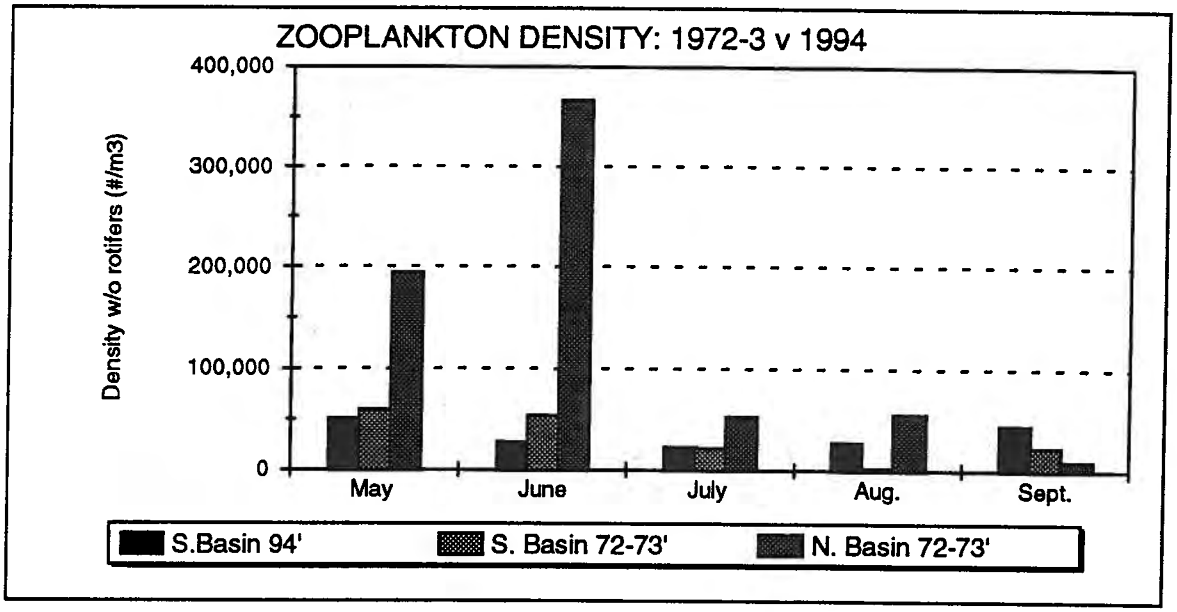


Figure 15. Density distribution of major taxa of zooplankton in the south basin of Lake Osoyoos during 1994 (this study) versus 1972-73 study of Allen and Meekin (1980) in the north and south basins. See appendices 7 and 8 for data.

Allen and Meekin (1980) reported total density of all species from several Lake Osoyoos stations sampled monthly in mid-May to mid-September 1972 and 1973. Unfortunately, total biomass of all species or individual species was not reported and the density information is only anecdotal. Allen and Meekin's data also does not include rotifers, but is useful for comparison of north and south basin production. Figure 15 shows generally higher zooplankton production in the north basin, at least in May and June. Dominant zooplankton during their 1972-73 surveys were copepods (*Cyclops* spp. and *Diaptomus* spp.), immature copepod nauplii, and the cladoceran *Daphia* spp. Noting again that their designation was anecdotal, the total density without rotifers was similar some 23 years later, although calanoids were more abundant than cyclopoids in 1994. This may not be significant to sockeye fry, as they are of similar size with the exception of *Epischura nevadensis,* a larger calanoid found in some of the 1994 samples.

Mesotrophic lakes are often very productive in terms of cladoceran zooplankton abundance. Large bodied cladocerans such as *Daphnia* sp. are able to consume a wide size range of prey compared to smaller zooplankton. However, most blue-green algae are not suitable prey for grazing cladocerans, because of their large, filamentous morphology or possibly the toxins they contain. In Lake Osoyoos, when blue-green algal biomass peaked in September (Fig. 11), the biomass of cladocerans declined to the seasonal minimum (Fig. 14). While other factors could have caused this phenomenon, such as increased planktivory (see below), the relationship certainly is of interest for further study.

Most crustacean zooplankton have a relatively high temperature tolerance (LT_{50} of 28 to 35°C, Welch 1992). So they may exist in the high temperature surface waters of Lake Osoyoos during the summer. Low dissolved oxygen in bottom waters of lakes may force zooplankton into near surface waters where predation increases due to increased light during the day. Anoxic conditions in bottom waters of Lake Osoyoos were probably the worst during the September sampling, and this could have caused the apparent decrease in desirable cladoceran populations discussed above.

Overall the abundance and biomass of desirable forms of zooplankton were relatively high in Lake Osoyoos, based on a comparison to other lakes that I have studied or about which I presently have published data. Also the mean size of the cladocerans was larger than the 1.3 mm carapace length size often considered a threshold for fish predation (Galbraith 1975, compare to zooplankton data in appendix 4). Total biomass of all zooplankton was about 1/2 of what I have seen in some eutrophic lakes.

I hope to be able to present a more detailed comparison of zooplankton population dynamics in Lake Osoyoos compared to other lakes in future reports. This effort will take time, as many authors report zooplankton results in differing units and without totals for all crustaceans vs. rotifers that would be useful in the present context.

Trophic State Determination and Trends

The trophic state of Lake Osoyoos may be determined using Carlson's (1977) trophic state index or TSI (Fig. 16). TSI was previously described and is an indication of the degree of enrichment of a lake both in this case determined by water transparency

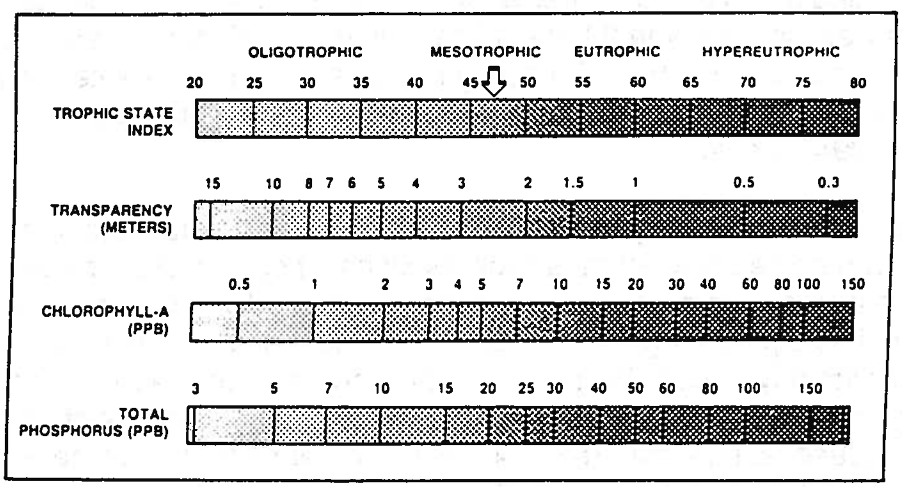


Figure 16. Graphic representation of scales for Carlson's Trophic Index (EPA 1990).

(Secchi disk depth), total phosphorus and chlorophyll *a* content during the summer months when conditions are often the worst. TSI works best in north temperate lakes that tend to be P limited and have turbidity primarily due to phytoplankton, which is probably the case for Lake Osoyoos. The index does not work in lakes that are turbid from erosion, or in lakes dominated by weeds (EPA 1990). Often not all three components of the TSI will agree exactly, as is the case for Lake Osoyoos, discussed below.

Secchi Disk

The average summer (June - Sept.) secchi disk transparency was 3.15 m (SD = 0.7, N = 4) and the April - late September average was virtually the same at 3.13 m (SD = 0.7, N = 6). This results in a Carlson Trophic Index value of 43.5 (using the formula of Carlson, 1977, Fig. 16). In 1971 the average April to October Secchi disk reading in Lake Osoyoos was 3.3 m (Blanton and Ng 1972, cited in Stockner and Northcote 1974). This is very similar to the 1994 average over the same time period of 3.15 m.

Chlorophyll a Pigment

Average summer chlorophyll *a* concentration of surface water in the south basin of Lake Osoyoos was 5.4 µg/L, equivalent to a Carlson Trophic Index value of 47.1. Mean summer chlorophyll *a* pigment concentration in the photic zone of Lake Osoyoos (probably north basin) was reported to be about 23 µg/L in the early 1970's, based on Fig. 3 of Stockner and Northcote (1974). This is over 4 times greater than the 1994 value, which is somewhat surprising due to the lack of water transparency change. I believe this to be a valid finding, as the concentrations used in the 1994 calculation were very similar to concurrent sampling results from the south central basin location.

There are other recent data that corroborate my 1994 findings regarding chlorophyll *a*. Canadian data from the north basin collected in September only of 1988-91 averaged 7.8 µg/L (SD = 2.0, N = 4). Historical data collected by the Washington Dept. of Ecology in the south basin were as follows: 7/15/91 = 3.3 µg/L, 6/6/89 = 2.3 µg/L, 9/8/89 = 6.0 µg/L, 5/18/02 = 0.82 and 8/31/92 = 1.29 (Rector 1993). These data suggest even lower concentrations at that time, but there may have been some analytical errors involved as chlorophyll *a* was not routinely analyzed by the state laboratory prior to the 1990's (Dr. A. Copping, Pers. Comm.).

Total Phosphorus

Average total phosphorus concentration of surface water was about 24 µg/L, equivalent to a Carlson Trophic Index value of 49.9. A detailed discussion of total P in the lake was previously included, only some summary information is presented below.

Total phosphorus was reported in the 1970-71 spring turnovers to average 76.5 µg/L total P (Stockner and Northcote 1974). Our earliest data from 1994 was from April 13th, when the concentration of total P was 55.7 µg/L at the international boundary, but this is too late in the year to be a highly useful comparison. The mean total P from summer samples of the epilimnion in 1994 was about 24 µg/L. Other previous data from July of 1974 ranged from 12 to 17 µg/L (Dion et al. 1976) and September only data from 1983 to 1991 averaged 14.2 µg/L. Together these data may be interpreted as showing a tentative increase in total P during the summer months, but the limited extent of the prior data argues for caution in the use of this comparison.

Total Nitrogen

Although not part of Carlsons Trophic Index, total nitrogen (total N) is included here as one more valuable indicator of conditions in Lake Osoyoos. Total N in surface waters of the south basin in the summer of 1994 averaged 616.6 µg/L, much higher than comparison data from both the 1980s that averaged about 400 µg/L. There is also some evidence that total N during the spring months was higher than in the early 1970s when Stockner and Northcote (1974) reported it to be 272 µg/L, but as previously discussed in the *Nutrients* section, the comparison is potentially bias because the prior samples were taken in the north basin and probably earlier in the year than our samples. Overall, the high concentrations of total N found in Lake Osoyoos in 1994 suggest that this be closely watched in the future.

Plankton Composition and Density

Evaluation of the plankton data is more difficult, but of great interest. With regard to trophic state trends, however, no firm conclusions may be reached because the prior data lacked biomass information (for phytoplankton) and biomass and density information (for zooplankton). The numerical dominance of potentially harmful blue-green algae in Lake Osoyoos throughout the spring to fall sampling period of 1994 is cause for concern.

Blue green algae became volumetrically dominant in the late summer, i.e., they were the largest biomass component of the phytoplankton. Concurrently, the biomass of desirable cladoceran zooplankton decreased by 50% as previously mentioned. If development in the watershed continues to increase, nutrient loading could lead to increased dominance of these harmful algae. Sockeye salmon and other fish populations could be negatively affected by reduction of desirable prey (e.g., cladoceran zooplankton), toxin production by the blue-green algae, and low dissolved oxygen conditions that accompany eutrophication.

There are no readily available historical phytoplankton species data to compare with the 1994 results. Stockner and Northcote (1974) discussed unpublished data collected as part of a study of all the Okanogan Valley lakes. They cite an average cell density of Lake Osoyoos of 5,470 cells/ml, but the time period and depth of survey was not stated. I will assume from the context of their paper that it was from surface or near surface samples and the time period apparently included spring through fall.

It is of interest that the average density of phytoplankton cells in near surface water samples from April to late September of 1994 was 6039.3 cells/ml (SD = 3,662.2, N = 6), which is very nearly the same as the study cited by Stockner and Northcote (1974). None of these numbers should be taken too seriously, as the spatial and temporal variability of phytoplankton is well known.

Summary of Trophic State Index and Related Factors

Weighing the first 3 factors equally, the overall Carlson Trophic Index value for Lake Osoyoos in 1994 would be 46.8, or in the middle of the mesotrophic range or "meso-eutrophic". Applying a qualitative equal weighting to the four physical and chemical factors described above (i.e., total P, total N, summer chlorophyll *a* concentration, secchi disk transparency), it appears that there has been a slight increase in the trophic state of Lake Osoyoos since the early 1970s. The increased total N and P is partly offset by chlorophyll *a* concentrations that have apparently declined. The last indicator was essentially neutral; secchi disk transparency remain unchanged. These indicators are obviously not all in agreement, resulting in a slightly equivocal situation. Additional data from 1995 will help establish the present trophic state by accounting for inter-annual variability. No firm conclusions should be assumed based on only one year's study of the lake.

The non-weighted average trophic state index (TSI) for Lake Osoyoos was 46.8, or in the middle of the mesotrophic range of values expressed in Figure 16. Again, this is the average of individual trophic indicators: Secchi disk transparency, chlorophyll *a* pigment concentration and total phosphorus concentration in surface waters during summer months (June to September).

The total P in surface waters during summer was mostly forms other than orthophosphate (Fig. 4); probably organic P due to phytoplankton biomass. It is unclear why this did not show up as increased chlorophyll *a*, but perhaps the analysis was confounded by the pooling of water samples from 1, 3 and 6 m that composed the "surface" sample. If blue-green algae were concentrated at one of the depths such as 1 m, then the pooling with other epilimnetic depths may have diluted the results. I was following a protocol established by the Washington Dept. of Ecology in the pooling, but may need to do some discrete depth sampling in 1995 to investigate this further. Another possible explanation could be that some of the phytoplankton may have had unusual photosynthetic pigment composition, with accessory pigments other than chlorophyll *a* being more important than usual.

Table 5. Summary of current trophic state index (TSI) and other possible trend indicators for Lake Osoyoos mostly compared to conditions in the early 1970s (from Stockner and Northcote 1974). See text for further limitations of the data.

Parameter & TSI	Apparent Trend	Quality & Value of Prior Data
Transparency 43.5 (Secchi Disk)	No change: 3.15 m now versus 3.3 m then	Probably very good
Chlorophyll *a* 47.1	Large decrease: 5.4 now versus 23 μg/L then	unknown, but probably fair as the fluorometric technique has been established for some time
Total phosphorus 49.9 (summer, surface only)	approx. 50% increase: 24 now 12 - 17 μg/L then	unknown, may have been poor due to lack of replicates and natural variability; methods may have changed
Total Nitrogen (summer, surface only or spring turnover)	Large increase compared to all prior data	Early data unknown, later data probably good. methods may have changed.
Phytoplankton Density (without rotifers)	No change: mean density of 5,470 then vs. 6,039 cells/L now	unknown, probably good as techniques are the same, depends on skill of taxonomist
Zooplankton Density	unknown, species composition may be similar	same as above

SUMMARY OF FISH CULTURE DATA

The following summarize fish cultural results of the net pens used in Lake Osoyoos in 1994. Some of the following information was paraphrased directly from a memo by Jerry Marco of the Colville Confederated Tribe Fish and Wildlife Department to the Wells Coordinating Committee dated May 9, 1994. Other information was from conference call or telephone call notes prepared by Rick Klinge or myself.

As described in the introduction, the pens were operated on a trial basis in 1994, with relatively few fish stocked. More fish would have been moved to the pens, but the fish were smaller than expected, based on results seen in the Lake Wenatchee program. Accordingly, a 3/16 inch mesh net was made up quickly, to replace the 1/4 inch mesh pens that had been previously purchased. Small bags of the each size of the mesh were prepared by the net manufacturer and sent to Cassimer Bar Hatchery so final decision of size of mesh could be made by staff.

On April 12, 1994, a total of 12,500 sockeye juveniles averaging 2.36 g (192 fish/lb.) for an estimated total of 29.48 kg (65 lbs.) were moved to the net pens from the Cassimer Bar Hatchery. The fish had previously (April 5-7) marked with a right ventral fin clip. After the fish were placed in the pens, but before release, they were given an additional, partial caudal fin clip to distinguish them from fish being released directly from Cassimer Bar. The tribal staff kept daily records of feed use, mortality, environmental conditions, etc. as shown in appendix .

By April 25th a subsampling of the fish in the net pens showed an average fork length of 73 mm and a mean weight of 3.26 g (139 fish/lb). By May 4th they had grown to an average fork length of 83 mm and averaged 4.93 g (92 fish/lb). On May 11th, the sockeye fry reportedly were 86.6 mm and averaged 6.25 g (73 fish/lb.). The fish were released 6 days later on May 17th when water temperature at the pens was probably just less than 16°C and the fish were estimated to be 7 grams. At that point the net

TABLE 6. Summary of fish cultural statistics. FCR = food conversion ratio.

Date and sample size	Length (mm)	Weight (grams)	Feed (kg)	FCR	No. of Fish	Density (lbs./cu.ft.)
April 12		2.36			12,500	0.015
April 25 (50)	73	3.26	25.2	2.24	12,499	0.021
May 4 (50)	83	4.93	24.5	1.18	12,494	0.032
May 11 (60)	86.6	6.25	19.0	1.16	12,476	0.040
May 17*	ND	7.0*	10.9	1.16	12,433	0.045
Total			79.6			

* Final weight estimate based on feed used during final interval and prior FCR.
ND = no data

pens were towed southward to about 20' depth and the fish were released. Summary statistics of fish production are shown below in table 6 based on the spreadsheet data shown in appendix 9.

During the 34 days of net pen operation the fish tripled their weight, but were smaller than originally planned for the program, i.e., 4.5 grams initially and 18.4 grams at release. This was due to the relatively small size at entry into the pens, the later than planned stocking date and the short culture period.

Pratt et al. (1991) reviewed the available literature showing that larger fish were needed to have optimum survival in the Pacific Ocean. Average size of naturally-produced Lake Osoyoos smolts has been about 110 mm, relatively large and in the upper end of the range of smolt size produced by other sockeye lakes in the world. Efforts should be made in 1995 to increase the size of the net-pen produced smolts, as discussed below in the final section: *Recommendations*.

It should be noted that the smolts produced by the net-pen program are "zero-aged", i.e., they migrate to the ocean before 1 year in freshwater, in this case after only about 6 month since hatch. Most naturally occurring smolts have reared in the lake for 1.5 years and have much longer to attain the average 110 mm size that was discussed above. The growth of the hatchery/net-pen fish was apparently forecast by using a standard salmonid/thermal unit relationship (Pratt et al. 1991) that may not be appropriate for sockeye. Compared to 1987-90 brood Lake Wenatchee sockeye, the Lake Osoyoos fish were several times larger in weight and much longer (see Figs. 5 & 6 of Flagg et al. 1991). The Lake Wenatchee fish were reared in Seattle with optimum temperature control that ranged from 5 to 17°C, and the Osoyoos fish were reared in groundwater that probably ranged from 12 to 13°C. By this measure, the 1994 hatchery/net-pen fish growth was fine but nevertheless there is probably room for improvement (see *Recommendations*).

Overall the feed conversion rate was near 1.1 for most of the culture period. This is relatively good but at the low loading density used I am sure the fish were utilizing wild feed that biased that relationship (see below). We had initially planned to rear the fish up to 0.24 lbs./cu.ft loading density, but the limited number of fry resulted in a maximum density of 0.045 lbs./cu.ft., about 5 times less than planned.

The number of fry available for planting in the pens in 1995 will be less than planned too, but at least two or three net pens will be used to keep the densities low. Lower than initially planned loading density will help prevent fish disease and increase the chance of using wild feed.

Judging from the above data, especially the rate of feed per body weight per day, there was some minor food wastage in 1994, as there inevitably is when the fish are small and small diameter feed is used. It is not possible, as has been requested in one permit, to estimate the actual amount of food wasted. Given the good FCR values, it must be fairly minimal (i.e., < 5 kg), but that is only a guesstimate. There were no antibiotics used, nor were there any signs of disease or parasitism.

Gut content study

To see if the fish were adapting to conditions in the lake prior to release, I inspected gut contents of six fish the day prior to release (May 16th). The sampled fish averaged 86.7 mm fork length, but that was after preservation that results in some shrinkage. The body cavity had been cut open to expedite preservation. Only a qualitative estimate of fullness was made, but all of the fish had stomachs and intestine that were relatively full. The contents of all of the stomachs clearly included small crustacean parts, indicating the fish were actively feeding on natural prey. The fish had been fed pelleted feed the prior day, but at the ambient water temperatures of the time and the passage of 24 hours, the guts could have been mostly evacuated of artificial feed. If time allows in 1995, I will volumetrically sample the contents and attempt to identify to general taxa using fresh samples immediately after sampling. It would also be of interest to sample earlier in the program to see if they the fish are selecting wild feed even in the presence of artificial feed.

FISH CULTURE IMPACT ASSESSMENT: LAKE BOTTOM

Samples of bottom sediment were taken at and nearby the pens before and after the fish were reared in the net pens. Results of total organic carbon (TOC) analysis are presented below in Table 7 and appendix 10.

These results show that no increase in total organic carbon was measured in 1994, which is not surprising given the small fish production in the pens. It appeared that TOC diminished in the later samples, but this is more likely due to natural variability. These results, along with the data collected in 1992 will give some basis for comparing 1995 results as well as judging the extent of background variation.

Table. 7. Total organic carbon and percent solids data from lake bottom near net pens before and after fish culture in Lake Osoyoos in 1994.

Date	Location	Total Organic Carbon (mg/kg)	Percent Solids
April 13, 1994	Under pens	45,057	
	50 m north	41,478	
	100 m north	45,919	
May 16, 1994	Under pens #1 (SW)	40,318	19.11%
	Under pens #2 (NE)	38,973	17.54%
	100 m north	44,751	18.04%

In October of 1992 in an area north of the actual pen location I found 2% TOC (i.e., 20,000 mg/kg) which was much less than expected (Rensel 1993). Canadian data from the early 1970s had shown a 4% TOC content in bottom sediments of the north basin, more similar to the 1994 results shown here. In 1995 I will collect bottom sediments at the net pen site and at a location due north and about 1/2 way to shore to see if average grain size is larger. If this is the case, water currents are probably stronger there which would explain the lower TOC results found in 1992. I would not be surprised if this was the case, as this area is very deep compared to other nearshore areas and the depth may be maintained by persistent currents.

FISH CULTURE IMPACT ASSESSMENT: MACROPHYTES

In addition to sampling of the sediments, a qualitative estimate of the species composition and distribution of macrophytes along the nearest shoreline to the pens was made to comply with Washington Dept. of Natural Resources (WDNR) lease requirements. Although I had shown in the initial report (Rensel 1993) that no solids from the pens would come anywhere near the shoreline, the WDNR had required the survey. It was stipulated that permanent stakes were to be set in the lake bottom to mark macrophyte beds and that photographs be taken annually in the same location. While I argued that this type of approach was relatively meaningless for determining anything but very large changes, the condition was required by a now retired official. After conferring with Douglas County PUD officials, it was decided that permanent stakes were too much of a potential hazard to water skiers and others recreating in the area.

In lieu of the staking, we surveyed the entire shoreline from Smith Point southeasterly to a point east south east of the net pen complex where there are several homes. That point was approximately 2,300 feet from the net pens. The survey was done during August when plant biomass was probably near maximum for the year. Six photographs were taken along representative reaches of the shoreline, for comparison to future years. These efforts surpass the required monitoring in terms of effort and may yield more meaningful results.

In 1995 we found several species of native macrophytes growing along the shoreline including Richardson's Pondweed (*Potamogeton richardsonii*), Curly-leaved pond weed (*P. crispus*), large-leaved pond weed (*P. amplifolius*) and Berchtold's pondweed (*P. berchtoldii*). The macrophyte growths were not continuos, but spaced unevenly along the shoreline in depths of a few meters. The general distribution was noted on the surveyor's chart of the area and will be compared to conditions next year. Some of the plants looked past their physiological optimum, and many had a partial coating of some kind of epiphytic green algae.

Eurasian Watermilfoil (*Myriophyllum spicatum*), a troublesome exotic species, was not seen along the nearest shorelines, although very dense growths were seen at the lake outlet adjacent to the state park. That area apparently has differing substrate composition due to the river currents. No other areas of the lake were surveyed, so tentative conclusions discussed here should not be applied to the entire lake.

LONG-TERM RISKS OF LAKE HABITAT DEGRADATION AND SOCKEYE SALMON

At present there is little evidence that the mesotrophic state of Lake Osoyoos is an immediate threat to the survival of the sockeye population. Certainly other factors are presently more important to the fish stock such as the thermal block to migration of adult spawners that occurs in some years in the lower Okanogan River and the apparent lack of fry recruitment. There is no evidence that food or space is limiting to sockeye production in the lake, and in fact the large size of the smolts in the past suggests no density dependence at present. However, Lake Osoyoos is fundamentally much more enriched than all other sockeye salmon nursery lakes and that difference raises some important questions.

All other North American sockeye lakes are essentially oligotrohic (low nutrient flux, clear water, cooler, higher dissolved oxygen at depth) and are not dominated by potentially harmful blue-green algae in the clement weather months. Lake Washington was mesotrophic for a period, but it is at the extreme southern end of the zoogeographic range for sockeye salmon and has other characteristics that differentiate it from Canadian and Alaskan sockeye lakes. Experience with trout lakes that are more similar to Osoyoos has shown that populations of desirable zooplankton prey can crash due to eutrophication and increased predation by introduced species such as mysid shrimp or forage fish. Examples of these types of "trophic cascade" problems in lakes were discussed in the report in the zooplankton section. At present there is no safety net or adequate base of knowledge with Lake Osoyoos to insure that subtle but adverse changes to the lake's ecosystem do not cause serious problems with the survival of the sockeye.

Certainly the hypoxic or anoxic conditions in the hypolimnion of Lake Osoyoos are severe and could become worse as development increases in the watershed. Not all human land use activities cause increased nutrient loading of aquatic systems, but in some cases agriculture, urban development and even treated municipal waste discharge may produce serious adverse effects. For example, there are now some well documented long -term studies that show near order of magnitude increases in nitrate loading to water sheds after some types of logging (e.g., Harr and Fredrikson 1988). In other cases, nutrient loading impacts from logging were not significant (e.g., Mullen and Moring 1988).

I was very surprised to see that prior investigations (e.g., Allen and Meekin, 1980 and Pratt et al. 1991), although acknowledging the enriched state of the lake, did not even mention the potential food web problems for sockeye salmon in Lake Osoyoos. Moreover, lake carrying capacity estimates of Pratt et al. (1991) based on euphotic zone volume and smolt production in Alaskan lakes must be seriously questioned because of the blue-green algal dominance and inappropriately warm epilimnion of Lake Osoyoos during summer. Certainly, there are no sockeye salmon lakes in Alaska with food web conditions that approach those found in Lake Osoyoos.

To improve long-term suitability of the lake for rearing sockeye fry during the summer months, it may be beneficial if trophic conditions were lowered to a condition less than the current mesotrophy. This would allow adequate food-web resources, but over a period of decades it could also reduce the problem of dissolved oxygen depletion in the deep waters that have more suitable water temperatures than the surface waters. It would also eventually result in a reduction in blue-green algae, that are relatively useless as prey for desirable zooplankton and have other negative effects. Development and land area in the Canadian portion of the watershed far surpasses that in the American side, so the issue becomes complicated when lake restoration is considered. It may not be technically or economically feasible to achieve an improvement in trophic status of Lake Osoyoos, but that decision could not be determined until a nutrient budget is researched.

RECOMMENDATIONS

Sockeye Fry Distribution Assessment

There have been no populations assessments (hydroacoustic soundings or nettings) of Lake Osoyoos sockeye fry in the late summer, although it was recommended by a prior study. Gillnet sampling was conducted only on one night in the south basin on August 10, 1972, but no fish were captured. If sockeye fry do not inhabit the south basin during the late summer, it begs the question of what happens to those fish that are there prior to that time? Do they migrate north into the north basin over the extremely shallow and narrow sill that would cause them to enter into higher temperature surface water? Do they outmigrate as zero-aged smolt or due they die do to unsuitable conditions, predation, etc.? These are questions that may be addressed to some degree by the tagging the net pen fish that is currently practiced, by capturing the fish at the out migration trap in the Okanogan River and by sampling the lake for fish after out migration. Vertical gill net sampling could be conducted in the south basin during late July or early August, concurrent with water quality monitoring to shed more light on this issue, although that would be beyond the current scope of this work.

Net pen Rearing Program

Although the hatchery/net-pen fish growth was good compared to another similar program, as previously discussed, it may be possible to significantly increase the size of the smolts through different fish-husbandry practices and feeds. Larger fish, similar to the naturally-occurring smolt would increase ocean survival and may be achieved by:

1) extending the total period of feeding each day, while reducing the amount of feed per feeding. In 1994 the last feeding was often 2 to 3 PM which is too early in the afternoon to cease feeding.

2) The use of new high energy feeds (e.g., Moore-Clark Co. Royal diet) may produce a startling increase in growth as it has with rainbow trout cultured in differing programs around the world (S. McKnight, personal communication).

3) Efforts should be made to increase the average size of the hatchery-produced fry that will be transferred to the net pens. Extended feeding hours and different feeds as well as photoperiod shifting may be possible approaches.

Water Quality Monitoring and Data Assessment in 1995

In 1995 I will be using a computerized Hydrolab multiprobe unit that allows concurrent collection of temperature, depth, conductivity, pH, redox and dissolved oxygen. The unit has a data logger and constant velocity water pump, but unlike the completely submersible CTD unit used in 1994, continuous monitoring of the results can be provided to a surface display/datalogger. In this manner, we can review the data as it is logged and provide quality control and assessment *in situ*. The unit should further improve the accuracy of the data and allow us to collect more data within the same time limitations, especially for dissolved oxygen to a depth of 50 m.

Given the importance of total phosphorus, chlorophyll *a* and Secchi disk transparency in assessing trophic index, I propose that three separate stations be utilized for collecting these specific data in the south basin in 1995 during the summer months. This would allow for replication in space and allow for identification of outlier data such as occurred in August of 1994 for Total P. The Boundary Point station would remain the main station with full profiles over depth, but two other stations, the south central basin station near the net pen location and one new station half-way between the two existing stations would be used only for the collection of the above mentioned parameters in surface waters. These changes would result in only minor increases in field time and laboratory costs because of savings involved in the use of the Hydrolab probe.

Another possible change in 1995 would be the addition of a station in the north basin for collection of water quality data. This would allow the comparison of north and south basin conditions, and provide better use of much of the historical data that has been collected in Canadian waters. It is probable that most of the sockeye fry use the north basin only during late summer, so the conditions there are relatively more important than in the south basin.

Other minor changes proposed for 1995 include use of an inexpensive but relatively accurate water temperature recording unit at the net pens, discrete sampling of several near surface depths for chlorophyll *a* on at least one sampling date in late summer, and collection of zooplankton at discrete depths near the thermocline at the same time. The vertical gill netting work described above would be more meaningful if it was conducted concurrent to the discrete depth sampling discussed here.

I also recommend the collection of net-pen fish stomachs during and immediately before release, to assess the use of wild feed and the ability of the fish to adapt to the lake. This is more of interest for fry that will remain in the lake over the summer than for the smolts released from the pens that may migrate immediately out of the lake.

The 1995 efforts should include an assessment of 1994 weather when the NOAA annual climate summary becomes available for Washington State. In this manner we can categorize 1994 in comparison to long-term averages and begin to judge the effects of weather on the hydrographic and biological results discussed herein.

LITERATURE CITED

Allen, R.L. and T.K. Meekin. 1980. Columbia River Sockeye Salmon Study, 1971-1974. Washington Dept. of Fisheries. Progress Report No. 120. Olympia WA. 75 pp.

Benndorf, J., H. Kneschke, K. Kossatz and E. Penz. 1984. Manipulation of the pelagic food web by stocking with predacious fishes. Int. Revue ges. Hydrobiol. 69: 407-428.

Biosonics. 1983. Hydroacoustic surveys of sockeye fry and smolts at Lake Osoyoos, March 23 and June 13, 1983. Report to Douglas County PUD by Biosonics, Inc. Seattle. 20 pp. and appendix.

Brooks, J.L. 1957. The systematics of North American *Daphnia.* Conn. Acad. Arts and Sci., New Haven. Vol. 13. 180 pp.

Carl, C.C., W.A. Clemens and C.C. Lindsey. 1959. The freshwater fishes of British Columbia. British Columbia Provincial Museum, Dept. of Education Handbook No. 5, 3rd edition, 192 pp. Not seen, cited in Allen and Meekin 1980.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-368.

Dion, N.P., G.C. Bortleson, J.B. McConnell and L.M. Nelson. 1976. Reconnaissance data on lakes in Washington, Water Supply Bulletin 43, Vol. 5. Washington Dept. of Ecology and U.S. Geological Survey. 264 pp.

Downing, J. A. and F. H. Rigler. 1984. A manual on methods for the assessment of secondary productivity, 2nd edition. IBP Handbook No. 17. Blackwell. 501 pp.

Edmondson, W. T. (Ed.) 1959. Fresh-water biology, 2nd edition. Wiley.

Edmondson, W. T. and G.G. Winberg (Eds.) 1971. A manual on methods for the assessment of secondary productivity in freshwaters. IBP Handbook No. 17. Blackwell. 358 pp.

Environmental Protection Agency (EPA). 1990. The Lake and Reservoir Restoration Guidance Manual. Office of Water, Washington D.C. Second Edition. EPA-440/4-90-006.

Flagg, T.A., J.L. Mighell, T.E. Ruehle, L.W. Harrell and C.V.W. Mahnken. 1991. Cle Elum Lake Restoration Feasibility Study: Fish Husbandry Research, 1989-1991. National Marine Fisheries Service. Prepared for Bonneville Power Administration, Portland Or. 52 pp.

Galbraith, Jr. M.G. 1975. The use of large *Daphnia* as indices of fishing quality for rainbow trout in small lakes. Verh. Internat. Verein. Limnol. 19:2485-92.

Harr, R.D. and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. Wat. Res. Bull. 24:1103-1111.

Hart, J.L. Pacific Fishes of Canada. Fisheries Research Board of Canada Bulletin 180. 740 pp.

Kent, M.L. 1990. Net pen liver disease (NLD) of salmonid fishes reared in sea water: species susceptibility, recovery, and probable cause. Dis. Aquat. Org. 8:21-28.

Mullen, D.M. and J.R. Moring. 1988. Partial deforestation and short-term autochthonous energy input to a small New England stream. Wat. Res. Bull. 24:1273-1279.

Patrick, R. and C.W. Reimer. 1975. The diatoms of the United States. Vol. 2, Part 1. Acad. of Nat. Sci., Philadelphia. 213 pp.

Pennak, R.W. 1989. Freshwater invertebrates of the United States, 3rd edition. Wiley, New York. 628 pp.

Pratt, K.L., D.W. Chapman and M. Hill. 1991. Potential to enhance sockeye salmon upstream from Wells Dam. Prepared for Douglas County Public Utility District. Don Chapman Consultants, Inc. Boise, Idaho. 87 pp.

Prescott, G.W. 1975. Algae of the Western Great Lakes Area, Revised edition. Wm. C. Brown Co., Dubuque. 977 pp.

Prescott, G.W. 1980. How to know the freshwater algae, 3rd edition. Wm. C. Brown, Co. Dubuque. 293 pp.

Porcella, D.B., S.A. Peterson and D.P. Larsen. 1980. Index to evaluate lake restoration. J. Environ. Eng. 106:1151-1169.

Rensel, J. 1993. Sockeye salmon enhancement in Lake Osoyoos with net pens. Final Report to Douglas County Public Utility District No. 1. Rensel Associates, Arlington. WA. 70 pp. plus figures and appendices.

Rector, J. 1993. Washington's Citizen Lake Monitoring Program 1992. Data Summary. Lake Osoyoos, Okanogan County. Washington State Department of Ecology. EILS Program. Olympia.

Scholz, A.T. et al. 1985. Biomanipulation of a trout fishery and its effect on zooplankton composition, phytoplankton biovolume, and water quality of Medical Lake, Spokane County, Washington, following restoration by treatment with alum. pp. 48-56. In: Lake and Reservoir Management: Practical Applications. Proceedings of the Fourth Annual Conference and International Symposium, October 16-19, 1984, McAfee, New Jersey. North American Lake Management Society.

Stein, J.R. and T.L. Coulthard. 1971. Water quality deterioration in Osoyoos Lake, British Columbia. B.C. Water Resour. Serv. Water Invest. Branch. unpublished report not seen by Rensel but cited by Stockner and Northcote 1974.

Stemberger, R.S. 1979. A Guide to Rotifers of the Laurentian Great Lakes. EPA-600/4-79-021.

Stockner, J.G. and T.G. Northcote. 1974. Recent limnological studies of Okanogan Basin lakes and their contribution to comprehensive water resource planning. J. Fish. Res. Bd. Can. 31:955-976.

Thorp, J.H. and A.P. Covich. 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego. 911 pp.

Welch, E.B. 1992. Ecological Effects of Waste Water. Second Edition. Cambridge University Press. Cambridge. 425 pp.

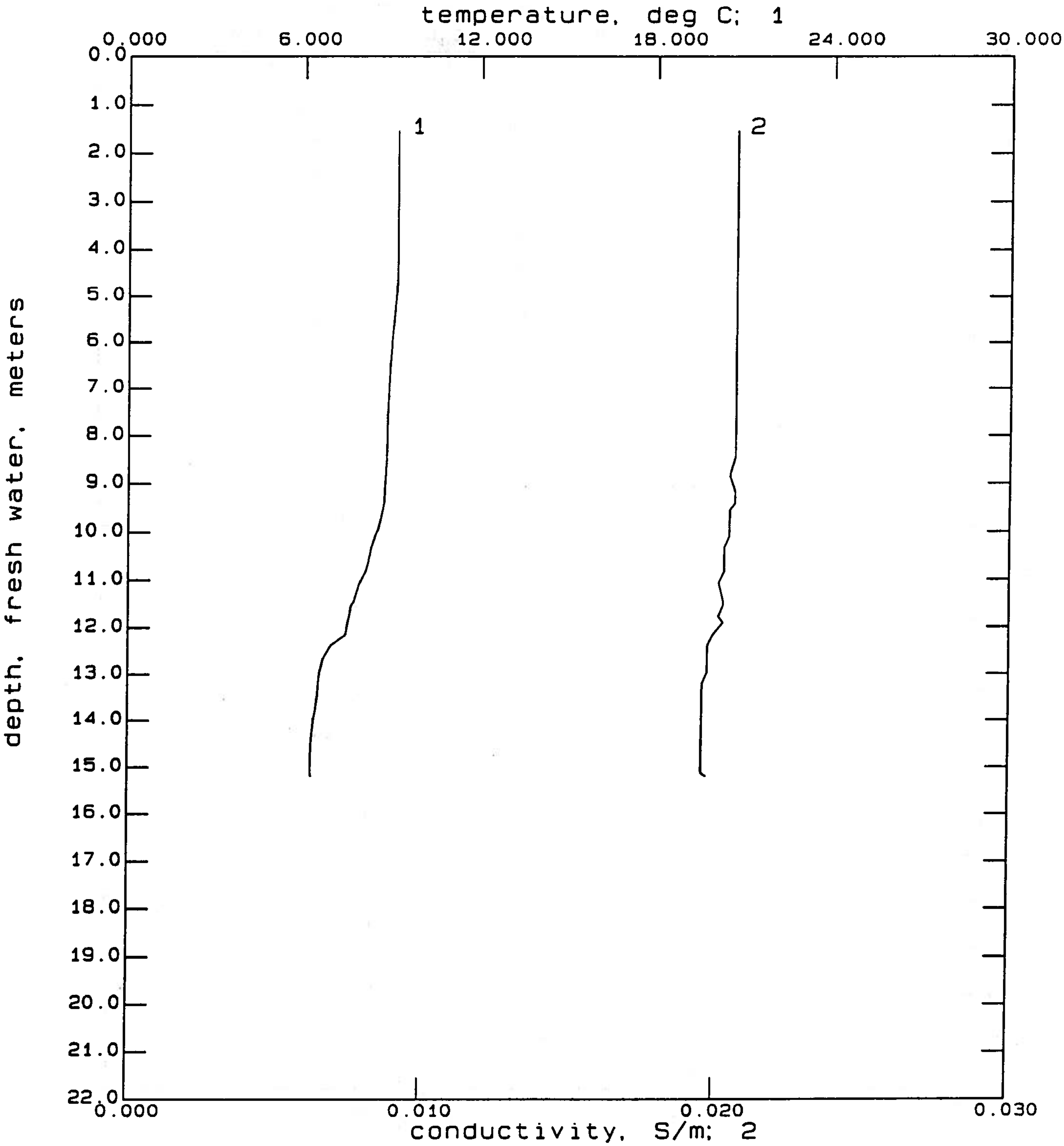
Appendix 1. Lake Osoyoos: Boundary Point Replicate Nutrients, 1994

Results in µg at./L except summary lines in bold that are in mg/L

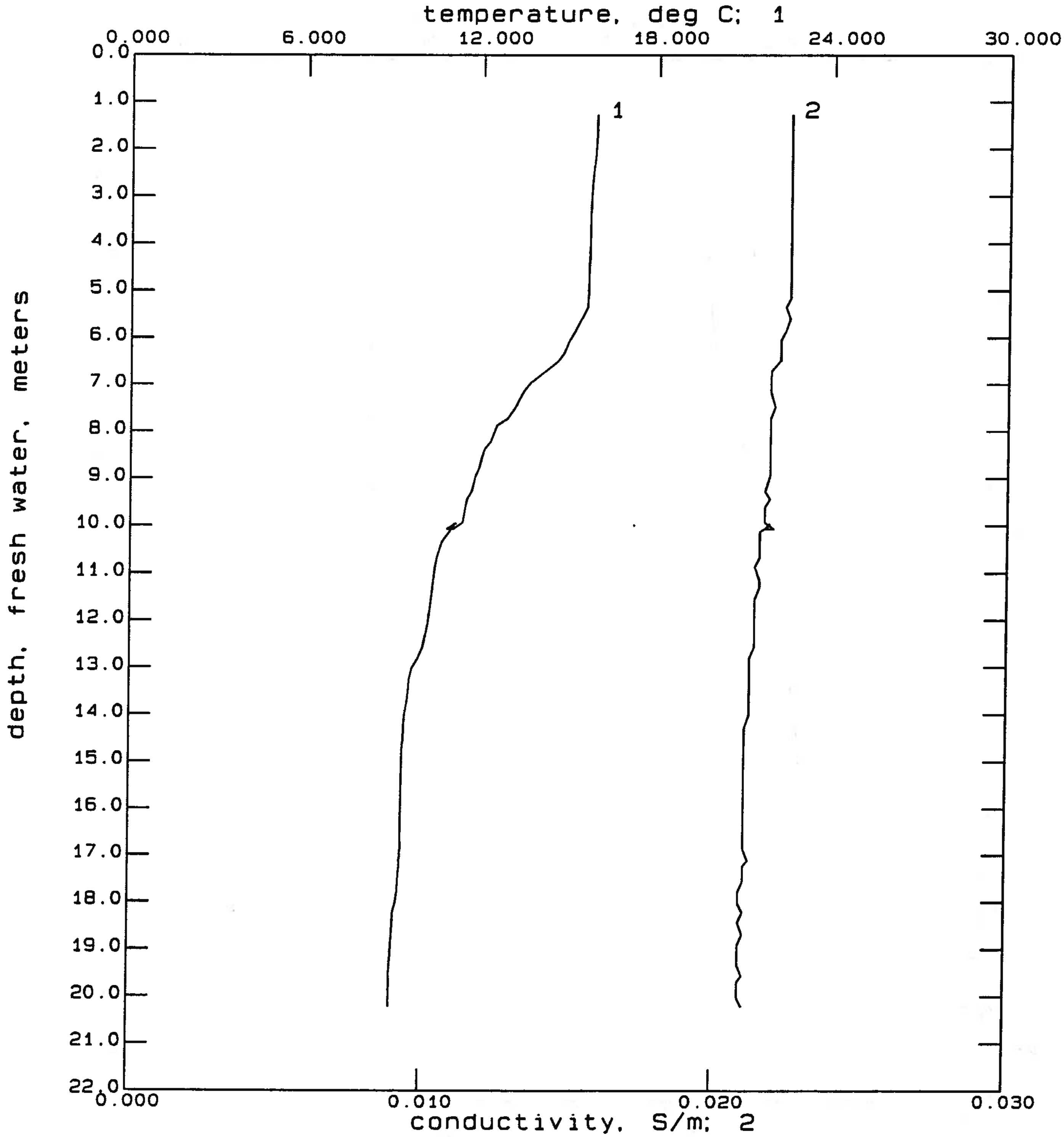
Date	Depth	Nitrate	Nitrite	Ammonium +Ammonia	Ortho-phosphate	Total N	Total P
April 14	0.5	0.5	0.03	0.62	1.47	30.26	1.82
		0.6	0.04	0.55	1.28	29.82	1.81
		0.7	0	0.12	1.01	31.85	1.77
		0.6	0.02	0.43	1.25	30.64	1.80
	µg/L---->	**8.40**	**0.33**	**6.02**	**38.82**	**429.01**	**55.75**
	Deep	0.05	0.01	1.05	1.1	26.01	1.18
		0.05	0	0.09	0.98	33.14	1.45
		0.04	0	1.35	1.27	26.78	1.27
		0.05	0.00	0.83	1.12	28.64	1.30
	µg/L---->	**0.65**	**0.05**	**11.62**	**34.58**	**401.01**	**40.26**
May 16	0.5	0.02	0.01	0.42	1.94	29.18	2.51
		0.03	0	0.42	2.11	23.86	2.39
		0.03	0.01	0.28	1.95	25.37	2.44
		0.03	0.01	0.37	2.00	26.14	2.45
	µg/L---->	**0.37**	**0.09**	**5.23**	**61.94**	**365.91**	**75.77**
	Deep	0.01	0.04	0.84	0.07	24.4	0.49
		0.01	0.04	0.74	0.04	21.79	0.46
		0.01	0.04	0.63	0.04	24.65	0.39
		0.01	0.04	0.74	0.05	23.61	0.45
	µg/L---->	**0.14**	**0.56**	**10.31**	**1.55**	**330.59**	**13.83**
June 16	0.5	0.22	0.02	1.04	0.11	37.71	1.04
	µg/L---->	**3.08**	**0.28**	**14.56**	**3.41**	**527.94**	**32.21**
	deep	0.19	0.05	0.97	0.05	25.61	0.43
	µg/L---->	**2.66**	**0.70**	**13.58**	**1.55**	**358.54**	**13.32**
July 25	0.5	0	0.01	0.48	0.06	45.16	0.87
		0	0.01	0.46	0.06	37.52	0.45
		0	0.01	0.47	0.06	41.34	0.66
	µg/L---->	**0.00**	**0.14**	**6.58**	**1.86**	**578.76**	**20.44**
	Deep	0.22	0.14	8.06	0.55	39.56	1.51
		0.2	0.1	9.07	0.62	38.28	1.19
		0.21	0.12	8.565	0.585	38.92	1.35
	µg/L---->	**2.94**	**1.68**	**119.91**	**18.12**	**544.88**	**41.81**
August 30	0.5	0.04	0.01	0.36	0.26	77.78	14.85
		0.08	0	0.35	0.22	67.71	9.72
		0.06	0.005	0.355	0.24	72.75	12.29
	µg/L---->	**0.84**	**0.07**	**4.97**	**7.43**	**1018.43**	**380.47**
	deep	0.04	0	15.31	1.36	45.29	2.4
		0.09	0	14.51	1.13	37.01	2.07
		0.065	0	14.91	1.245	41.15	2.24
	µg/L---->	**0.91**	**0.00**	**208.74**	**38.56**	**576.10**	**69.22**
Sept. 29	Surf	0.24	0.03	0.4	0.16	42.57	0.61
		0.17	0.01	0.85	0.17	47.77	0.66
		0.17	0.01	0.51	0.19	68.53	0.68
		0.19	0.02	0.59	0.17	52.96	0.65
	µg/L---->	**2.71**	**0.23**	**8.21**	**5.37**	**741.39**	**20.13**
	deep	0.17	0.01	25.61	2.15	66.34	3.1
		0.17	0.01	27.09	1.81	66.64	3.31
		0.17	0.01	27.55	2.09	56.38	2.82
		0.17	0.01	26.75	2.02	63.12	3.08
	µg/L---->	**2.38**	**0.14**	**374.50**	**62.46**	**883.68**	**95.28**

Appendix 2. Lake Osoyoos: South Central Basin, Replicate Nutrients, 1994							
	Results in µg at./L except summary lines in bold that are in mg/L						
Date	Depth	Nitrate	Nitrite	Ammonium +Ammonia	Ortho-phosphate	Total N	Total P
April 14	Surface	0.03	0	0.26	0.04	25.81	0.54
		0.03	0	0.09	0.02	26.72	0.56
		0.02	0	0.02	0.02	29.21	0.77
		0.03	0.00	0.12	0.03	27.25	0.62
	µg/L---->	**0.37**	**0.00**	**1.73**	**0.83**	**381.45**	**19.30**
	Deep	0.01	0	0.29	0.13	24.11	1.77
		0.01	0	0.35	0.14	24.27	1.72
		0	0	0.35	0.29	21.66	1.41
		0.01	0.00	0.33	0.19	23.35	1.63
	µg/L---->	**0.09**	**0.00**	**4.62**	**5.78**	**326.85**	**50.58**
May 16	Surf	0	0.02	0.46	0.02	21.73	0.43
	µg/L---->	**0.00**	**0.28**	**6.44**	**0.62**	**304.22**	**13.32**
	Botttom	0	0.02	0.2	0.02	23.77	0.33
	µg/L---->	**0.00**	**0.28**	**2.80**	**0.62**	**332.78**	**10.22**
June 16	Surf	0.00	0.02	0.09	0.01	30.00	0.41
	µg/L---->	**0.00**	**0.28**	**1.26**	**0.31**	**420.00**	**12.70**
	Botttom	0.13	0.05	1.49	0.07	45.99	2.85
	µg/L---->	**1.82**	**0.70**	**20.86**	**2.17**	**643.86**	**88.26**
July 25	Surf	0.17	0.01	1.54	0.10	64.66	0.83
	µg/L---->	**2.38**	**0.14**	**21.56**	**3.10**	**905.24**	**25.71**
	Botttom	0.06	0	0.61	0.04	27.2	0.36
	µg/L---->	**0.84**	**0.00**	**8.54**	**1.24**	**380.80**	**11.15**
August 30	Surf	0.09	0	1.17	0.89	47.14	0.67
	µg/L---->	**1.26**	**0.00**	**16.38**	**27.56**	**659.96**	**20.75**
	Botttom	0.08	0	0.43	0.14	48.35	0.92
	µg/L---->	**1.12**	**0.00**	**6.02**	**4.34**	**676.90**	**28.49**
Sept. 29	Surf	0.17	0.01	0.5	0.12	48.68	0.59
	µg/L---->	**2.38**	**0.14**	**7.00**	**3.72**	**681.52**	**18.27**
	Botttom	0.17	0.01	4.4	0.26	36.6	0.81
	µg/L---->	**2.38**	**0.14**	**61.60**	**8.05**	**512.40**	**25.09**

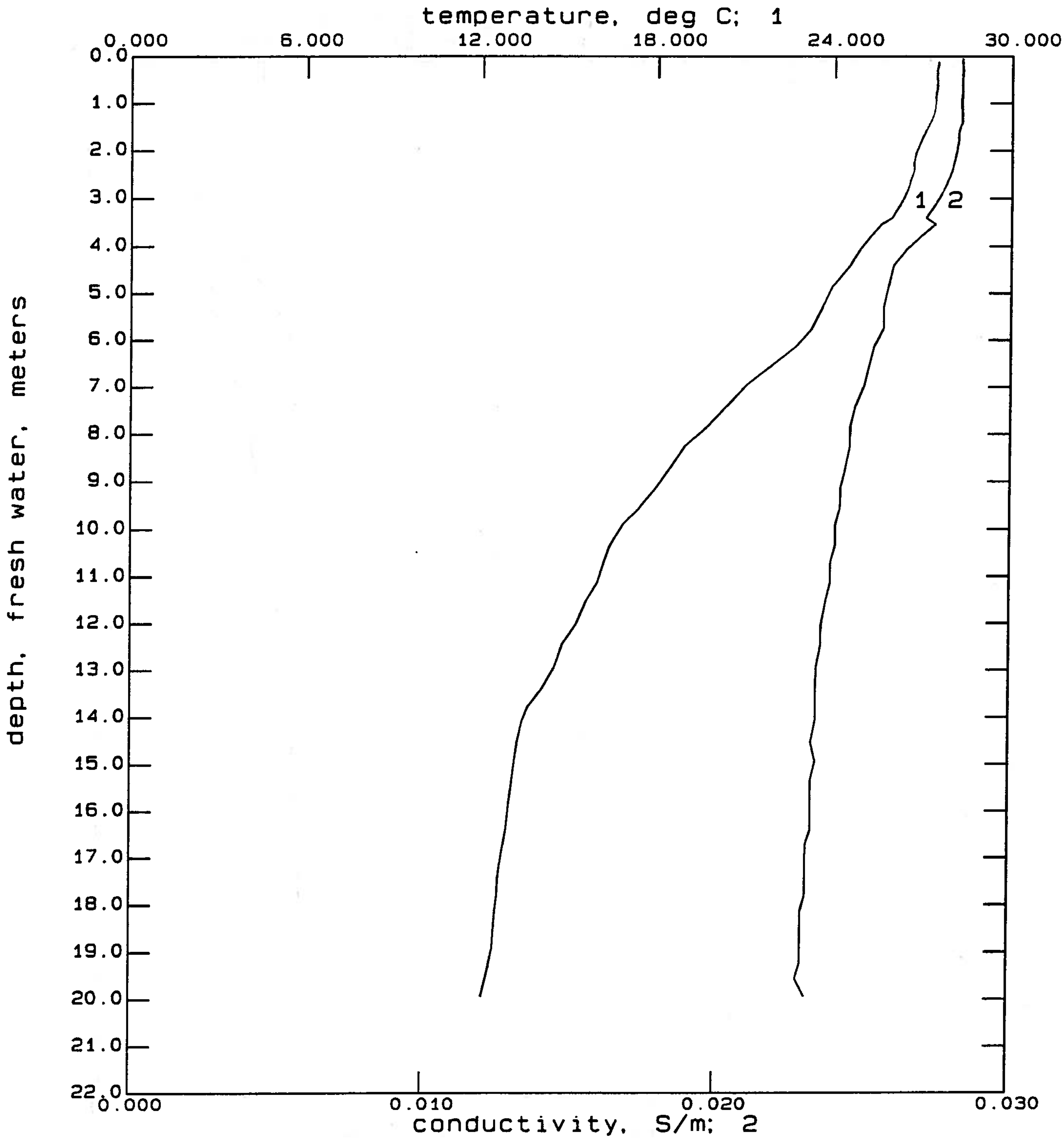
Appendix 3. CTD profiles and data from Lake Osoyoos in 1994



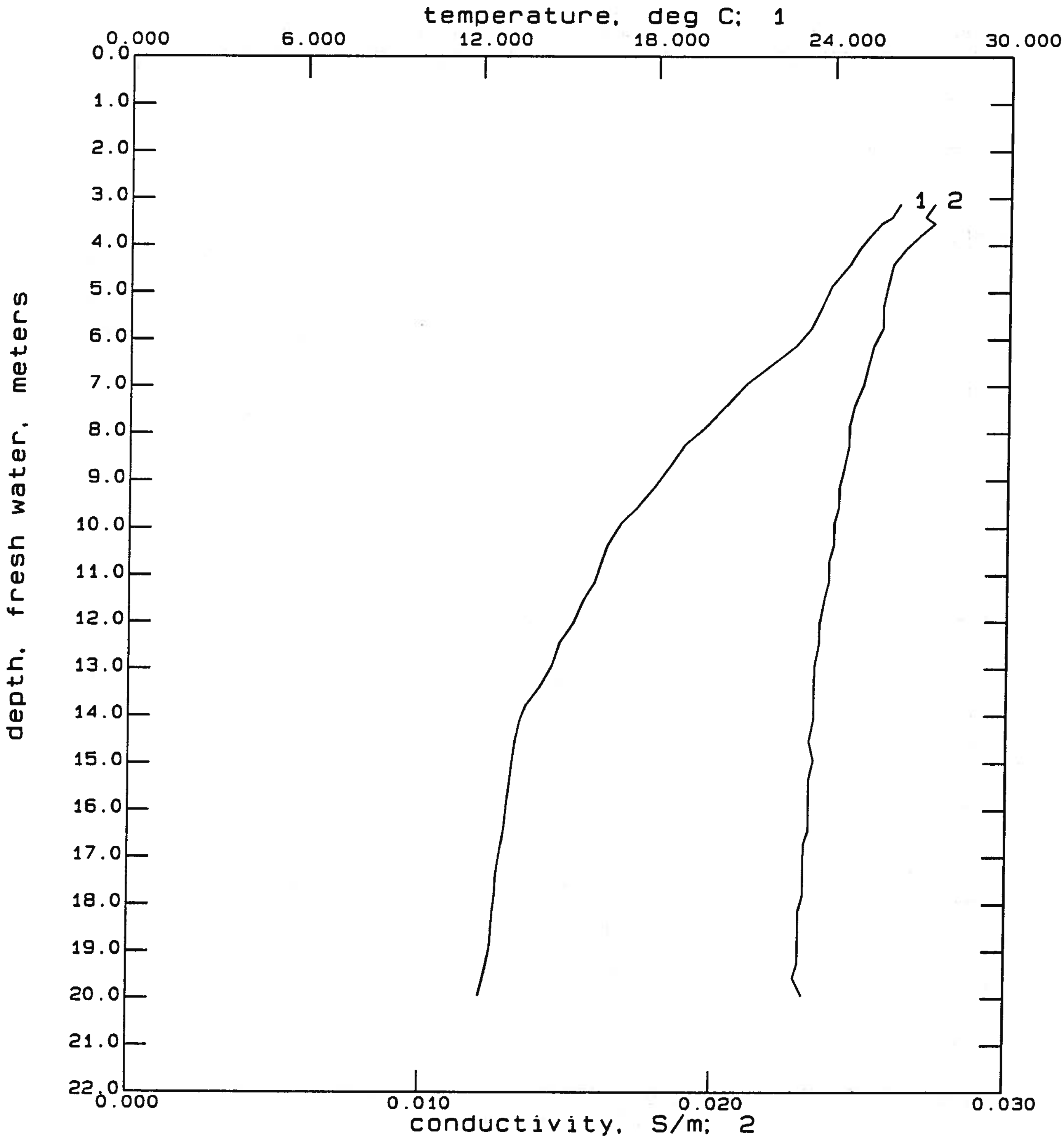
DJACK301.CNV: Lake Osoyoos: Boundary Pt. April 13, 1994



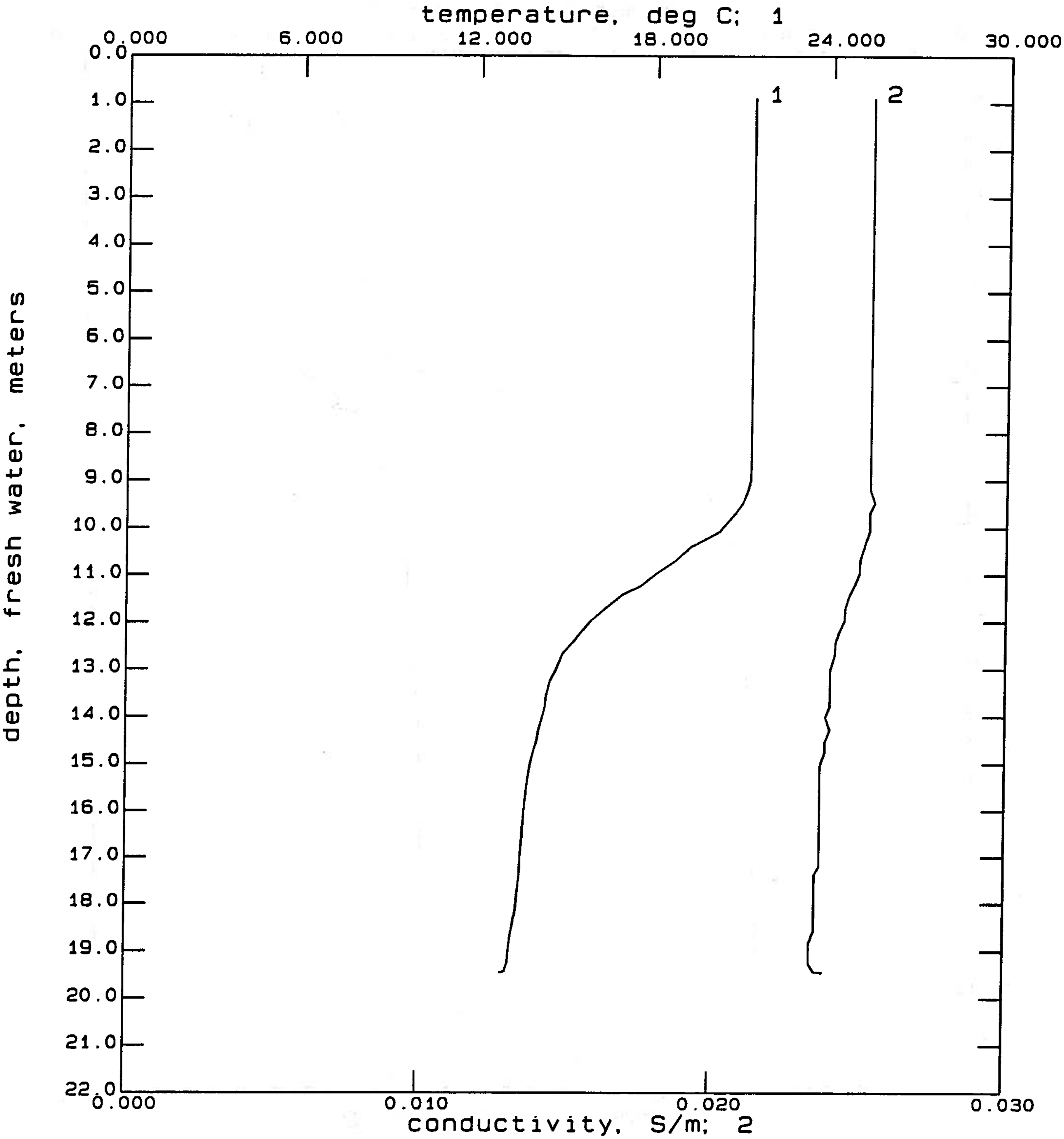
DMAY00.CNV: Lake Osoyoos: Boundary Point, May 16, 1994



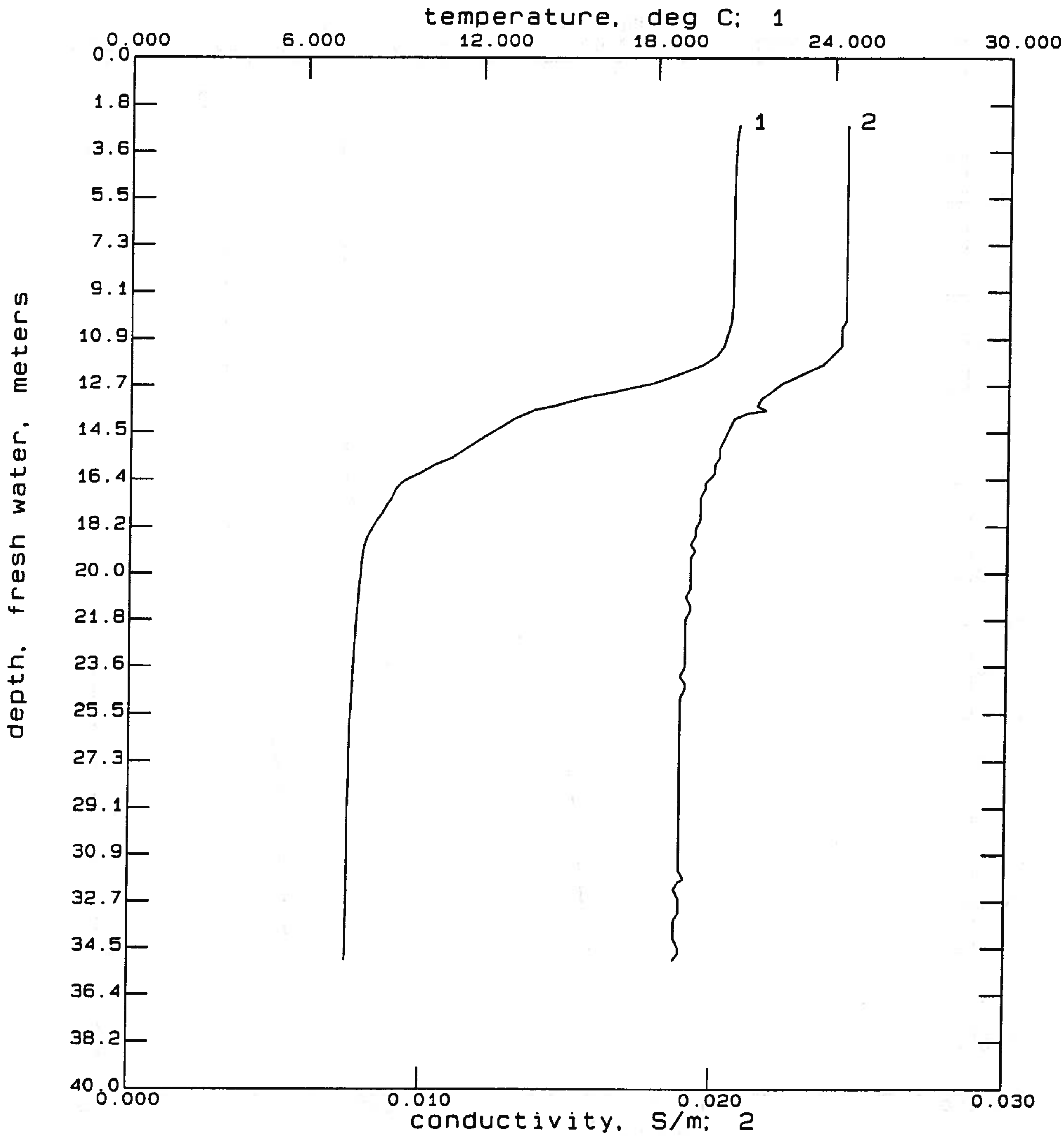
DJULYN3.CNV: Lake Osoyoos: Boundary Point, July 25, 1994



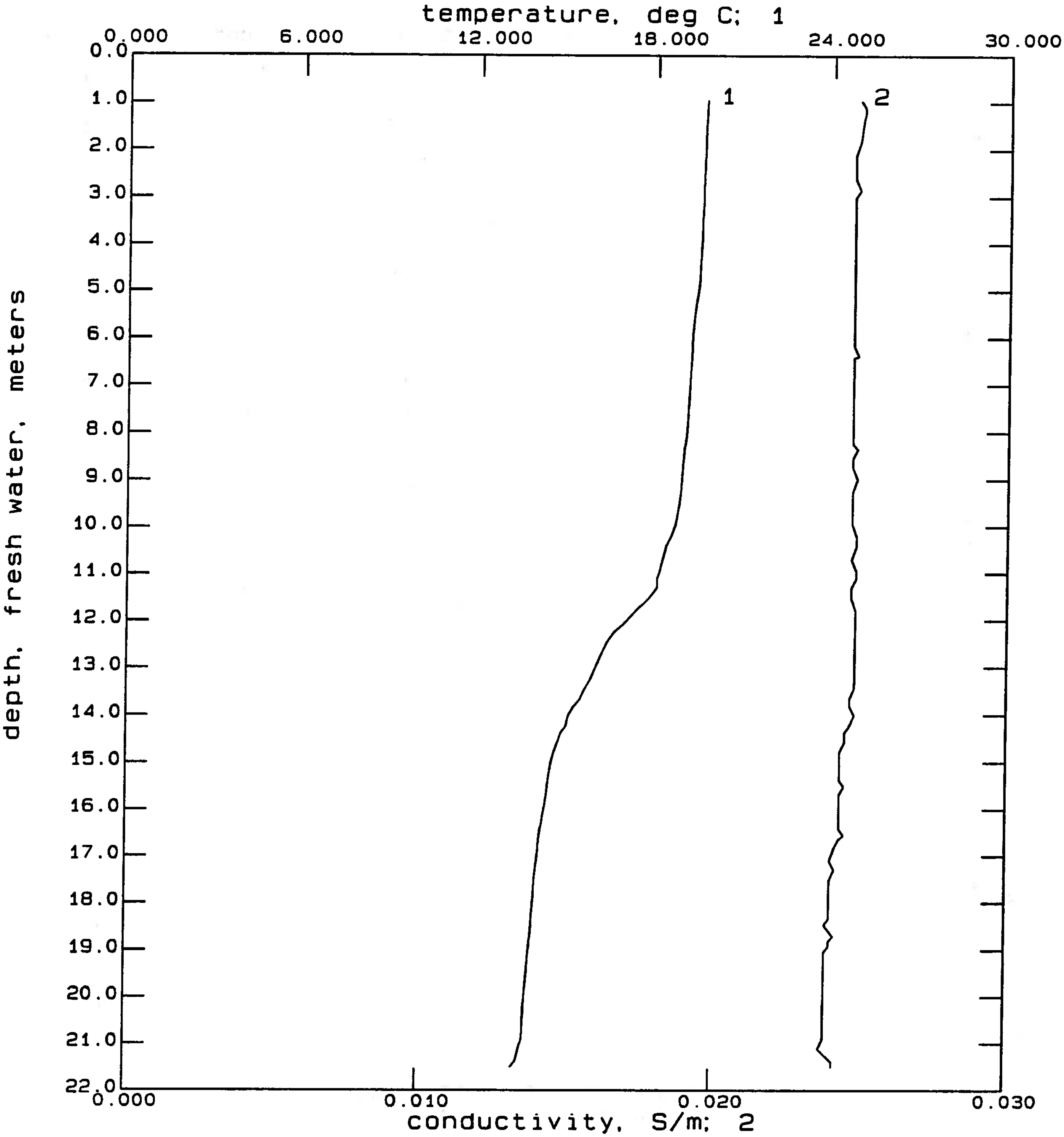
DJULYN3.CNV: Lake Osoyoos: Between Pens & River Mouth ~~5~~ July 25/16/94



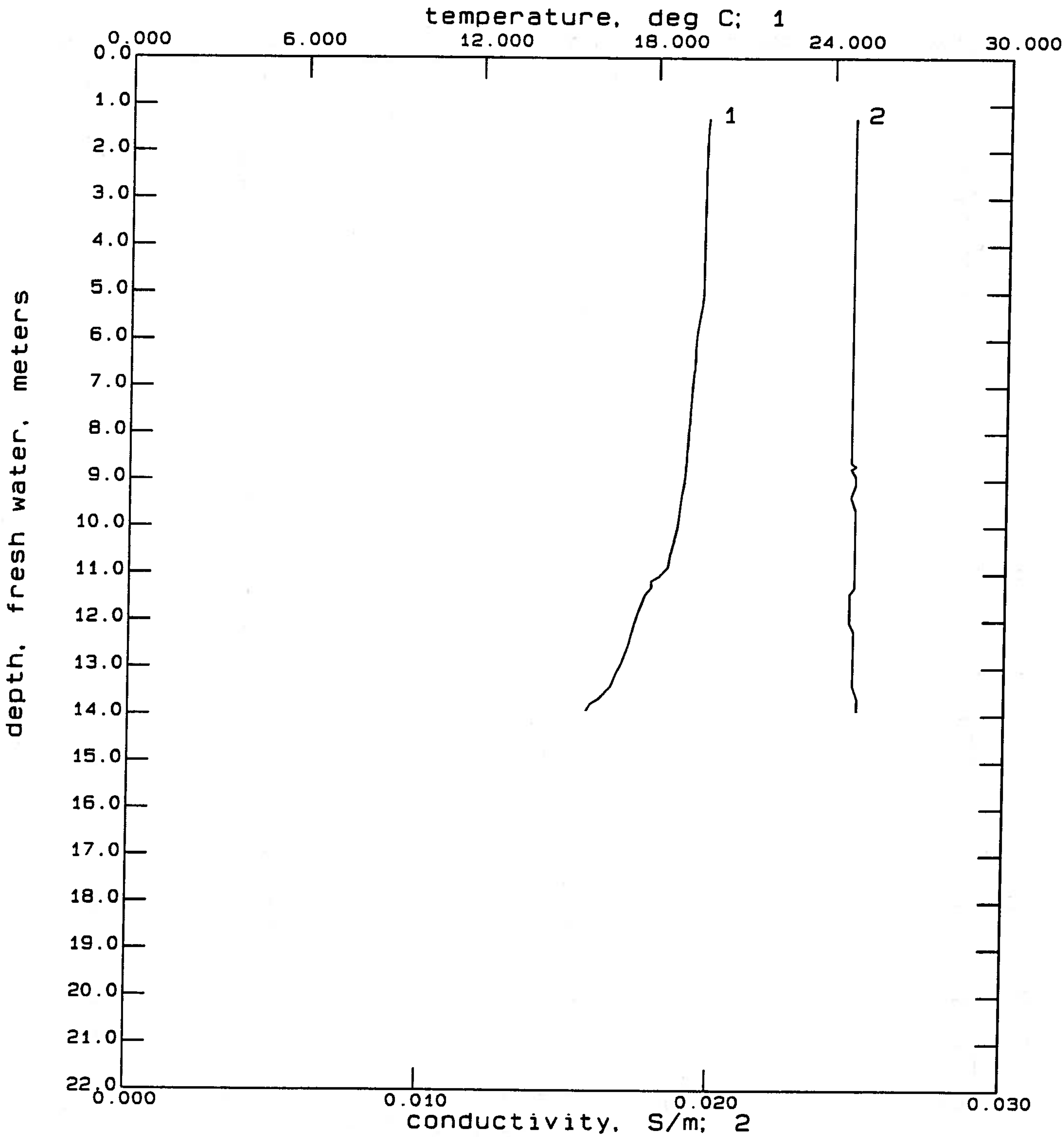
DAUG100.CNV: Lake Osoyoos: Boundary Point, August 30, 1994



DAUG101.CNV: Lake Osoyoos: North Basin, August 30, 1994



DSEPT01.CNV: Lake Osoyoos: Boundary Point, Sept. 29, 1994



DSEPT03.CNV: Lake Osoyoos: South Central Basin, Sept. 29, 1994

SOUTH CENTRAL BASIN: RAW CTD DATA

April 13, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	7.668	7.1997	0.01983	0.0085
2	7.778	7.1977	0.01983	0.0086
3	7.750	7.1997	0.01983	0.0085
4	7.723	7.2000	0.01983	0.0084
5	7.723	7.2003	0.01983	0.0084
6	7.860	7.2006	0.01983	0.0084
7	7.832	7.2046	0.01983	0.0082
8	7.887	7.2046	0.01983	0.0082
9	7.696	7.2066	0.01983	0.0081
10	7.969	7.2105	0.01983	0.0079
11	7.887	7.2135	0.01983	0.0077
12	7.942	7.2145	0.01982	0.0077
13	7.914	7.2145	0.01982	0.0077
14	7.860	7.2164	0.01982	0.0076
15	7.832	7.2204	0.01982	0.0074
16	8.024	7.2194	0.01982	0.0074
17	8.105	7.2184	0.01982	0.0075
18	8.160	7.2204	0.01982	0.0073
19	8.024	7.2193	0.01982	0.0074
20	7.996	7.2193	0.01982	0.0074
21	8.078	7.2213	0.01982	0.0073
22	8.133	7.2223	0.01982	0.0072
23	8.160	7.2193	0.01982	0.0074
24	8.242	7.2093	0.01982	0.0079
25	8.242	7.1923	0.01982	0.0088
26	8.242	7.1754	0.01982	0.0097
27	8.324	7.1704	0.01982	0.0100
28	8.187	7.1604	0.01982	0.0105
29	8.406	7.1574	0.01982	0.0106
30	8.269	7.1494	0.01982	0.0110
31	8.379	7.1443	0.01982	0.0113
32	8.351	7.1553	0.01982	0.0107
33	8.379	7.1373	0.01982	0.0116
34	8.406	7.1064	0.01982	0.0132
35	8.433	7.0974	0.01982	0.0137
36	8.488	7.0794	0.01982	0.0146
37	8.597	7.0504	0.01982	0.0161
38	8.625	7.0114	0.01981	0.0180
39	8.625	6.9714	0.01965	0.0190
40	8.734	6.9363	0.01965	0.0207
41	8.761	6.9193	0.01965	0.0216
42	8.871	6.9083	0.01965	0.0221
43	8.925	6.8942	0.01965	0.0228
44	9.035	6.8882	0.01965	0.0230
45	8.980	6.8842	0.01965	0.0232
46	8.980	6.8741	0.01965	0.0237
47	9.089	6.8681	0.01965	0.0240
48	9.089	6.8601	0.01965	0.0244
49	9.199	6.8360	0.01965	0.0255
50	9.281	6.8209	0.01965	0.0262
51	9.226	6.8099	0.01965	0.0267
52	9.335	6.7978	0.01965	0.0273
53	9.417	6.7868	0.01964	0.0278
54	9.554	6.7707	0.01964	0.0286
55	9.499	6.7516	0.01964	0.0294
56	9.526	6.7305	0.01964	0.0304
57	9.663	6.7235	0.01964	0.0307
58	9.608	6.7174	0.01964	0.0310
59	9.636	6.7164	0.01964	0.0310
60	9.909	6.7174	0.01964	0.0310
61	9.909	6.7184	0.01964	0.0309
62	9.936	6.7163	0.01964	0.0310
63	10.046	6.7133	0.01964	0.0312
64	10.100	6.7073	0.01964	0.0314
65	10.128	6.6962	0.01964	0.0319
66	10.210	6.6700	0.01964	0.0331
67	10.319	6.6308	0.01964	0.0349
68	10.401	6.6097	0.01964	0.0358
69	10.319	6.6006	0.01964	0.0362
70	10.428	6.5965	0.01964	0.0363
71	10.538	6.5794	0.01964	0.0371
72	10.538	6.5552	0.01964	0.0381
73	10.592	6.5240	0.01964	0.0395
74	10.565	6.4917	0.01964	0.0408
75	10.647	6.4433	0.01963	0.0429
76	10.510	6.3221	0.01963	0.0478
77	10.510	6.2239	0.01963	0.0516
78	10.702	6.3706	0.01963	0.0458
79	10.702	6.4674	0.01963	0.0418
80	10.784	6.4926	0.01963	0.0408
81	10.674	6.4966	0.01963	0.0406
82	10.784	6.5137	0.01963	0.0399
83	10.866	6.5178	0.01963	0.0397
84	10.838	6.5329	0.01963	0.0391
85	10.866	6.5620	0.01963	0.0378
86	10.866	6.5832	0.01963	0.0369
87	10.948	6.5922	0.01963	0.0365
88	10.975	6.6153	0.01963	0.0355
89	11.002	6.6646	0.01963	0.0333
90	11.002	6.6957	0.01963	0.0319
91	11.084	6.7058	0.01963	0.0315
92	11.057	6.7098	0.01963	0.0313
93	11.166	6.7118	0.01963	0.0312
94	11.112	6.7138	0.01963	0.0311
95	11.112	6.7137	0.01963	0.0311
96	11.221	6.7157	0.01963	0.0310
97	11.194	6.7288	0.01963	0.0304
98	11.194	6.7528	0.01963	0.0293
99	11.248	6.7789	0.01963	0.0281
100	11.276	6.7980	0.01963	0.0272
101	11.248	6.8150	0.01963	0.0264
102	11.330	6.8320	0.01963	0.0256
103	11.276	6.8521	0.01963	0.0247
104	11.358	6.8631	0.01963	0.0241
105	11.385	6.8711	0.01963	0.0237
106	11.303	6.8731	0.01963	0.0237
107	11.330	6.8760	0.01963	0.0235
108	11.385	6.8800	0.01963	0.0233
109	11.440	6.8900	0.01963	0.0228
110	11.467	6.8940	0.01963	0.0226

April 13, 1994 Cont.

Scan	Depth m	Temp °C	Conductivity	Density
111	11.467	6.9200	0.01963	0.0214
112	11.467	6.9601	0.01963	0.0194
113	11.522	7.0021	0.01979	0.0183
114	11.549	7.0320	0.01979	0.0168
115	11.522	7.0560	0.01979	0.0156
116	11.494	7.0800	0.01979	0.0144
117	11.576	7.1019	0.01979	0.0133
118	11.576	7.1458	0.01979	0.0111
119	11.740	7.1777	0.01979	0.0094
120	11.686	7.1887	0.01979	0.0088
121	11.686	7.1986	0.01979	0.0083
122	11.795	7.2046	0.01979	0.0080
123	11.768	7.2085	0.01979	0.0078
124	11.932	7.2109	0.01979	0.0077
125	11.850	7.2132	0.01979	0.0075
126	11.904	7.2155	0.01979	0.0074
127	11.795	7.2195	0.01979	0.0072
128	11.986	7.2185	0.00914	-0.0544
129	11.932	7.2105	0.00209	-0.0931
130	11.932	7.0868	0.00127	-0.0914
131	12.123	6.8587	0.00111	-0.0819

May 16, 1994 (mid lake station)

Scan	Depth m	Temp °C	Conductivity	Density
1	0.047	15.8233	0.02300	-0.9224
2	0.101	15.8318	0.02300	-0.9238
3	0.320	15.8361	0.02300	-0.9244
4	0.702	15.7736	0.02295	-0.9145
5	1.030	15.7111	0.02290	-0.9046
6	1.330	15.6485	0.02285	-0.8947
7	1.603	15.5932	0.02284	-0.8859
8	1.931	15.5600	0.02284	-0.8805
9	2.314	15.5362	0.02284	-0.8767
10	2.614	15.4817	0.02269	-0.8687
11	3.078	15.4212	0.02269	-0.8591
12	3.461	15.3870	0.02269	-0.8537
13	3.816	15.3495	0.02269	-0.8478
14	4.117	15.3187	0.02269	-0.8430
15	4.472	15.2333	0.02269	-0.8296
16	4.909	15.0680	0.02253	-0.8046
17	5.237	14.7578	0.02237	-0.7581
18	5.619	14.4409	0.02237	-0.7110
19	5.974	14.2529	0.02237	-0.6836
20	6.220	14.0921	0.02221	-0.6612
21	6.548	13.7397	0.02206	-0.6124
22	6.876	13.2120	0.02205	-0.5410
23	7.122	12.9656	0.02205	-0.5089
24	7.368	12.9143	0.02205	-0.5023
25	7.641	12.8318	0.02205	-0.4917
26	7.942	12.7387	0.02205	-0.4799
27	8.269	12.6774	0.02205	-0.4722
28	8.570	12.6498	0.02205	-0.4687
29	8.898	12.6009	0.02189	-0.4634
30	9.199	12.4495	0.02189	-0.4447
31	9.526	12.2834	0.02189	-0.4244
32	9.827	11.9850	0.02189	-0.3890
33	10.100	11.6635	0.02189	-0.3521
34	10.319	11.3868	0.02173	-0.3221
35	10.483	11.0514	0.02204	-0.2846
36	10.674	10.7428	0.02203	-0.2528
37	10.647	10.6951	0.02203	-0.2480
38	10.784	10.4721	0.02172	-0.2275

May 16, 1994 (at net pens)

Scan	Depth m	Temp °C	Conductivity	Density
1	2.969	15.2290	0.02253	-0.8296
2	3.188	15.2196	0.02253	-0.8282
3	3.352	15.2110	0.02253	-0.8268
4	3.570	15.1968	0.02253	-0.8246
5	3.761	15.1825	0.02253	-0.8224
6	3.898	15.1682	0.02253	-0.8202
7	3.980	15.1331	0.02253	-0.8147
8	4.062	15.1374	0.02253	-0.8154
9	4.226	15.0706	0.02253	-0.8051
10	4.308	14.9599	0.02253	-0.7881
11	4.362	14.9427	0.02253	-0.7854
12	4.608	14.8447	0.02253	-0.7705
13	4.799	14.7018	0.02237	-0.7497
14	4.991	14.5965	0.02237	-0.7340
15	5.182	14.5084	0.02237	-0.7209
16	5.291	14.3907	0.02237	-0.7036
17	5.564	14.2260	0.02222	-0.6804
18	5.838	14.1165	0.02221	-0.6647
19	6.056	14.0660	0.02221	-0.6575
20	6.357	14.0573	0.02221	-0.6563
21	6.657	13.9868	0.02221	-0.6463
22	6.931	13.9380	0.02221	-0.6394
23	7.231	13.8961	0.02221	-0.6335
24	7.422	13.8655	0.02221	-0.6292
25	7.668	13.8437	0.02221	-0.6261
26	7.860	13.8079	0.02221	-0.6211
27	8.133	13.7266	0.02206	-0.6106
28	8.379	13.5847	0.02206	-0.5911
29	8.625	13.3274	0.02205	-0.5563
30	8.898	13.1379	0.02205	-0.5313
31	9.089	13.0637	0.02205	-0.5216
32	9.390	12.7795	0.02205	-0.4850
33	9.554	12.0738	0.02189	-0.3994
34	9.800	11.6383	0.02189	-0.3492
35	10.046	11.3895	0.02188	-0.3216
36	10.182	11.1816	0.02188	-0.2992
37	10.374	10.9885	0.02188	-0.2788
38	10.674	10.7400	0.02172	-0.2541
39	10.920	10.4703	0.02172	-0.2274
40	11.139	10.3157	0.02172	-0.2125
41	11.303	10.1995	0.02172	-0.2014
42	11.522	10.1034	0.02187	-0.1917
43	11.549	9.9970	0.02203	-0.1810

SOUTH CENTRAL BASIN: RAW CTD DATA (Continued)

July 25, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	2.423	15.4035	0.01034	-0.9121
2	2.696	15.4087	0.01034	-0.9129
3	2.969	15.4172	0.01034	-0.9142
4	3.270	15.4132	0.01034	-0.9136
5	3.461	15.4092	0.01034	-0.9129
6	3.789	15.4052	0.01034	-0.9123
7	3.980	15.3976	0.01034	-0.9111
8	4.280	15.3856	0.01034	-0.9092
9	4.526	15.3771	0.01034	-0.9079
10	4.854	15.3737	0.01034	-0.9074
11	5.155	15.3643	0.01034	-0.9059
12	5.455	15.3404	0.01018	-0.9028
13	5.756	15.3464	0.01018	-0.9038
14	6.111	15.3276	0.01018	-0.9008
15	6.493	15.3216	0.01018	-0.8999
16	6.849	15.2806	0.01018	-0.8935
17	7.204	15.2652	0.01018	-0.8911
18	7.532	15.2626	0.01018	-0.8907
19	7.860	15.2626	0.01018	-0.8907
20	8.187	15.2652	0.01018	-0.8911
21	8.543	15.2626	0.01018	-0.8907
22	8.789	15.2592	0.01018	-0.8902
23	9.171	15.2575	0.01018	-0.8899
24	9.472	15.2549	0.01018	-0.8895
25	9.745	15.2549	0.01018	-0.8895
26	10.073	15.2549	0.01018	-0.8895
27	10.346	15.2635	0.01018	-0.8908
28	10.592	15.2686	0.01018	-0.8916
29	10.948	15.2738	0.01018	-0.8924
30	11.276	15.2738	0.01018	-0.8924
31	11.604	15.2763	0.01018	-0.8928
32	11.932	15.2772	0.01018	-0.8929
33	12.232	15.2746	0.01018	-0.8925
34	12.588	15.2849	0.01018	-0.8941
35	12.943	15.2883	0.01018	-0.8946
36	13.216	15.2780	0.01018	-0.8930
37	13.599	15.2729	0.01018	-0.8922
38	13.927	15.2635	0.01018	-0.8908
39	14.282	15.2661	0.01018	-0.8912
40	14.638	15.2678	0.01018	-0.8914
41	14.966	15.2498	0.01018	-0.8886
42	15.376	15.2575	0.01018	-0.8898
43	15.731	15.2592	0.01018	-0.8901
44	16.114	15.2592	0.01018	-0.8901
45	16.470	15.2532	0.01018	-0.8891
46	16.743	15.2729	0.01018	-0.8922
47	17.044	15.2703	0.01018	-0.8918
48	17.235	15.2789	0.01018	-0.8931
49	17.509	15.2832	0.01018	-0.8938
50	17.809	15.2669	0.01018	-0.8912
51	18.165	15.2447	0.01018	-0.8878
52	18.438	15.2421	0.01018	-0.8874
53	18.849	15.2421	0.01018	-0.8874
54	19.122	15.2413	0.01018	-0.8873
55	19.478	15.2344	0.01018	-0.8862

August 25, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	2.833	21.7448	0.02552	-2.0689
2	3.024	21.7324	0.02552	-2.0661
3	3.215	21.7339	0.02552	-2.0664
4	3.379	21.7246	0.02552	-2.0643
5	3.597	21.7153	0.02552	-2.0622
6	3.871	21.7059	0.02552	-2.0601
7	4.117	21.6958	0.02552	-2.0578
8	4.335	21.6880	0.02552	-2.0560
9	4.526	21.6826	0.02552	-2.0548
10	4.745	21.6802	0.02552	-2.0543
11	4.936	21.6740	0.02552	-2.0528
12	5.100	21.6491	0.02552	-2.0472
13	5.291	21.6296	0.02552	-2.0428
14	5.592	21.6203	0.02552	-2.0407
15	5.701	21.6133	0.02552	-2.0391
16	5.920	21.6062	0.02552	-2.0375
17	6.084	21.6000	0.02552	-2.0361
18	6.220	21.5945	0.02552	-2.0349
19	6.384	21.5930	0.02552	-2.0345
20	6.575	21.5875	0.02552	-2.0333
21	6.739	21.5797	0.02552	-2.0315
22	6.931	21.5696	0.02552	-2.0293
23	7.122	21.5517	0.02552	-2.0252
24	7.368	21.5267	0.02552	-2.0196
25	7.477	21.4869	0.02552	-2.0107
26	7.668	21.4478	0.02552	-2.0019
27	7.914	21.3884	0.02552	-1.9887
28	8.269	21.2930	0.02552	-1.9674
29	8.570	21.1527	0.02567	-1.9358
30	8.761	20.9162	0.02567	-1.8839
31	8.953	20.8177	0.02567	-1.8625
32	9.089	20.8114	0.02552	-1.8617
33	9.363	20.5627	0.02551	-1.8081
34	9.636	20.0505	0.02551	-1.6996
35	10.018	19.5619	0.02535	-1.5992
36	10.401	19.2506	0.02535	-1.5362
37	10.702	18.7765	0.02519	-1.4429
38	11.030	18.3359	0.02503	-1.3583
39	11.358	17.4983	0.02472	-1.2035
40	11.740	16.7750	0.02471	-1.0748
41	12.068	16.3347	0.02455	-1.0000
42	12.369	15.3432	0.02439	-0.8388
43	12.533	14.7601	0.02469	-0.7475

September 29, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	2.396	19.6092	0.02473	-1.6117
2	2.614	19.5852	0.02473	-1.6068
3	2.860	19.5747	0.02472	-1.6046
4	3.106	19.5659	0.02467	-1.6030
5	3.297	19.5571	0.02462	-1.6014
6	3.488	19.5482	0.02457	-1.5998
7	3.816	19.5442	0.02457	-1.5990
8	4.117	19.5410	0.02457	-1.5983
9	4.362	19.5394	0.02472	-1.5974
10	4.608	19.5378	0.02457	-1.5977
11	4.909	19.5362	0.02457	-1.5973
12	5.127	19.5290	0.02457	-1.5959
13	5.237	19.5225	0.02472	-1.5939
14	5.264	19.5258	0.02472	-1.5946
15	5.264	19.5249	0.02472	-1.5944
16	5.428	19.5241	0.02457	-1.5949
17	5.646	19.5145	0.02457	-1.5929
18	5.974	19.4333	0.02472	-1.5758
19	6.166	19.3537	0.02472	-1.5597
20	6.357	19.3021	0.02472	-1.5493
21	6.439	19.3070	0.02472	-1.5502
22	6.521	19.3118	0.02472	-1.5512
23	6.657	19.2748	0.02472	-1.5438
24	6.767	19.2240	0.02472	-1.5336
25	6.958	19.1925	0.02472	-1.5272
26	7.258	19.1667	0.02472	-1.5221
27	7.614	19.1158	0.02472	-1.5119
28	7.887	19.0204	0.02472	-1.4929
29	8.187	18.9557	0.02472	-1.4801
30	8.379	18.9160	0.02472	-1.4723
31	8.597	18.8941	0.02472	-1.4680
32	8.789	18.8787	0.02487	-1.4643
33	8.953	18.8730	0.02472	-1.4638
34	9.117	18.8568	0.02472	-1.4606
35	9.390	18.8398	0.02472	-1.4573
36	9.554	18.8195	0.02487	-1.4526
37	9.745	18.7895	0.02487	-1.4467
38	10.018	18.7318	0.02487	-1.4355
39	10.210	18.6400	0.02487	-1.4176
40	10.319	18.5472	0.02487	-1.3996

BOUNDARY POINT: RAW CTD DATA

April 13, 1994

Scan	Depth m	Temp °C	Conductivity µS	Density
1	1.534	9.1459	0.02072	-0.1154
2	1.688	9.1469	0.02072	-0.1154
3	1.916	9.1449	0.02072	-0.1153
4	1.994	9.1452	0.02072	-0.1153
5	1.994	9.1455	0.02072	-0.1153
6	2.222	9.1459	0.02072	-0.1154
7	2.298	9.1458	0.02072	-0.1154
8	2.605	9.1458	0.02072	-0.1154
9	2.758	9.1448	0.02072	-0.1153
10	2.896	9.1458	0.02072	-0.1154
11	3.126	9.1427	0.02072	-0.1151
12	3.293	9.1437	0.02072	-0.1152
13	3.509	9.1457	0.02072	-0.1154
14	3.661	9.1447	0.02072	-0.1153
15	3.968	9.1446	0.02072	-0.1153
16	4.120	9.1446	0.02072	-0.1153
17	4.350	9.1436	0.02071	-0.1152
18	4.579	9.1415	0.02071	-0.1150
19	4.656	9.1395	0.02071	-0.1149
20	4.885	9.1233	0.02071	-0.1136
21	5.039	9.0961	0.02071	-0.1114
22	5.284	9.0617	0.02071	-0.1087
23	5.590	9.0213	0.02071	-0.1056
24	5.727	8.9980	0.02071	-0.1038
25	6.033	8.9575	0.02070	-0.1007
26	6.340	8.9332	0.02070	-0.0988
27	6.494	8.9058	0.02070	-0.0967
28	6.646	8.8906	0.02070	-0.0955
29	6.800	8.8794	0.02070	-0.0947
30	7.029	8.8571	0.02070	-0.0930
31	7.412	8.8378	0.02070	-0.0916
32	7.642	8.8216	0.02070	-0.0903
33	7.932	8.8145	0.02070	-0.0898
34	8.085	8.8094	0.02069	-0.0894
35	8.256	8.8033	0.02069	-0.0890
36	8.469	8.7962	0.02069	-0.0884
37	8.774	8.7809	0.02053	-0.0882
38	8.869	8.7586	0.02052	-0.0866
39	9.159	8.7372	0.02069	-0.0841
40	9.406	8.7159	0.02069	-0.0825
41	9.542	8.6793	0.02052	-0.0807
42	9.925	8.5338	0.02051	-0.0703
43	10.078	8.4206	0.02051	-0.0623
44	10.326	8.2888	0.02034	-0.0542
45	10.633	8.1898	0.02033	-0.0475
46	10.845	8.0922	0.02033	-0.0412
47	11.076	7.8888	0.02015	-0.0292
48	11.459	7.6992	0.02031	-0.0167
49	11.536	7.6135	0.02031	-0.0117
50	11.766	7.5566	0.02014	-0.0094
51	11.919	7.4924	0.02030	-0.0047
52	12.150	7.4323	0.01997	-0.0033
53	12.380	6.9434	0.01978	0.0212
54	12.668	6.6714	0.01977	0.0338
55	12.975	6.5548	0.01976	0.0389
56	13.205	6.5086	0.01960	0.0399
57	13.455	6.4844	0.01959	0.0409
58	13.819	6.4128	0.01959	0.0439
59	13.993	6.3517	0.01959	0.0463
60	14.279	6.3105	0.01959	0.0479
61	14.530	6.2810	0.01958	0.0491
62	14.837	6.2619	0.01958	0.0498
63	15.124	6.2609	0.01958	0.0499
64	15.200	6.2767	0.01975	0.0503

May 16, 1994

Scan	Depth m	Temp °C	Conductivity µS	Density
1	1.713	15.5646	0.02283	-0.8813
2	1.959	15.5578	0.02283	-0.8802
3	2.204	15.5305	0.02283	-0.8759
4	2.341	15.5138	0.02283	-0.8732
5	2.587	15.4970	0.02283	-0.8705
6	2.887	15.4803	0.02283	-0.8679
7	3.188	15.4632	0.02283	-0.8652
8	3.461	15.4590	0.02283	-0.8645
9	3.652	15.4445	0.02283	-0.8622
10	3.925	15.4325	0.02283	-0.8603
11	4.171	15.4069	0.02283	-0.8562
12	4.335	15.3694	0.02283	-0.8503
13	4.663	15.3139	0.02267	-0.8423
14	4.909	15.1796	0.02267	-0.8213
15	5.127	15.0734	0.02252	-0.8055
16	5.455	14.9155	0.02236	-0.7820
17	5.619	14.6589	0.02251	-0.7426
18	5.920	14.5821	0.02236	-0.7319
19	6.084	14.2071	0.02220	-0.6778
20	6.439	13.9234	0.02220	-0.6374
21	6.712	13.8056	0.02204	-0.6216
22	6.931	13.7356	0.02204	-0.6119
23	7.286	13.6770	0.02204	-0.6038
24	7.504	13.6297	0.02204	-0.5973
25	7.668	13.5912	0.02220	-0.5913
26	7.942	13.5236	0.02204	-0.5828
27	8.133	13.4411	0.02204	-0.5717
28	8.406	13.3294	0.02204	-0.5567
29	8.625	13.1099	0.02204	-0.5277
30	8.843	12.8516	0.02204	-0.4943
31	9.007	12.3962	0.02219	-0.4367
32	9.144	12.3337	0.02203	-0.4298
33	9.390	12.0113	0.02188	-0.3922
34	9.554	11.8495	0.02203	-0.3726
35	9.827	11.7819	0.02187	-0.3656
36	9.964	11.5274	0.02203	-0.3361
37	10.210	11.3770	0.02172	-0.3212
38	10.374	10.9724	0.02187	-0.2772
39	10.538	10.8665	0.02171	-0.2671
40	10.838	10.7054	0.02156	-0.2515
41	10.975	10.5789	0.02186	-0.2373
42	11.166	10.5523	0.02171	-0.2355
43	11.385	10.3841	0.02155	-0.2199
44	11.713	10.2458	0.02155	-0.2067
45	11.877	10.1461	0.02155	-0.1974
46	12.150	10.0675	0.02155	-0.1901
47	12.369	9.9518	0.02155	-0.1795
48	12.588	9.8869	0.02170	-0.1728

July 25, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	1.303	15.8102	0.01036	-0.9766
2	1.549	15.7992	0.01036	-0.9748
3	1.767	15.8017	0.01036	-0.9752
4	2.068	15.8045	0.01036	-0.9756
5	2.259	15.8074	0.01036	-0.9761
6	2.150	15.8102	0.01036	-0.9766
7	2.122	15.8085	0.01036	-0.9763
8	2.095	15.8119	0.01036	-0.9768
9	2.068	15.8119	0.01036	-0.9768
10	2.095	15.8093	0.01036	-0.9764
11	2.122	15.8161	0.01036	-0.9775
12	2.068	15.8195	0.01036	-0.9781
13	2.013	15.8229	0.01036	-0.9786
14	1.931	15.8288	0.01036	-0.9796
15	2.013	15.8322	0.01036	-0.9801
16	1.959	15.8330	0.01036	-0.9803
17	2.013	15.8339	0.01036	-0.9804
18	2.068	15.8313	0.01036	-0.9800
19	2.041	15.8305	0.01036	-0.9798
20	2.068	15.8313	0.01036	-0.9800
21	2.013	15.8245	0.01036	-0.9789
22	1.986	15.8211	0.01036	-0.9783
23	1.986	15.8186	0.01036	-0.9779
24	1.959	15.8186	0.01036	-0.9779
25	1.849	15.8186	0.01036	-0.9779
26	1.795	15.8194	0.01036	-0.9781
27	1.822	15.8177	0.01036	-0.9778
28	1.849	15.8033	0.01036	-0.9755
29	1.849	15.8025	0.01036	-0.9753
30	1.959	15.8050	0.01036	-0.9757
31	2.122	15.7965	0.01036	-0.9744
32	2.368	15.7948	0.01036	-0.9741
33	2.450	15.7999	0.01036	-0.9749
34	2.532	15.8058	0.01036	-0.9759
35	2.450	15.8050	0.01036	-0.9757
36	2.396	15.8016	0.01036	-0.9752
37	2.423	15.7973	0.01036	-0.9745
38	2.423	15.7973	0.01036	-0.9745
39	2.450	15.8024	0.01036	-0.9753
40	2.423	15.8151	0.01036	-0.9774
41	2.396	15.8194	0.01036	-0.9780
42	2.396	15.8227	0.01036	-0.9786
43	2.423	15.8261	0.01036	-0.9791
44	2.450	15.8270	0.01036	-0.9793
45	2.478	15.8261	0.01036	-0.9791
46	2.478	15.8287	0.01036	-0.9796
47	2.505	15.8261	0.01036	-0.9791
48	2.532	15.8270	0.01036	-0.9793
49	2.505	15.8278	0.01036	-0.9794
50	2.532	15.8320	0.01036	-0.9801
51	2.532	15.8346	0.01036	-0.9805
52	2.532	15.8363	0.01036	-0.9808
53	2.614	15.8456	0.01036	-0.9823
54	2.751	15.8507	0.01036	-0.9831
55	3.106	15.8668	0.01036	-0.9857
56	3.352	15.8490	0.01036	-0.9828
57	3.488	15.8235	0.01036	-0.9787
58	3.516	15.8286	0.01036	-0.9795
59	3.543	15.7854	0.01036	-0.9726
60	3.679	15.7565	0.01036	-0.9679
61	3.761	15.7480	0.01036	-0.9666
62	3.871	15.7472	0.01036	-0.9664
63	3.953	15.7489	0.01036	-0.9667
64	3.953	15.7480	0.01036	-0.9666
65	4.007	15.7514	0.01036	-0.9671
66	4.007	15.7582	0.01036	-0.9682
67	4.007	15.7599	0.01036	-0.9685
68	4.089	15.7361	0.01036	-0.9646
69	4.198	15.7072	0.01036	-0.9600
70	4.362	15.6962	0.01036	-0.9583
71	4.581	15.6852	0.01036	-0.9565
72	4.909	15.6818	0.01036	-0.9559
73	5.182	15.6945	0.01036	-0.9580
74	5.401	15.7030	0.01036	-0.9593
75	5.619	15.6936	0.01036	-0.9578
76	5.756	15.7021	0.01036	-0.9592
77	6.002	15.6987	0.01036	-0.9586
78	6.220	15.6987	0.01036	-0.9586
79	6.493	15.6979	0.01036	-0.9585
80	6.739	15.6826	0.01036	-0.9560
81	6.903	15.6809	0.01036	-0.9558
82	7.067	15.6834	0.01036	-0.9562
83	7.231	15.6681	0.01036	-0.9537
84	7.450	15.6401	0.01036	-0.9493
85	7.614	15.6163	0.01036	-0.9455
86	7.750	15.6044	0.01036	-0.9436
87	7.942	15.5814	0.01036	-0.9399
88	8.187	15.5652	0.01035	-0.9374
89	8.406	15.5541	0.01035	-0.9356
90	8.543	15.5388	0.01035	-0.9332
91	8.761	15.5320	0.01035	-0.9321
92	8.980	15.5303	0.01036	-0.9318
93	9.226	15.5303	0.01035	-0.9318
94	9.526	15.5294	0.01035	-0.9317
95	9.718	15.5286	0.01035	-0.9315
96	10.046	15.5277	0.01035	-0.9314
97	10.292	15.5235	0.01035	-0.9307
98	10.483	15.5132	0.01035	-0.9291
99	10.674	15.5090	0.01035	-0.9284
100	10.920	15.5013	0.01035	-0.9272
101	11.139	15.4970	0.01035	-0.9265
103	11.386	15.5013	0.01035	-0.9272
104	11.604	15.5039	0.01035	-0.9276
105	11.877	15.4953	0.01035	-0.9263
106	12.123	15.4851	0.01035	-0.9247
107	12.342	15.4766	0.01020	-0.9240
108	12.642	15.4774	0.01035	-0.9234
109	12.861	15.4817	0.01035	-0.9241
110	13.025	15.4834	0.01035	-0.9244
111	13.189	15.4817	0.01035	-0.9241
112	13.435	15.4783	0.01035	-0.9236
113	13.626	15.4749	0.01035	-0.9230
114	13.790	15.4723	0.01035	-0.9226
115	13.982	15.4723	0.01035	-0.9226
116	14.146	15.4723	0.01020	-0.9233

BOUNDARY POINT: RAW CTD DATA, Continued

July 25, 1994 cont.

Scan	Depth m	Temp °C	Conductivit	Density
117	14.419	15.4834	0.01035	-0.9243
118	14.665	15.5012	0.01035	-0.9272
119	14.857	15.4876	0.01035	-0.9250
120	15.021	15.4842	0.01020	-0.9251
121	15.212	15.4799	0.01035	-0.9238
123	15.458	15.4748	0.01035	-0.9230
124	15.567	15.4697	0.01035	-0.9222
125	15.759	15.4705	0.01035	-0.9223
126	15.977	15.4700	0.01030	-0.9224
127	16.333	15.4694	0.01025	-0.9226
128	16.497	15.4688	0.01020	-0.9227
129	16.770	15.4637	0.01035	-0.9212
130	17.099	15.4629	0.01020	-0.9218
131	17.345	15.4637	0.01035	-0.9212
132	17.345	15.4671	0.01035	-0.9217
133	17.538	15.4671	0.01035	-0.9217

August 30, 1994

Scan	Depth m	Temp °C	Conductivit	Density
1	0.893	21.3225	0.02536	-1.9748
2	1.194	21.3233	0.02536	-1.9750
3	1.576	21.3233	0.02536	-1.9750
4	1.959	21.3214	0.02536	-1.9746
5	2.314	21.3196	0.02536	-1.9742
6	2.587	21.3178	0.02536	-1.9737
7	2.969	21.3146	0.02536	-1.9730
8	3.324	21.3146	0.02536	-1.9730
9	3.652	21.3146	0.02536	-1.9730
10	3.925	21.3154	0.02536	-1.9732
11	4.226	21.3153	0.02536	-1.9731
12	4.472	21.3153	0.02536	-1.9731
13	4.772	21.3138	0.02536	-1.9728
14	4.991	21.3098	0.02536	-1.9719
15	5.155	21.3043	0.02536	-1.9707
16	5.428	21.2996	0.02536	-1.9696
17	5.674	21.2988	0.02536	-1.9694
18	5.947	21.2988	0.02536	-1.9694
19	6.220	21.2972	0.02536	-1.9691
20	6.603	21.2980	0.02536	-1.9692
21	6.931	21.2980	0.02536	-1.9692
22	7.286	21.2988	0.02536	-1.9694
23	7.641	21.2980	0.02536	-1.9692
24	7.914	21.2995	0.02536	-1.9695
25	8.269	21.2979	0.02536	-1.9692
26	8.488	21.2956	0.02536	-1.9686
27	8.707	21.2956	0.02536	-1.9686
28	8.980	21.2901	0.02536	-1.9674
29	9.199	21.2062	0.02536	-1.9488
30	9.472	21.0273	0.02551	-1.9088
31	9.690	20.7871	0.02535	-1.8571
32	10.073	20.2575	0.02535	-1.7437
33	10.374	19.3554	0.02519	-1.5580
34	10.702	18.7514	0.02503	-1.4386
35	10.975	18.1011	0.02502	-1.3138
36	11.221	17.5950	0.02486	-1.2205
37	11.412	16.9694	0.02471	-1.1089
38	11.713	16.3734	0.02455	-1.0066
39	11.959	15.9178	0.02454	-0.9306
40	12.178	15.6132	0.02438	-0.8819
41	12.451	15.2844	0.02423	-0.8272
42	12.697	14.9208	0.02422	-0.7741
43	12.998	14.7280	0.02407	-0.7456
44	13.244	14.5200	0.02407	-0.7145
45	13.544	14.3946	0.02407	-0.6961
46	13.790	14.3460	0.02406	-0.6890
47	14.009	14.2837	0.02391	-0.6777
48	14.282	14.1394	0.02406	-0.6591
49	14.528	14.0742	0.02391	-0.6505
50	14.747	13.9619	0.02391	-0.6345
51	15.021	13.8528	0.02375	-0.6199
52	15.321	13.7742	0.02375	-0.6090
53	15.595	13.7322	0.02375	-0.6031
54	15.786	13.6998	0.02375	-0.5986
55	16.032	13.6630	0.02375	-0.5936
56	16.278	13.6378	0.02375	-0.5901
57	16.388	13.6148	0.02375	-0.5869
58	16.552	13.6034	0.02375	-0.5854
59	16.798	13.5666	0.02375	-0.5803
60	17.016	13.5420	0.02375	-0.5770
61	17.208	13.5359	0.02375	-0.5761
62	17.372	13.5245	0.02359	-0.5753
63	17.563	13.4929	0.02359	-0.5710
64	17.809	13.4533	0.02359	-0.5657
65	17.946	13.4366	0.02359	-0.5634
66	18.165	13.3986	0.02359	-0.5583
67	18.356	13.3346	0.02359	-0.5497
68	18.575	13.2704	0.02359	-0.5412
69	18.821	13.2060	0.02343	-0.5334
70	19.040	13.1751	0.02343	-0.5293
71	19.259	13.1460	0.02343	-0.5255
72	19.423	13.0586	0.02359	-0.5133
73	19.450	12.8905	0.02389	-0.4900

September 29, 1994

Scan	Depth m	Temp °C	Conductivity	Density
1	0.948	19.6667	0.02489	-1.6228
2	1.112	19.6498	0.02504	-1.6187
3	1.221	19.6466	0.02504	-1.6181
4	1.358	19.6349	0.02499	-1.6159
5	1.576	19.6231	0.02494	-1.6137
6	1.822	19.6113	0.02489	-1.6115
7	2.122	19.5977	0.02473	-1.6093
8	2.368	19.5848	0.02473	-1.6067
9	2.614	19.5648	0.02473	-1.6026
10	2.860	19.5495	0.02489	-1.5988
11	2.997	19.5471	0.02473	-1.5989
12	3.133	19.5470	0.02473	-1.5989
13	3.297	19.5374	0.02473	-1.5970
14	3.543	19.5189	0.02473	-1.5932
15	3.898	19.5077	0.02473	-1.5909
16	4.171	19.4900	0.02473	-1.5873
17	4.390	19.4715	0.02473	-1.5835
18	4.526	19.4586	0.02473	-1.5809
19	4.608	19.4538	0.02473	-1.5799
20	4.772	19.4417	0.02473	-1.5775
21	4.991	19.4103	0.02473	-1.5711
22	5.237	19.3403	0.02473	-1.5570
23	5.619	19.2710	0.02473	-1.5430
24	5.947	19.2242	0.02473	-1.5336
25	6.166	19.2064	0.02473	-1.5300
26	6.384	19.1992	0.02488	-1.5279
27	6.411	19.1975	0.02473	-1.5283
28	6.575	19.1773	0.02473	-1.5242
29	6.767	19.1628	0.02473	-1.5213
30	6.931	19.1442	0.02472	-1.5176
31	7.258	19.1232	0.02472	-1.5134
32	7.532	19.1014	0.02472	-1.5090
33	7.832	19.0755	0.02472	-1.5039
34	8.078	19.0407	0.02472	-1.4970
35	8.242	19.0075	0.02472	-1.4904
36	8.351	18.9751	0.02488	-1.4833
37	8.543	18.9525	0.02472	-1.4795
38	8.734	18.9200	0.02472	-1.4731
39	8.980	18.8941	0.02488	-1.4673
40	9.281	18.8633	0.02472	-1.4619
41	9.581	18.8016	0.02472	-1.4498
42	9.936	18.7042	0.02472	-1.4307
43	10.210	18.5496	0.02487	-1.4001
44	10.428	18.3832	0.02487	-1.3681
45	10.702	18.2680	0.02471	-1.3467
46	10.948	18.1779	0.02487	-1.3290
47	11.112	18.0903	0.02487	-1.3124
48	11.303	18.0894	0.02471	-1.3129
49	11.522	17.8290	0.02471	-1.2642
50	11.795	17.3731	0.02486	-1.1801
51	12.068	16.9734	0.02486	-1.1089
52	12.232	16.6685	0.02486	-1.0557
53	12.451	16.4135	0.02485	-1.0120
54	12.697	16.2267	0.02485	-0.9805
55	12.970	16.0275	0.02485	-0.9473
56	13.244	15.8464	0.02485	-0.9175
57	13.435	15.6699	0.02484	-0.8889
58	13.654	15.5048	0.02469	-0.8631
59	13.818	15.2838	0.02469	-0.8281
60	14.009	15.1067	0.02484	-0.7998
61	14.228	15.0295	0.02469	-0.7886
62	14.364	14.8698	0.02453	-0.7649
63	14.583	14.7484	0.02453	-0.7465
64	14.775	14.6389	0.02437	-0.7308
65	14.993	14.5396	0.02437	-0.7160
66	15.212	14.4825	0.02437	-0.7075
67	15.376	14.4514	0.02437	-0.7030
68	15.513	14.4228	0.02452	-0.6980
69	15.677	14.3960	0.02437	-0.6948
70	15.895	14.3448	0.02437	-0.6873
71	16.114	14.2867	0.02437	-0.6789
72	16.278	14.2529	0.02437	-0.6740
73	16.388	14.2095	0.02437	-0.6677
74	16.415	14.1903	0.02437	-0.6649
75	16.552	14.1712	0.02452	-0.6614
76	16.634	14.1503	0.02437	-0.6592
77	16.825	14.1277	0.02421	-0.6567
78	17.099	14.0886	0.02406	-0.6518
79	17.290	14.0477	0.02421	-0.6452
80	17.509	14.0154	0.02406	-0.6414
81	17.727	14.0015	0.02405	-0.6394
82	17.837	13.9858	0.02405	-0.6372
83	18.056	13.9614	0.02405	-0.6337
84	18.165	13.9457	0.02405	-0.6315
85	18.329	13.9326	0.02405	-0.6297
86	18.466	13.9203	0.02390	-0.6287
87	18.712	13.8898	0.02421	-0.6229
88	18.821	13.8662	0.02405	-0.6203
89	18.931	13.8514	0.02405	-0.6182
90	19.040	13.8295	0.02390	-0.6159
91	19.204	13.8129	0.02390	-0.6136
92	19.560	13.7701	0.02390	-0.6076
93	19.860	13.7298	0.02390	-0.6021
94	20.052	13.7097	0.02390	-0.5993
95	20.216	13.6887	0.02389	-0.5964
96	20.517	13.6677	0.02389	-0.5935
97	20.681	13.6642	0.02389	-0.5930
98	20.900	13.6458	0.02389	-0.5904
99	21.119	13.5362	0.02374	-0.5762
100	21.392	13.4308	0.02420	-0.5596
101	21.501	13.2645	0.02420	-0.5374

Appendix 4. Chlorophyll a, phytoplankton and zooplankton data

RENSELCHL

Scale:	1	3	10	30	K1x=	0.00713	
Factor:	1	2.68	7.5	28.1	Fo/Fa max=		2.01

Lorenzen fluorometer HOT_TO_GO

Sample#	Depth (m)	Vol. filt. (l)	Scale	diln denom	Fo	Fa	Chlorophyll mg/m^3	Phaeopig. mg/m^3	Fo/Fa
BP4-13	1,3,6	0.020	2.68	1.0	38.5	21.0	4.633	0.982	1.83
SCB4-13	1,3,6	0.020	2.68	1.0	47.0	27.0	5.295	1.925	1.74
BP5-16	1,3,6	0.020	2.68	1.0	35.0	19.0	4.236	0.844	1.84
SCB5-16	0.5	0.020	2.68	1.0	29.0	17.0	3.177	1.369	1.71
BP6-16	1,3,6	0.020	7.5	1.0	63.5	34.5	2.743	0.553	1.84
SCB6-16	1,3,6	0.020	7.5	1.0	54.5	31.0	2.223	0.739	1.76
BP7-25	1,3,6	0.020	7.5	1.0	61.5	34.5	2.554	0.742	1.78
SCB7-25	1,3	0.020	7.5	1.0	42.5	24.0	1.750	0.543	1.77
BP8-30	1,3,6	0.030	2.68	1.0	74.0	37.0	6.530	0.065	2.00
SCB8-30	0.5,4,6	0.030	1	1.0	19.0	09.5	4.493	0.045	2.00
BP9-29	1,3,6	0.020	2.68	1.0	75.0	37.5	9.927	0.099	2.00
SCB9-29	1,3,6	0.020	2.68	1.0	64.0	33.5	8.074	0.883	1.91
CR/RWL7-25	2	0.020	7.5	1.0	32.0	20.0	1.135	0.776	1.60

LAKE OSOYOOS PHYTOPLANKTON
DATE: 04/13/94
STATION: Boundary Point Composite **SAMPLE STATUS: Lugol PRESERVED**
(Surf,1m,3m,6m)

Taxon	Cells/ml	µm3/cell	µm3/ml	comments
Cyanophyta				
Chroococcus sp.	8.00	150	1,204	
Oscillatoria tenuis	**1,540.00**	**129**	**198,066**	**dominant**
Taxon Subtotal	**1548**		**199,270**	
Chlorophyta				
filamentous green	8.00	2,826	22,608	
colonial green(sph)	48.00	180	8,616	
Taxon Subtotal	**56**		**31,224**	
Chrysophyta				
Dinobryon bavaricum	12.00	1,172	14,067	
Dinobryon sp.	24.00	1,178	28,260	
Bacillariophyceae				
Asterionella formosa	208.00	371	77,264	
Cyclotella sp.	2.00	4,522	9,043	
Epithemia sp.	1.00	32,028	32,028	
Fragilaria crotonensis	67.00	683	45,761	
Fragilaria sp.	60.00	600	36,000	
Melosira italica	176.00	2,041	359,216	
Melosira sp. B	44.00	1,407	61,896	
Stephanodiscus niagarae	5.00	79,128	395,640	
Synedra ulna	2.00	10,257	20,515	
Synedra acus	3.00	1,256	3,768	
Tabellaria fenestrata	85.00	4,800	408,000	
Taxon Subtotal	**689**		**1,491,458**	
Cryptophyta				
Euglenophyta				
Pyrrhophyta				
Peridinium sp.	1.00	66,317	66,317	
Taxon Subtotal	**1**		**66,317**	
Chloromonadophyta				

			(µm3/ml)	(mm3/L)
Total Number/ml	**2294**	**Total Volume**	**1,788,269**	**1.79**
% Cyanophyta	**67.48**	% Cyanophyta	**11.14**	
% Chlorophyta	**2.44**	% Chlorophyta	**1.75**	
% Chrysophyta	**30.03**	% Chrysophyta	**83.40**	
% Pyrrhophyta	**0.04**	% Pyrrhophyta	**3.71**	

Note: *=colony/ml

LAKE OSOYOOS PHYTOPLANKTON
DATE: 05/16/94
STATION: Boundary Point Surf Composite **SAMPLE STATUS: Lugol PRESERVED**

Taxon	Cells/ml	µm3/cell	µm3/ml	comments
Cyanophyta				
Aphanizomenon flos-aquae	**7,176.00**	**118**	**846,768**	**dominant**
Chroococcus sp.	12.00	150	1,805	
Coelosphaerium Naegelianum	100.00	14	1,413	broken colony
Gomphosphaeria lacustris	40.00	16	659	
Oscillatoria tenuis	910.00	129	117,039	
Taxon Subtotal	**8238**		**967,685**	
Chlorophyta				
Dictyosphaerium sp.	36.00	113	4,069	
filamentous green	2.00	3,391	6,782	
colonial green(sph)	8.00	180	1,436	
Taxon Subtotal	**46**		**12,288**	
Chrysophyta				
Dinobryon bavaricum	164.00	1,077	176,631	
Dinobryon sp.	87.00	1,178	102,443	
Bacillariophyceae				
Asterionella formosa	160.00	371	59,434	
Cyclotella sp.	3.00	3,768	11,304	
Fragilaria crotonensis	173.00	683	118,159	
Fragilaria sp.	20.00	600	12,000	
Melosira italica	6.00	2,041	12,246	
Stephanodiscus niagarae	5.00	102,892	514,458	
Synedra sp.	8.00	180	1,436	
Synedra acus	13.00	1,256	16,328	
Taxon Subtotal	**639**		**1,024,438**	
Cryptophyta				
Cryptomonas ovata	3.00	3,467	10,400	
Cryptomonas sp.	12.00	1,641	19,694	
Chroomonas sp.	17.00	791	13,452	
Taxon Subtotal	**32**		**43,546**	
Euglenophyta				
Pyrrhophyta				
Peridinium sp.	2.00	44,902	89,804	
Taxon Subtotal	**2**		**89,804**	
Chloromonadophyta				

			(um3/ml)	(mm3/L)
Total Number/ml	**8957**	**Total Volume**	**2,137,761**	**2.14**
% Cyanophyta	**91.97**	% Cyanophyta	**45.27**	
% Chlorophyta	**0.51**	% Chlorophyta	**0.57**	
% Chrysophyta	**7.13**	% Chrysophyta	**47.92**	
% Cryptophyta	**0.36**	% Cryptophyta	**2.04**	
% Pyrrhophyta	**0.02**	% Pyrrhophyta	**4.20**	

Note: *=colony/ml

LAKE OSOYOOS PHYTOPLANKTON
DATE: 06/16/94
STATION: Boundary Point Surf Composite SAMPLE STATUS: Lugol PRESERVED

Taxon	Cells/ml	µm3/cell	µm3/ml	Comments
Cyanophyta				
Anabaena circinalis-like	30.00	150	4,514	
Aphanizomenon flos-aquae	416.00	118	49,088	
Aphanocapsa sp.	100.00	4	419	
Chroococcus sp.	8.00	182	1,459	
Gomphosphaeria lacustris	200.00	16	3,297	
Oscillatoria tenuis	280.00	129	36,012	
Taxon Subtotal	**1034**		**94,788**	
Chlorophyta				
Closteriopsis longissima	1.00	24,233	24,233	
Oocystis sp.	4.00	402	1,608	
filamentous green	10.00	3,419	34,195	
colonial green(sph)	8.00	180	1,436	
Taxon Subtotal	**23**		**61,471**	
Chrysophyta				
Mallomonas sp. B	1.00	2,872	2,872	
chrysophyte (flagel)	2.00	10,048	20,096	
Bacillariophyceae				
Asterionella formosa	272.00	371	101,038	
Cyclotella sp.	7.00	3,768	26,376	
Fragilaria crotonensis	250.00	683	170,750	
Melosira sp.	3.00	3,077	9,232	
Stephanodiscus niagarae	1.00	84,780	84,780	
Synedra sp.	2.00	224	449	
Synedra ulna	3.00	5,861	17,584	
Synedra ulna	3.00	12,822	38,465	
Taxon Subtotal	**544**		**471,641**	
Cryptophyta				
Cryptomonas ovata	14.00	3,467	48,532	
Taxon Subtotal	**14**		**48,532**	
Euglenophyta				
Pyrrhophyta				
Ceratium hirundinella	2.00	60,000	120,000	
Taxon Subtotal	**2**		**120,000**	
Chloromonadophyta				

			(um3/ml)	(mm3/L)
Total Number/ml	**1617**	**Total Volume**	**796,433**	**0.80**
% Cyanophyta	**63.95**	% Cyanophyta	**11.90**	
% Chlorophyta	**1.42**	% Chlorophyta	**7.72**	
% Chrysophyta	**33.64**	% Chrysophyta	**59.22**	
% Cryptophyta	**0.87**	% Cryptophyta	**6.09**	
% Pyrrhophyta	**0.12**	% Pyrrhophyta	**15.07**	

Note: *=colony/ml

LAKE OSOYOOS PHYTOPLANKTON
DATE: 07/25/94
STATION: Boundary Point 0+3m CompositeSAMPLE STATUS: Lugol PRESERVED

Taxon	Cells/ml	µm3/cell	µm3/ml	Comments
Cyanophyta				
Anabaena sp.	10.00	132	1,319	cells elongate
Anabaena circinalis-like	520.00	150	78,237	
Anabaena sp. (strait-chn)	294.00	182	53,617	cells elongate
Aphanizomenon flos-aquae	377.00	118	44,486	
Aphanocapsa sp.	3,120.00	4	13,062	
Chroococcus sp.	64.00	182	11,672	
Gomphosphaeria lacustris	360.00	16	5,935	
Oscillatoria tenuis	438.00	129	56,333	
Taxon Subtotal	**5183**		**264,661**	
Chlorophyta				
Ankistrodesmus falcatus	1.00	1,130	1,130	
Dictyosphaerium sp.	16.00	180	2,872	
Oocystis sp.	8.00	733	5,861	
Oocystis sp.	4.00	264	1,055	
Staurastrum sp. A	3.00	3,939	11,816	
filamentous green	1.00	7,536	7,536	
colonial green(sph)	8.00	180	1,436	
Taxon Subtotal	**41**		**31,707**	
Chrysophyta				
Dinobryon sp.	12.00	586	7,034	
Mallomonas sp. A	1.00	4,308	4,308	
Bacillariophyceae				
Cyclotella sp.	3.00	2,543	7,630	
Fragilaria crotonensis	270.00	683	184,410	
Synedra sp.	17.00	224	3,814	stellate
Synedra acus	4.00	1,635	6,542	
Synedra ulna	1.00	10,990	10,990	
Taxon Subtotal	**308**		**224,728**	
Cryptophyta				
Cryptomonas sp.	7.00	1,758	12,309	
Rhodomonas sp.	7.00	293	2,051	
Chroomonas sp.	18.00	879	15,826	
Taxon Subtotal	**32**		**30,186**	
Euglenophyta				
Pyrrhophyta				
Peridinium sp. (tiny)	1.00	1,407	1,407	
Taxon Subtotal	**1**		**1,407**	
Chloromonadophyta				

			(um3/ml)	(mm3/L)
Total Number/ml	**5565**	**Total Volume**	**552,689**	**0.55**
% Cyanophyta	93.14	% Cyanophyta	47.89	
% Chlorophyta	0.74	% Chlorophyta	5.74	
% Chrysophyta	5.53	% Chrysophyta	40.66	
% Cryptophyta	0.58	% Cryptophyta	5.46	
% Pyrrhophyta	0.02	% Pyrrhophyta	0.25	

Note: *=colony/ml

LAKE OSOYOOS PHYTOPLANKTON
DATE: 08/30/94
STATION: Boundary Point Composite **SAMPLE STATUS: Lugol PRESERVED**

Taxon	Cells/ml	µm3/cell	µm3/ml	Comments
Cyanophyta				
Anabaena sp.	882.00	228	201,064	cells elongate
Anabaena circinalis-like	1,700.00	150	255,776	
Anabaena sp. (strait-chn)	4,508.00	335	1,509,879	cells elongate
Aphanizomenon flos-aquae	585.00	118	69,030	
Aphanocapsa sp.	1,500.00	4	6,280	
Aphanothece sp.	100.00	6	628	
Chroococcus sp.	4.00	182	729	
Coelosphaerium Naegelianum	100.00	14	1,413	
Gomphosphaeria lacustris	320.00	16	5,275	
+ *Lyngbya sp.*	1.00	443,117	443,117	1 filament
+ *Lyngbya sp.*	1.00	10,770	10,770	1 filament
Microcystis aeruginosa	100.00	14	1,413	
Oscillatoria tenuis	228.00	129	29,324	
Taxon Subtotal	**10029**		**2,534,699**	
Chlorophyta				
Ankistrodesmus falcatus	1.00	1,130	1,130	
Pandorina morum	8.00	335	2,679	
Scenedesmus sp. A	1.00	536	536	
Staurastrum sp. A	3.00	3,939	11,816	
filamt green (Mougeotia-like)	441.00	3,077	1,357,045	
green unicell(sph)	5.00	697	3,483	
colonial green nanno (ell)	32.00	50	1,608	
colonial green(sph)	24.00	523	12,560	
Taxon Subtotal	**515**		**1,390,858**	
Chrysophyta				
Dinobryon sp.	14.00	742	10,386	
Mallomonas sp. B	1.00	2,872	2,872	
Bacillariophyceae				
Cyclotella sp.	3.00	3,140	9,420	
Fragilaria crotonensis	270.00	683	184,410	
Melosira sp. B	12.00	3,617	43,407	
Synedra sp.	75.00	224	16,828	stellate
Synedra acus	5.00	3,956	19,782	
Taxon Subtotal	**380**		**287,105**	
Cryptophyta				
Cryptomonas sp.	7.00	1,758	12,309	
Chroomonas sp.	14.00	879	12,309	
Taxon Subtotal	**21**		**24,618**	
Euglenophyta				
Pyrrhophyta				
Chloromonadophyta				

			(um3/ml)	(mm3/L)
Total Number/ml	**10945**	**Total Volume**	**4,237,280**	**4.24**
% Cyanophyta	**91.63**	% Cyanophyta	**59.82**	
% Chlorophyta	**4.71**	% Chlorophyta	**32.82**	
% Chrysophyta	**3.47**	% Chrysophyta	**6.78**	
% Cryptophyta	**0.19**	% Cryptophyta	**0.58**	

Note: *=colony/ml
+= filament

LAKE OSOYOOS PHYTOPLANKTON
DATE: 09/29/94
STATION: Boundary Point 1,3,6m CompositSAMPLE STATUS: Lugol PRESERVED

Taxon	Cells/ml	µm3/cell	µm3/ml	Comments
Cyanophyta				
Anabaena sp.	270.00	228	61,550	cells elongate
Anabaena circinalis-like	110.00	150	16,550	
Anabaena sp. (strait-chn)	3,872.00	424	1,641,341	
Aphanizomenon flos-aquae	884.00	118	104,312	
Aphanocapsa sp.	300.00	4	1,256	
Aphanothece sp.	100.00	6	628	
Chroococcus sp.	8.00	182	1,459	
Coelosphaerium Naegelianum	500.00	14	7,065	
+ *Lyngbya sp.*	1.00	316,512	316,512	1 filament
Oscillatoria tenuis	420.00	129	54,018	
Taxon Subtotal	**6465**		**2,204,691**	
Chlorophyta				
Ankistrodesmus falcatus	1.00	293	293	
Ankistrodesmus sp.	6.00	234	1,407	
Nephrocytium sp.	4.00	469	1,876	
Oocystis sp.	4.00	733	2,931	
Pandorina morum	40.00	335	13,397	
Pandorina morum	32.00	628	20,096	
filamt green (Mougeotia-like)	184.00	2,261	415,987	
green unicell(sph)	2.00	697	1,393	
colonial green(sph)	32.00	382	12,208	
Taxon Subtotal	**305**		**469,588**	
Chrysophyta				
Dinobryon sp.	2.00	742	1,484	
Mallomonas sp. B	2.00	2,872	5,744	
Bacillariophyceae				
Cyclotella sp.	2.00	4,559	9,119	
Fragilaria crotonensis	10.00	683	6,830	
Synedra sp.	27.00	224	6,058	stellate
Synedra acus	1.00	2,638	2,638	
Taxon Subtotal	**44**		**31,872**	
Cryptophyta				
Cryptomonas sp.	19.00	1,758	33,410	
Rhodomonas sp.	7.00	293	2,051	
Chroomonas sp.	14.00	879	12,309	
Taxon Subtotal	**40**		**47,770**	
Euglenophyta				
Euglena sp.	2.00	6,462	12,924	
Taxon Subtotal	**2**		**12,924**	
Pyrrhophyta				
Peridinium sp. (tiny)	2.00	1,407	2,813	
Taxon Subtotal	**2**		**2,813**	
Chloromonadophyta				

			(um3/ml)	(mm3/L)
Total Number/ml	**6858**	**Total Volume**	**2,769,659**	**2.77**
% Cyanophyta	94.27	% Cyanophyta	79.60	
% Chlorophyta	4.45	% Chlorophyta	16.95	
% Chrysophyta	0.64	% Chrysophyta	1.15	
% Cryptophyta	0.58	% Cryptophyta	1.72	
% Euglenophyta	0.03	% Euglenophyta	0.47	
% Pyrrhophyta	0.03	% Pyrrhophyta	0.10	

Note: *=colony/ml
+= filament

LAKE OSOYOOS ZOOPLANKTON DATA

STATION: Boundary Point-surf tow
DATE: 13 Apr 94

NOTE: ID and presence only

Taxon	Present	Ave lngth male(mm)	Ave lngth fem (mm)	comments
PHYLUM ARTHROPODA				
Subphylum Crustacea				
Class Copepoda				
Order Calanoida				
copepodid	X		0.6-0.7	
Leptodiaptomus ashlandi	X	1.16	1.29	
Order Cyclopoida				
copepodid	X		0.6-0.7	
Diacylops bicuspidatus thomasi	X		1.29	
Nauplii (cal+cyc)	X		<.3	
Class Branchiopoda(cladocerans)				
Daphnia (juv)	X		<1.0	
Daphnia sp. (rnd-hd D. gal mend?)	X		1.70	
Subphylum Uniramia				
Class Insecta				
Order Diptera	no			
PHYLUM ROTIFERA				
Type 1 (mostly loricated malleates)				
Kellicottia longispina	X			
Keratella cochlearis	X			
Keratella hiemalis	X			
Keratella quadrata	X			dominant
Notholca acuminata	X			
Notholca foliacea	X			
Type 2 (mostly illoricate virgates/incudates)				
Polyarthra dolichoptera	X			
Polyarthra sp.	X			
Synchaeta sp.	X			
Type 3 (mostly malleoramates)				
Conochilus sp.	X			
Filinia terminalis	X			
Others	no			

LAKE OSOYOOS ZOOPLANKTON DATA — *WATER Environmental Services, Inc.*

STATION: Boundary Pt. NOTE: Zoop net diam 20cm

DATE: 16 May 94

Taxon	Ave lngth male(mm)	Ave lngth fem (mm)	#/m3	Estim Dry wt. ug/male	Estim Dry wt. ug/fem	ug/m3
PHYLUM ARTHROPODA						
Subphylum Crustacea						
Subclass Copepoda						
Order Calanoida						
Copepodid		0.6-0.7	3,268	0	2.5	8,169
Leptodiaptomus ashlandi	1.16	1.33	4,357	6	10	34,854
Order Cyclopoida						
Copepodid		0.6-0.7	5,446	0	2	10,892
Diacyclops bicuspidatus thomasi	1.00	1.26	2,541	3	5.8	13,724
Nauplii (cal+cyc)		<.3	25,414	0	0.25	6,354
Class Branchiopoda(cladocerans)						
Daphnia (juv)		<1.0	5,446	0	5	27,229
Daphnia sp. (md-hlmt gal mend?)		1.89	1,815	8	33	59,904
Bosmina longirostris (adult)		0.35	1,815	0	1	1,815
Class Insecta						
Order Diptera						
PHYLUM ROTIFERA						
Type 1 (mostly loricated malleates)						
Kellicottia longispina		0.21	23,599	0	0.02	472
Keratella cochlearis		0.16	21,783	0	0.01	218
Keratella cochlearis (robust)		0.21	5,446	0	0.02	109
Keratella quadrata		0.18	34,490	0	0.069	2,380
Type 2 (mostly illoricate virgates/incudates)						
Polyarthra sp. (small)		0.10	7,261	0	0.03	218
Polyarthra sp.		0.15	9,076	0	0.07	635
Type 3 (mostly malleoramates)						
Collotheca sp.		0.21	10,892	0	0.01	109
Others						

	Total Density #/m3	Total Density #/L	Total Dry Wt. Biomass ug/m3	Total Dry Wt. Biomass ug/L
	162,650	**162.65**	**167,081**	**167.08**
% Calanoid Copepods	4.69		25.75	
% Cyclopoid Copepods	4.91		14.73	
% Nauplii	15.63		3.80	
% Cladocerans	5.58		53.24	
% Rotifers	69.20		2.48	
% Dipterans	0.00		0.00	

Number of species 11

LAKE OSOYOOS ZOOPLANKTON DATA
STATION: Boundary Pt.
DATE: 16 Jun 94

WATER Environmental Services, Inc.
NOTE: Zoop net diam 20cm

Taxon	Ave lngth male(mm)	Ave lngth fem (mm)	#/m3	Est.Dry wt ug/male	Est.Dry wt ug/fem	ug/m3
PHYLUM ARTHROPODA						
Subphylum Crustacea						
Subclass Copepoda						
Order Calanoida						
Copepodid		0.6-0.7	713	0	2.5	1,783
Leptodiaptomus ashlandi	1.16	1.33	5,350	6	10	42,089
Epischura nevadensis	2.10		357	20	24	7,134
Order Cyclopoida						
Copepodid		0.6-0.7	3,567	0	2	7,134
Diacyclops bicuspidatus thomasi	1.00	1.12	2,140	3	5	9,987
Nauplii (cal+cyc)		<.3	12,484	0	0.25	3,121
Class Branchiopoda(cladocerans)						
Daphnia (juv)		<1.0	1,070	0	5	5,350
Daphnia sp. (tall gal mend?)		2.30	1,070	8	48	51,363
Diaphanosoma sp. (small)		1.00	357	0	5	1,783
Leptodora kindtii		6.00-7.00	357	0	60	21,401
Class Insecta						
Order Diptera						
PHYLUM ROTIFERA						
Type 1 (mostly loricated malleates)						
Kellicottia longispina		0.21	17,834	0	0.02	357
Keratella cochlearis		0.16	3,567	0	0.01	36
Keratella cochlearis (robust)		0.21	12,484	0	0.02	250
Type 2 (mostly illoricate virgates/incudates)						
Gastropus stylifer		0.11	1,783	0	0.03	54
Type 3 (mostly malleoramates)						
Collotheca sp.		0.21	12,484	0	0.01	125
Conochilus sp.		0.15	80,255	0	0.025	2,006
Conochilus sp. (small)		0.14	53,503	0	0.01	535
Others						

	Total Density #/m3	Total Density #/L	Total Dry Wt. Biomass ug/m3	Total Dry Wt. Biomass ug/L
	209,376	209.38	154,508	154.51
% Calanoid Copepods	3.07		33.01	
% Cyclopoid Copepods	2.73		11.08	
% Nauplii	5.96		2.02	
% Cladocerans	1.36		51.71	
% Rotifers	86.88		2.18	
% Dipterans	0.00		0.00	

Number of species 12

LAKE OSOYOOS ZOOPLANKTON DATA　　　*WATER Environmental Services, Inc.*

STATION: Boundary Pt.　　NOTE: Zoop net diam 20cm

DATE: 25 Jul 94

Taxon	Ave lngth male(mm)	Ave lngth fem (mm)	#/m3	Est.Dry wt ug/male	Est.Dry wt ug/fem	ug/m3
PHYLUM ARTHROPODA						
Subphylum Crustacea						
Subclass Copepoda						
Order Calanoida						
Copepodid		0.6-0.7	4,459	0	2.5	11,146
Leptodiaptomus ashlandi	1.16	1.33	2,497	6	10	20,688
Epischura nevadensis	2.10	2.31	178	20	30	5,350
Order Cyclopoida						
Copepodid		0.6-0.7	357	0	2	713
Diacyclops bicuspidatus thomasi	1.00	1.12	713	3	5	3,567
Nauplii (cal+cyc)		<.3	7,134	0	0.25	1,783
Class Branchiopoda(cladocerans)						
Daphnia (juv)		<1.0	1,783	0	5	8,917
Daphnia sp. (tall gal mend?)		2.45	892	8	50	44,586
Diaphanosoma sp.		1.50	1,783	0	17	30,318
Diaphanosoma sp. (small)		1.00	2,854	0	5	14,268
Leptodora kindtii		7.0-10.0	18	0	75	1,338
Class Insecta						
Order Diptera						
PHYLUM ROTIFERA						
Type 1 (mostly loricated malleates)						
Kellicottia longispina		0.21	1,783	0	0.02	36
Type 2 (mostly illoricate virgates/incudates)						
Ascomorpha sp.		0.12	3,567	0	0.023	82
Polyarthra sp. (small)		0.10	1,783	0	0.03	54
Synchaeta sp.		0.21	1,783	0	0.075	134
Synchaeta sp. (small)		0.10	1,783	0	0.02	36
Type 3 (mostly malleoramates)						
Collotheca sp.		0.19	23,185	0	0.01	232
Others						

	Total Density #/m3	Total Density #/L	Total Dry Wt. Biomass ug/m3	Total Dry Wt. Biomass ug/L
	56,553	56.55	143,248	143.25
% Calanoid Copepods	12.61		25.96	
% Cyclopoid Copepods	1.89		2.99	
% Nauplii	12.61		1.25	
% Cladocerans	12.96		69.41	
% Rotifers	59.92		0.40	
% Dipterans	0.00		0.00	

Number of species 12

LAKE OSOYOOS ZOOPLANKTON DATA — *WATER Environmental Services, Inc.*

STATION: Boundary Pt. NOTE: Zoop net diam 20cm

DATE: 30 Aug 94

Taxon	Ave lngth male(mm)	Ave lngth fem (mm)	#/m3	Est.Dry wt ug/male	Est.Dry wt ug/fem	ug/m3
PHYLUM ARTHROPODA						
Subphylum Crustacea						
Subclass Copepoda						
Order Calanoida						
Copepodid		0.6-0.7	1,892	0	2.5	4,729
Leptodiaptomus ashlandi	1.16	1.33	3,182	6	10	24,248
Epischura nevadensis	2.10	2.31	344	20	30	7,739
Order Cyclopoida						
Copepodid		0.6-0.7	516	0	2	1,032
Diacyclops bicuspidatus thomasi	1.00	1.12	258	3	5	1,290
Nauplii (cal+cyc)		<.3	18,057	0	0.25	4,514
Class Branchiopoda(cladocerans)						
Daphnia sp. (tall gal mend?)		1.89	172	8	33	5,675
Diaphanosoma sp.		1.75	1,118	0	24	26,828
Diaphanosoma sp. (small)		1.40	2,064	0	14	28,892
Class Insecta						
Order Diptera						
PHYLUM ROTIFERA						
Type 1 (mostly loricated malleates)						
Kellicottia longispina		0.21	860	0	0.02	17
Type 2 (mostly illoricate virgates/incudates)						
Polyarthra sp. (small)		0.10	6,879	0	0.03	206
Polyarthra sp.		0.14	860	0	0.06	52
Trichocerca sp. B		0.08	1,720	0	0.006	10
Type 3 (mostly malleoramates)						
Collotheca sp.		0.19	6,019	0	0.01	60
Conochilus sp.		0.15	26,656	0	0.025	666
Conochilus sp. (small)		0.10	4,299	0	0.01	43
Others						

	Total Density #/m3	Total Density #/L	Total Dry Wt. Biomass ug/m3	Total Dry Wt. Biomass ug/L
	74,895	74.89	106,003	106.00
% Calanoid Copepods	7.23		34.64	
% Cyclopoid Copepods	1.03		2.19	
% Nauplii	24.11		4.26	
% Cladocerans	4.48		57.92	
% Rotifers	63.15		1.00	
% Dipterans	0.00		0.00	

Number of species 11

LAKE OSOYOOS ZOOPLANKTON DATA — *WATER Environmental Services, Inc.*

STATION: Boundary Pt. NOTE: Zoop net diam 20cm

DATE: 29 Sep 94

Taxon	Ave lngth male(mm)	Ave lngth fem (mm)	#/m3	Est.Dry wt ug/male	Est.Dry wt ug/fem	ug/m3
PHYLUM ARTHROPODA						
Subphylum Crustacea						
Subclass Copepoda						
Order Calanoida						
Copepodid		0.6-0.7	8,805	0	2.5	22,013
Leptodiaptomus ashlandi	1.16	1.26	8,071	6	9.5	62,874
Epischura nevadensis	2.10	2.31	92	20	30	1,834
Order Cyclopoida						
Copepodid		0.6-0.7	1,101	0	2	2,201
Diacyclops bicuspidatus thomasi	1.00	1.12	825	3	5	4,127
Nauplii (cal+cyc)		<.3	24,764	0	0.25	6,191
Class Branchiopoda(cladocerans)						
Diaphanosoma sp.		1.68	367	0	20	7,338
Diaphanosoma sp. (small)		1.40	917	0	14	12,841
Class Insecta						
Order Diptera						
PHYLUM ROTIFERA						
Type 1 (mostly loricated malleates)						
Kellicottia longispina		0.21	1,834	0	0.02	37
Keratella quadrata		0.18	917	0	0.069	63
Type 2 (mostly illoricate virgates/incudates)						
Polyarthra sp. (small)		0.08	7,338	0	0.015	110
Polyarthra sp.		0.10	917	0	0.03	28
Trichocerca cylindrica		0.32	917	0	0.05	46
Type 3 (mostly malleoramates)						
Collotheca sp. (small)		0.12	3,669	0	0.005	18
Others						

	Total Density #/m3	Total Density #/L	Total Dry Wt. Biomass ug/m3	Total Dry Wt. Biomass ug/L
	60,535	60.54	119,721	119.72
% Calanoid Copepods	28.03		72.44	
% Cyclopoid Copepods	3.18		5.29	
% Nauplii	40.91		5.17	
% Cladocerans	2.12		16.85	
% Rotifers	25.76		0.25	
% Dipterans	0.00		0.00	

Number of species 9

Appendix Table 5. Density and biovolume of phytoplankton by percent from monthly collections in surface waters (1, 3 and 6 m) of the south basin of Lake Osoyoos at Boundary Point during 1994.

DENSITY	April	May	June	July	August	Sept.
(by percent)	--------	--------	--------	--------	--------	--------
Cyanophyta	67.48	91.97	63.95	93.14	91.63	94.27
(blue-greens)						
Chlorophyta	2.44	0.51	1.42	0.74	4.71	4.45
(greens)						
Chrysophyta	30.03	7.13	33.64	5.53	3.47	0.64
(diatoms/browns)						
Cryptophyta		0.36	0.87	0.58	0.19	0.58
(small flagellates)						
Euglenophyta						0.03
(Euglena sp.)						
Pyrrhophyta	0.04	0.02	0.12	0.02		0.03
(dinoflagellates)						
BIOVOLUME	April	May	June	July	August	Sept.
(by percent)						
Cyanophyta	11.14	45.27	11.90	47.89	59.82	79.60
(blue-greens)						
Chlorophyta	1.75	0.57	7.72	5.74	32.82	16.95
(greens)						
Chrysophyta	83.40	47.92	59.22	40.66	6.78	1.15
(diatoms/browns)						
Cryptophyta		2.04	6.09	5.46	0.58	1.72
(small flagellates)						
Euglenophyta						0.47
(Euglena sp.)						
Pyrrhophyta	3.71	4.20	15.07	0.25		0.10
(dinoflagellates)						

Appendix Table 6. Density and biovolume of zooplankton by percent from monthly collections in surface tows (5 m to surface) of the south basin of Lake Osoyoos at Boundary Point during 1994.

DENSITY by percent	May	June	July	August	Sept.
Calanoid Copepods	4.69	3.07	12.61	7.23	28.03
Cyclopoid Copepods	4.91	2.73	1.89	1.03	3.18
Nauplii	15.63	5.96	12.61	24.11	40.91
Cladocerans	5.58	1.36	12.96	4.48	2.12
Rotifers	69.20	86.88	59.92	63.15	25.76
BIOVOLUME by percent	May	June	July	August	Sept.
Calanoid Copepods	25.76	33.01	25.96	34.64	72.44
Cyclopoid Copepods	14.73	11.08	2.99	2.19	5.29
Nauplii	3.80	2.02	1.25	4.26	5.17
Cladocerans	53.24	51.71	69.41	57.92	16.85
Rotifers	2.48	2.18	0.40	1.00	0.25

Appendix Table 7. Density of zooplankton from monthly collections in surface tows (5 m to surface) of the south basin of Lake Osoyoos at Boundary Point during 1994.

DENSITY (number per m3)	May	June	July	August	Sept.
Calanoid Copepods	7,625	6,420	7,134	5,418	16,968
Cyclopoid Copepods	7,987	5,707	1,070	774	1,926
Nauplii	25,414	12,484	7,134	18,057	24,764
Cladocerans	9,076	2,854	7,330	3,354	1,284
Rotifers	112,547	182,274	33,884	47,293	15,592
Total w/ Rotifers	162,649	209,739	56,552	74,896	60,534
Total w/o Rotifers	50,102	27,465	22,668	27,603	44,942

Appendix Table 8. Density of zooplankton in 1972 and 1973 from prior study of the the south basin of Lake Osoyoos at Boundary Point by Allen and Meekin (1980).

DENSITY no./m^3,	May	June	July	Aug.	Sept.
1972*					
All zooplankton except rotifers: south basin, 2 m	12,529	20,272	23,064	5,423	
All zooplankton except rotifers: north basin, 2 m		26,770	12,169	6,997	1,134
1973*					
All zooplankton except rotifers: south basin, 2 m	106,932	86,667	20,759		45,385
All zooplankton except rotifers: north basin: 2 m	194,272	340,000	40,910	48,148	9,195
Average of 1972-73 south basin	59,731	53,470	21,912	2,712	22,693
Average of 1972-73 north basin	194,272	366,770	53,079	55,145	9,195

Appendix 9.

Fish Cultural Data: Lake Osoyoos Net pens 1994, transcribed from Colville Tribe Daily records

Date	Water Temp. (°C)	Dissolved Oxygen (mg/L)	Secchi Disk (m)	Feedings per day	Feed Use (lbs.)	Morts (number)	Comments
----------	----------	----------	----------	----------	----------	----------	----------
April 14	9.2	13.2		4	5	0	
15	9.2	13.2		4	5	0	
16	10.5	10.5		4	4.5	0	possible error in water temp./DO
17	13.6	9.7		4	4.5		possible error in water temp.
18	11.4	11.4	2	7	4	0	
19	13.8	9.5	3.75	8	5	0	
20	12.1	11.6	3	8	5	0	
21	12.4	10.6	2.25	3	4.5	0	Thundershowers, missed one feeding
22	12.7	10.5	2.75	4	6		
23	12.8	8	3.5	4	6		
24	13.2	10.7	3	4	6		
25	12.3	10.7	2.75	6	6	1	50 fish sampled for size
26	13.1		2.75	4	6		60 fish sampled for John (Morrison?)
27	12.9		2	4	6		
28	13.6		2.5	4	6	0	
29	13.1		2	4	6	1	
30	12.2		2.5	4	6		
May 1	13.3		3	4	6	1	Other depths had less temp.
2	14.1	10.2	3.75	3	6		
3	14	10.2	2.75	2	6	3	
4							50 fish sampled, clipped upper caudal fin
5	14.1	10.6	2.75	4	6	4	now at 92/#
6	15.4	10.2	2.75	4	6	2	
7	15.1	10.5	2.75	4	8	0	
8	15.8	10.6	2.75	4	8		
9	16.9	9.72	3	3	8	10	("old morts"), water temp. 13.4 C @20'
10	17.6	9.9	2.75	2	6	2	No feed in PM, sample tommorow
11							No feeding, viral and size sample
12	17.6	9.82	2.75	4	6	.	fish feeding slow today
13	18	10.2	2.75	4	6		
14				2	6		Only PM feeding, working Twin Lakes in AM
15	16.2		2.75	4	6	3	
16	15.9	9.2	3	0	0	20	Rensel sampled gut contents of 6 fish
17	15.7			0	0	20	Fish subsampled, pens towed to 20' deep near river
							and fish released at 0930
Sum					**175.5**	**67**	
Average	**13.8**	**10.5**	**2.8**	**3.9**	**5.5**		
Range	**9.2 - 17.6**	**8 - 13.2**	**2 - 3.75**	**0 - 6**	**4.5 - 8**		

Fish size at start (g) =	2.3	Fish population at start =	12500	Total biomas	28.7	kg @ sta
Fish size at end (g) =	6.25	Fish population at end =	12433	Total biomas	77.7	kg @ en
feed use to May 11 (kg	68.7	Increase in biomass (kg) :	49.0			
		Percent mortality =	0.5			
		Feed conversion ratio =	1.4	lbs. feed (10% moisture) to wet fish flesh, only to 5/11/94		
Initial stocking density (kg/m3) =	0.238	0.015	lbs./cu.ft.			
final stocking density (kg/m3) =	0.642	0.040	lbs./cu.ft.	Wells Agreement calls for < 0.33 lbs.\cu.ft.,		
				we had planned not to exceed 0.24 lbs./cu.ft.		

Appendix 10. Sediment total organic carbon data

MISCSAV1.XLS

AQUATIC RESEARCH INCORPORATED

LABORATORY & CONSULTING SERVICES

3927 AURORA AVENUE NORTH, SEATTLE, WA 98103

PHONE: (206) 632-2715 FAX: (206) 632-2417

CASE FILE NUMBER:	RA001-03	PAGE 1	
REPORT DATE:	05/23/94		
DATE SAMPLED:	05/16/94	DATE RECEIVED:	05/17/94

FINAL REPORT, LABORATORY ANALYSIS OF SELECTED PARAMETERS ON WATER SAMPLES FROM JACK RENSEL / LAKE OSOYOOS

CASE NARRATIVE

Three sediment samples were received by the laboratory in good condition. The samples were analyzed according to the chain-of-custody. No difficulties were encountered in the preparation or analysis of these samples. Sample data follows while QA/QC data is contained on subsequent pages.

SAMPLE DATA - DRY WEIGHT BASIS

SAMPLE ID	%SOLIDS	TOC (mg/kg)
#1 CORE (PENS)	19.11%	40,318
#2 CORE (PENS)	17.54%	38,973
3 CORE REFERENCE	18.04%	44,751

AQUATIC RESEARCH INCORPORATED
LABORATORY & CONSULTING SERVICES
3927 AURORA AVENUE NORTH, SEATTLE, WA 98103
PHONE: (206) 632-2715 FAX: (206) 632-2417

CASE FILE NUMBER: RA001-03 **PAGE 2**
REPORT DATE: 05/23/94
DATE SAMPLED: 05/16/94 **DATE RECEIVED:** 05/17/94
FINAL REPORT, LABORATORY ANALYSIS OF SELECTED PARAMETERS ON WATER SAMPLES FROM JACK RENSEL / LAKE OSOYOOS

QA/QC DATA

QC PARAMETER	% SOLIDS	TOC (mg/kg)
METHOD	EPA 160.3	EPA 415.1
DATE ANALYZED	05/18/94	05/19/94
DETECTION LIMIT	0.50%	150
DUPLICATE		
SAMPLE ID	CORE 3	CORE 3
ORIGINAL	18.04%	44,751
DUPLICATE	19.22%	48,475
RPD	6.33%	7.99%
SPIKE SAMPLE		
SAMPLE ID		CORE 3
ORIGINAL		44,751
SPIKED SAMPLE		96,320
SPIKE ADDED		60,000
% RECOVERY	NA	85.95%
QC CHECK		
FOUND		9818
TRUE		9960
% RECOVERY	NA	98.57%
BLANK	NA	<150

RPD = RELATIVE PERCENT DIFFERENCE.
NA = NOT APPLICABLE OR NOT AVAILABLE.
NC = NOT CALCULABLE DUE TO ONE OR MORE VALUES BEING BELOW THE DETECTION LIMIT.
OR = RECOVERY NOT CALCULABLE DUE TO SPIKE SAMPLE OUT OF RANGE OR SPIKE TO LOW RELATIVE TO SAMPLE CONCENTRATION.

SUBMITTED BY:

Steven Lazoff
Laboratory Director

MINUTES OF THE WELLS COORDINATING COMMITTEE

1994

APPENDIX - M

WELLS PROJECT COORDINATING COMMITTEE
MEETING JANUARY 27, 1994
SUMMARY[1]

Agreements Reached

1. The committee will rank the three proposals received on the study of sockeye fry emergence in the Okanogan River in 1994 and notify Rick Klinge of their rankings by noon on Monday January 31, 1994. He will average the ranks to arrive at the committee recommendation. The P.U.D. will choose among the three.

2. The committee will meet by telephone conference call at 3:00 P.M. Thursday February 3, 1994 to decide whether or not to proceed with the study of adult salmon behavior in response to the Methow River weirs, using radiotelemetry.

3. The committee recommended that Douglas County P.U.D. extend the deadline for the final report from CRITFC on the evaluation of effectiveness of using video cameras to estimate the passage of adult sockeye at Zosel Dam, so that the results can be interpreted in light of the findings of Biosonics with respect to the hydroacoustic evaluation.

I. Status of Studies

A. 1992 Sockeye Telemetry Study. Klinge reported that NMFS informed him the report should be available soon.

B. Sockeye Fry Emergence. Klinge reported that Douglas P.U.D. had received three responses to the request for proposals to study sockeye fry emergence in the Okanogan River, from Parametrix, Inc., from B.C. Environment, and from the Okanogan Indian Band. He asked for input from the committee. He distributed copies of the proposals and a summary table comparing them. The summary table did not identify by name those entities that responded, but labeled them "A", "B", and "C". He said they all look at timing of emergence, and are therefore responsive to the RFP. The sampling methods differ among the three. Rod Woodin observed that none of them seem to use the best technology for determining the starting date for sampling. Knowing the starting date for spawning, it should be possible to calculate the hatching date from temperature units. Hevlin thought that the hydraulic sampling proposed in "B" was not necessary or desirable. After a discussion, it was decided that those members with additional comments should communicate them to Klinge by noon on Monday, January 31, 1994. Members were asked to rank the proposals in order of preference. Klinge will average the ranks to develop a recommendation of the committee. Douglas P.U.D. will choose among the three. It was suggested that the chosen proposal might include a step that is unnacceptable, and that Douglas P.U.D. could deal with that during the contract negotiations. Scribner observed that there would be some advantages, beyond the technical, to having the work performed by B.C. Environment.

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1. Prepared by R. Whitney

C. Radiotelemetry Study of Methow River Weirs. Klinge reported there were two proposals received, one from the Yakima Tribe, and one from mid-Columbia River Consultants. Tom Scribner explained that the Yakama Tribe has expertise in handling the adults and applying the tags. They did it for Lowell Stuehrenberg. Joel Hunt would be added to the staff for the data analysis. He is experienced in that work. Heinith asked what happens if the study reveals a problem with the weir? Klinge responded that there might be several things that could be done, such as removal of a panel in the weir to allow a portion of the run to pass unimpeded. It would be possible to experiment with various modifications to explore for a solution. Woodin said that WDFW is interested in the study, but feels that 1994 might not be the best year for it, considering the low predicted run sizes. Perhaps it would be possible to set a threshold level on the run size to decide whether to proceed or not. Scribner agreed, and suggested that whoever gets the contract should be able to adjust their plans accordingly. Klinge felt that there was a risk associated with buying perhaps 200 tags and not using them. The batteries deteriorate on the shelf. He would like a decision from the committee that they plan to go forward, before he gives the go-ahead for tag purchase. He will need to discuss this with his people. He will need a decision by next Thursday, February 3. Woodin said he would do his best to get a decision from his agency by then. Hevlin expressed an interest in keeping the numbers of tagged fish to around 100 in any case. The committee agreed to meet by telephone conference call on Thursday, February 3, 1994 to decide whether to proceed with the radiotelemetry study in 1994.

D. Project Mortality. Klinge referred to the Skalski analysis of the numbers of tagged fish that would be required for determining project mortality with given levels of precision. At the last meeting there was a discussion of which species would be best to use. He suggested fall chinook or sockeye. Scribner said that it would take a lot of convincing to persuade him that a study should be done in 1994. It might not be needed at all. Heinith agreed. Hevlin needs to talk to his people.

E. Okanogan Spawning Survey. Klinge had distributed to the committee a draft RFP for this study. Heinith had commented that he thought it needed to include lakeshore spawning. Klinge has been unable to verify that there is lakeshore spawning. He wants to look into it further. He expects to put out the RFP in May or June, which gives plenty of time to develop it further.

F. Current Studies. Klinge referred to a letter he received from Bob Heinith in which Heinith expressed his concern about Douglas P.U.D.'s failure to require contractor's to adhere to schedules for delivery of reports. Klinge provided a status report for studies now underway. The status of the study of sockeye movements using radiotelemetry is well known to all of us. The report was due at the end of 1993. However, the study was expanded to the area above Wells Dam, at the recommendation of the committee, which required more data analysis and time on the part of the contractor. Also, at the end of 1993, the contractor was asked to develop a proposal for a study of chinook in the entire mid-Columbia reach. The contractor asked for permission to extend his deadline in order to be able to spend his time preparing that proposal. Douglas P.U.D. agreed to that, and asked him to provide the report as soon as possible. Klinge expects to receive it next month. The predator indexing study has remained on schedule throughout the year. The contract calls for a draft report to be submitted in February, 1994. He is expecting to hear from Craig Burley with suggestions for follow-up studies in the mid-Columbia. The CRITFC draft report on evaluation of video technology for estimating passage of adult sockeye at Zosel Dam was received on time. Parametrix, Inc. provided a draft report of their spawning ground survey, which was on time. Biosonics report on the hydroacoustic estimation of sockeye passage at Zosel Dam has been delayed because of techical difficulties. There was an electronic failure in the data processing step, so that it has become necessary to bit-pad the data by hand. Biosonics notified him of the problem and he approved an extension of time for preparation of their report. Heinith said this latter has created a problem because it would be desirable to integrate that study with the CRITFC video study at Zosel Dam. All agreed that it would be desirable to do so. The chair suggested that the committee recommend to Douglas P.U.D. that they extend the deadline for finalization of the CRITFC report so that the authors could have the benefit of studying the Biosonics report, as well as vice versa. The committee agreed. Klinge said he would send a letter to CRITFC, extending their deadline.

2. **Hatchery Update.**

A. **Methow Supplementation Facility.** Rod Woodin distributed copies of a report from Heather Bartlett on the operations associated with the Methow facility.

B. **Cassimer Bar Sockeye Facility.** Jerry Marco referred to the draft evaluation plan that Klinge had distributed at the last meeting, at which time Klinge asked that comments be forwarded to Marco. Jerry said he will revise the plan, according to suggestions received, and will distribute it before the next meeting. They would like to do some smolt trapping below the Similkameen. They will release some marked fish above the trap to estimate its efficiency. They will also ask Paul Wagner at McNary to look for marks. The fish are doing well. The U.S. Fish and Wildlife Service will do another viral test in the near future. Klinge said the net pens are ordered. Everything is on schedule for that phase.

3. **Okanogan Sockeye Plan.** Klinge and Feldman had prepared a revised draft of the plan. Feldman expressed his continuing concern that the Wells Committee seems to be adopting these sockeye, when in fact there are numerous other entities that have jurisdiction over them. For example, it is a transboundary stock, as defined in the convention between the U.S. and Canada for management of salmon. He is concerned about how to incorporate other entities with jurisdiction into the plan. In response, other members agreed with the point, but suggested somebody needs to start somewhere with an overall plan that will provide a logical basis for any management that is undertaken. We should just do the best we can with whatever authority we can muster.

4. **Other.**

A. **Bob Heinith Letter of January 14, 1994 to Klinge.** The specific points raised in the letter are discussed above. In addition, Klinge raised the point that Heinith sent a copy of his letter to FERC, which Klinge felt was contrary to the understanding he thought had been developed at the October meeting, that such issues would be dealt with in the committee rather than drawing FERC into the matter. There was a discussion of the current role of FERC with respect to the committee, since the lawsuit over Wells Dam in the mid-Columbia Proceeding has been settled. And there was a discussion about the proper modes of communication with FERC. Committee members have not received instructions on this subject. Heinith will discuss it with his people. Klinge reminded the committee that when FERC becomes involved, the matter is out of his hands. Cary Feldman pointed out that regardless of what is proper or not proper, it would seem to be wise to withhold firing big guns until there is a truly big issue, worth going to war over.

B. Next meeting. The committee agreed to meet again on March 3, 1994 at Sea-Tac in conjunction with the meeting of the mid-Columbia Coordinating Committee.

WELLS PROJECT COORDINATING COMMITTEE
MEETING FEBRUARY 3, 1994
SUMMARY[1]

Agreements Reached

1. The committee agreed that, if certain conditions are met, a study of adult movements around the Chewack trap should be conducted in 1994. The conditions relate to minimizing the potential impact on the total run. A protocol was agreed to that is intended to minimize the impact.

2. The committee ranked the proposals received for the study. The proposal identified as "Proposal X" was ranked number 1 by four of the six representatives participating.

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The meeting was held by telephone conference call at 3:00 P.M. February 3, 1994, as agreed at the January meeting of the Wells Project Coordinating Committee. Participating were Rick Klinge, Douglas P.U.D.; Rod Woodin, WDF; Bill Hevlin, NMFS; Jerry Marco, Colville Confederated Tribes; Bob Bugert, WDF; Bob Heinith, CRITFC; Tom Scribner, Yakama Indian Nation; and Richard Whitney, Chair. The purpose of the meeting was to make a decision as to whether or not to proceed in 1994 with a study, using radiotelemetry, of adult chinook movements near the weirs on the Chewack and Twisp rivers. The concern was that early forecasts of run size indicated that few adults might be returning, and that as a result, the study might require use of a high proportion of those fish that would be present.

1. **Radiotelemetry Study.** Rod Woodin asked Klinge how many adults would need to be tagged. Klinge had talked to people at the University of Idaho. They felt that 120 total tagged might be sufficient to give 30 recoveries at each weir, and that would be enough for a minimum. Hevlin asked about the escapement last year. Scribner thought that would have no bearing on the decision. More important is the prediction for low numbers returning this year. The prediction is based on returns of jacks last year, and the relationship is not a strong one. But there has been no change in the prediction since the one the committee reviewed at the last meeting. Woodin reported that the 1993 spawning ground survey indicated that of the fish passing above Wells Dam, 37% ended up in the Methow, 26% in the Chewack and 26% in the Twisp. If 120 adults are marked at Wells Dam, that would probably give 30 or more returns at each of the sites of interest.

Hevlin observed that Meekin found that of 2400 fish at Wells Dam, 1500 were available for spawning. A little more than one-third were hatchery fish. Woodin noted that the tribal report says that 35% of the spawners checked were hatchery fish, which agrees with that observation. This means that probably one-third of the fish taken in the Wells trap would be rejected and not tagged. Scribner suggested that the Yakamas could read scales of fish at the Wells Dam trap to avoid marking hatchery fish. There was a discussion about how to hold the fish for recovery after anesthetiz-

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1. Prepared by R. Whitney

ing and marking them. The question was raised, why not mark hatchery fish? The response was that wild fish are the target population in those going to the Chewack or Twisp rivers. Woodin said that avoiding hatchery fish would avoid having marked fish return to the Winthrop Hatchery where they would not provide us with the desired information. He expressed a concern about any study that would require marking more than 10% of the natural population. Klinge observed that would require a run size of 1200 fish in order to be able to mark 120 fish. Woodin suggested that the study might proceed in two ways. If early indications are for a low run, then the study could be stopped. Or, perhaps more practical would be to mark 10% of the fish each week, since the final run size might not be known until late. He said that the projection is for 4900 fish at Bonneville Dam. Larry LaVoy has data from the Wenatchee River fish showing a strong component of age 5 fish, which is not a good sign under the circumstances. Scribner said he thinks the situation is the same for fish out of the Methow. LaVoy thinks the run might only be in the neighborhood of 6-800 fish at Wells, and not the 1200 desired.

Klinge said he liked the idea of proceeding with marking 10% of the fish per week, with the understanding the total marked would not exceed 120 fish. He suggested they operate the trap at Wells only three days per week. Woodin specified limits of 10% of the count at Wells or 120 fish, whichever is least. There was a discussion about potential effects on brood stock collection. Bugert raised the question whether this study should be tied to the Chiwawa River study by Chelan P.U.D. Scribner advised that they should not be tied together. Klinge said he would talk to Dick Nason of Chelan P.U.D. There was a discussion of whether the results of study at one of the weirs could be applied to the others. There was no clear answer. Scribner thought it would be of benefit to do studies at both sites. Hevlin said he was more concerned about the effects of the study on the run in the Chewawa than in the Methow (Twisp). He suggested putting off the Chewawa study and concentrate on the Twisp. There was a discussion of this suggestion and of which site to choose, if there be only one. Jerry asked what corrective measures could be taken if problems in passage are observed in the study. Klinge said that at the Twisp they could remove panels in the weir, if the trap appears to block fish. It would be more difficult to react at the Chewack. There is not much that could be done on the spot. It was noted that marked fish would not have to be handled at the weir. The antennae could be touched and the record would be made instantly. The fish would then be allowed to pass upriver, hopefully to spawn. The only risk is that marked fish might somehow be adversely affected in their ability to spawn. It was decided that, since the fish will have to be marked at Wells Dam, and there is no way of separating those destined for the Chewack from those headed for the Twisp, studies at both sites might as well proceed.

There was a discussion of whether it might be possible to proceed on the basis of counts in the lower river, perhaps at Priest Rapids. Scribner felt that there would not be a good relationship between the counts there and counts at Wells, particularly since fish turn into other tributaries on the way. Rocky Reach counts were suggested as guidelines. Klinge felt that those counts would not give them enough time to react. Travel time from Rocky Reach to Wells Dam is only about 1 day.

The committee agreed on the following conditions to be applied in proceeding with the study:

1. There will be a count of wild fish taken in the Wells trap. This will provide an estimate of the percentage of wild fish in the run on a weekly basis.

2. Marks will be applied to 10% of the wild run, weekly. Wild fish will be identified by their scale patterns. Marking will be done 3 days per week.

3. The maximum number to be marked will be 120 fish.

2. Review of Proposals Received. Klinge had distributed copies of proposals received in response to the RFP. He had removed the headings that identified the names of the contractors submitting the proposals and had substituted letters of the alphabet. The committee was asked to rank the proposals in order of technical merit. The Chair reminded the committee members that the rankings were advisory to Douglas P.U.D. That the P.U.D. had indicated a willingness to select among the top three ranked by the committee. Hevlin said he felt the best proposal was the one labeled X by Klinge. Woodin also felt X was best. It indicated a better udnerstanding of the problem. Jerry Marco agreed that X looked best to him, although Y included good quality control. Klinge also liked X. Heinith suggested there be a contingency plan developed prior to beginning the marking.

WELLS PROJECT COORDINATING COMMITTEE
MEETING MARCH 3, 1994
SUMMARY[1]

Agreements Reached

1. The committee adopted the bypass operating plan for Wells Dam.
2. Designated representatives for bypass operation will be Rick Klinge, Brian Cates and Jerry Marco.
3. The minutes of the previous meetings were approved.
4. The members developed a gentlemen's agreement that they would attempt to resolve differences and problems within the committee before outside entities are brought into the issue.

The Wells Project Coordinating Committee met at 9:00 A.M. March 3, 1994 at the West Coast Sea-Tac Hotel in Seattle in conjunction with the meeting of the mid-Columbia Coordinating Committee. The agenda followed was mailed to the full mailing list prior to the meeting. Those in attendance are listed on the attached roster.

1. **Status of Studies**

A. **Okanogan Sockeye Fry Emergence Study.** Rick Klinge reported that the P.U.D. had selected B.C. Environment to conduct the study, based on the average rankings of the proposals by the committee. Sampling is scheduled to start next week with fyke nets. Heinith expressed a concern about the sampling locations. He felt there was a need to sample in the river oxbows, Hevlin pointed out that those are screened, and there is also a return to the river at the lower end of each oxbow. Heinith was interested in the irrigation take-offs. Hevlin observed that to identify all of the irrigation take-offs would require a separate study. Heinith expressed concern about timing of emergence of fry in the different segments of the spawning area. Woodin observed that the total spawning area is too short to expect a difference in time of emergence that would be caused by differences in temperature units. Emergence time will be determined by time of deposition. Hevlin further observed that the irrigation diversions are not watered up until May 1. Scribner wondered whether Shepherd could look at the oxbows. Klinge said he would talk to Shepherd.

Klinge wondered whether CRITFC had been in contact with the Canadian Dept. of Fisheries and Oceans regarding concerns about what is being done with the Okanogan sockeye. Heinith said that he had not talked to Sandy Argue of DFO, but he felt that the subject might have come up in the context of this being a transboundary stock that should be included in the U.S./Canada treaty considerations. Klinge said the Jim Hefernin had talked to Sandy and raised the question whether it was appropriate for the Canadian DFO to conduct the study, given the transboundary status of the stock. Heinith was not aware of that. Woodin observed that transboundary stocks are an issue. However, the Okanogan stocks are so small that Washington Department of Fisheries and Wildlife people did not think that the stock

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1. Prepared by R. Whitney

would ever be significant enough to belong in those transboundary discussions. Hevlin suggested that Klinge inform the Canadians that we have no control over what CRITFC does.

B. Spring 1994 Radiotelemetry Studies in the Methow River. Klinge reported that the tags have been purchased for the study. They have met with people from the University of Idaho. They will have equipment in the field by the end of the month. Hevlin asked that the protocol be put down on paper. The study plan should show where the receivers will be located. Scribner said he would get together with Steve Hays of Chelan to desing an antenna layout. Hevlin reported that Steve Hays will set up a workshop on handling and tagging. Scribner said the Yakama Tribe will be there.

C. Decision on Project Mortality Study in 1995. Klinge said that it probably would not be feasible to conduct the project mortality study in 1995. The members reviewed Chelan P.U.D.'s proposal for survial studies to include Rocky Reach and Rock Island. Woodin observed that it is hard to visualize how it would be possible to obtain enough fish for the study. There followed a discussion of the numbers of fish required, based on the Skalski analysis. Location(s) of release were also discussed, along with the species and stock of fish to be used. Woodin noted that the fish would have to be transported to the release sites, and this introduces a possible confounding effect on survival. Wells Hatchery is probably the appropriate place to raise the experimental group(s). Scribner brought up a number of biological questions, such as "Should the study consider the numbers of fish actually returning to different areas?; Are we interested in both spring and summer chinook?; Should zero-age fish be included as well as yearlings?". There was a discussion of whether the study was necessary or desirable. Klinge said that at this time, there is interest in Douglas P.U.D. in knowing what the project mortality is. The committee does need to hammer out the details of how to go about measuring it. Woodin brought up a concern about the consequenses of the release of the spring chinook below Wells Dam. Scribner felt that if those fish can be identified when they return they could be hauled to the Winthrop for use as brood stock there, that would deal with any potential problem. However, he would be concerned about those not captured or identified. There are still some possible risks. He will talk to Bruce Watson to see if he can put something on paper that would address that situation. Klinge said he would talk to Dick Nason bout possible interest in combining the project mortality studies.

2. Hatchery Update

A. Methow Supplementation Facility.

(1) **Production.** Klinge reported that they will be watering up the acclimation pond on the Chewack. They are going to put the fish in a quasi-natural setting with Christmas trees in the raceways. They will use video to observe their behavior. The fish at the Twisp facility will not be treated this way. He distributed reports from the hatcheries.

(2) **Evaluation Plan.** Scribner reviewed a meeting he arranged with Jim Spotts, who is Regional Biologist with the U.S. Forest Service. Also in attendance were Sandy Noble, Joel Hubbell, Bob Bugert. Spotts became agitated when he learned that hatchery fish had been used as brood stock for the "natural" stock in the Methow River. The group informed him that this had been done in the past, but that it would not happen again. Each fish will be examined to determine its origin. Woodin agreed that this is an issue with which we w ill have to deal. Scribner noted that 35-40% of

the spawners are probably of hatchery origin, but this would be hard to prove. Woodin said that Bugert's protocol will call for taking fish identified as being of hatchery origin to the Winthrop National Fish hatchery.

Klinge said that he is working on the Annual Evaluation Plan. A draft has been ready for nearly a year now. There was a meeting in February to determine what part we could agree to at this point in time and to put other issues off to be dealt with later. Mike Erho had concerns about that process. They are now talking about a preamble to the document, to set the stage as it were for the direction in which the plan is to go. Bugert and Erho are working on it. Doulgas wants to keep the hatchery program on track as a supplementation facility. Hevlin suggested that we need to raise the priority of this effort. He wondered how the work could be expedited. Could the Chair assist? Klinge had no objection to the Chair getting involved. The Chair was asked to follow up on this and in particular to obtain agreement on a schedule for completion of the plan. Woodin emphasized the need for a plan as a justification for continuing the evaluation studies we are doing and the positions of the people responsible for doing the work.

(3) **Suggestion to Pit-Tag at the Chewack Smolt Trap.** Hevlin suggested that spring chinook smolts taken in the trap at the Chewack should be pit-tagged, since they are being handled anyway. He is interested in developing information on travel time of wild fish, which is lacking. Scribner noted that they do not anethetize fish that are counted from the trap. He would be concerned about the additional handling required for tagging. A discussion of the numbers required for expected recovery of a reasonable number at McNary Dam would be about 1500 fish. Woodin struggled with the question whether the information would be worthwhile. Heinith felt the same way. Woodin observed that those Chewack fish are scattered among fish that are closely monitored. Marked hatchery fish give information on time of arrival at McNary, so the additional information would not be useful in management decisions. Hevlin is concerned about early migrating fish in the mid-Columbia. This would be a chance to verify their arrival at McNary. It might help us argue with BPA for April water releases in the mid-Columbia. Scribner raised the question about what percentage of the run or of the sample Hevlin would like to see marked? Hevlin said he would have to think more about that. He would not like to see a high percentage marked. Perhaps there are not enough available to provide a reasonable sample with a restriction that only a small percentage of the run should be marked. Woodin repeated his feeling that for management decisions, we should continue to key in on the presence of fish regardless of their origin.

B. Cassimer Bar Sockeye Facility.

(1) **1993 Brood and Operations.** Klinge summarized for Marco, who was unable to stay for the meeting today. The fish were tested for IHN. Those with IHN positive parents are negative. Last week the fish were 1300 per pound. They can double their weight every 10 days.

(2) **Evaluation Plan.** Klinge reminded the committee that Jerry had submitted an evaluation plan. There were suggestions. It has been reviewed and revised. Klinge will mail it out.

(3) **Status of Lake Osoyoos Net Pens.** Klinge reported that at the Shorelines hearing, the Okanogan Board brought Bruce Shepherd of British Columbia into the process, which he thought was not totally appropriate, but there it was. The Board was concerned about possible Canadian objections. Shepherd participated by telephone conference call at the

hearing. The Board then recessed for a week to receive written information from Canada. Based on the input from Canada, the Board approved the permit with 11 conditions that addressed the Canadian concerns. One condition in particular concerns Klinge, and that is that the net pens be moved to the south end of the lake to release the fish. The concern is about the net collapsing on fish as it would be towed through the water. However, on the positive side, the net pens are ordered. They will have them set up by the middle of April with fish in them.

3. Bypass Operating Plan for 1994.

A. Approval of the Plan. Klinge summarized the plan, which is the same as in 1993 except that it calls for earlier monitoring with hydroacoustics. Hydroacoustic monitoring will begin March 27. The baffles will be in place then, ready to begin operating. Scribner said he would forward information from the smolt trap on the Chewack to Klinge for use by the team. The team still decides when to begin bypass operation. The committee approved the Bypass Operating Plan for 1994.

Hevlin wanted to point out that last year he wrote a memo suggesting that the bypass begin operating when the index reached 100. Klinge agreed to begin half-time operation at that point. Hevlin appreciated that because that raised the probability that some bypass would be operating when the first wave of migrants appeared at the project. Secondly, he wanted to offer the opinion that early fyke net sampling is not helpful, because there is no evidence that non-salmonids appear that early. He also feels that the one fyke net does not provide a good representative sample of fish passing through the turbines, because the horizontal distribution of fish is not random. He urged caution in interpreting fyke net catches.

B. Bypass Team for 1994. The designated representatives for the bypass operating team in 1994 will be Brian Cates, Jerry Marco and Rick Klinge. Alternates for Cates and Marco respectively will be Bill Hevlin and Bob Heinith. Klinge agreed to arrange for Biosonics to give a mini-workshop on hydroacoustics for Cates and Marco.

4. Miscellaneous.

A. Okanogan Sockeye Plan. The committee expressed concern that the plan is not yet in place. The Chair was asked to help get it moving again.

B. Finalization of Minutes. The chair observed that he had experienced difficulty in arriving at agreed-upon wording in one portion of the summary of the October 15, 1993 meeting. Therefore, he recorded in the summary his own recollection of what was said, as well as Bob Heinith's recollection. He had discussed this with those directly involved. Since he felt there could be no objection to this proceedure, he declared the summary to be the final version. The summaries of the November and December meetings had already been finalized, because no comments or suggestions (other than strictly editorial corrections) were raised. There being no comments or suggestions on the January meeting summary, it was approved as presented.

C. Other

(1) **DFOP.** Bob Heinith presented a copy of the draft DFOP to Klinge and asked for comments. He said that Larry Basham wants to meet with the three P.U.D.s in Wenatchee sometime during the week of March 21-25. Hevlin explained that Larry had taken information provided by the P.U.D.s and rearranged it into the DFOP. He would appreciate review and approval by the P.U.D.s.

(2) **Interagency Meeting April 28.** Hevlin notified the members that there is an international meeting scheduled in Oroville on April 28 to discuss with the Okanogan Water District water levels for Lake Osoyoos in 1994.

(3) **Sampling of Sockeye at Wells Dam.** Klinge asked that CRITFC coordinate their sampling at Wells Dam with the brood stock collection by the Colville Confederated Tribes. Klinge wrote Jeff Fryer and asked him to coordinate with Jerry Marco. Heinith said that CRITFC might conduct limited sampling at Wells Dam in conjunction with Jerry, but they will minimize their presence.

(4) **Monitoring at Zosel Dam.** Heinith wondered whether there were plans to monitor adult passage at Zosel Dam. Klinge said not this year.

(5) **Correspondence.** The committee discussed the question whether it is appropriate for members to copy their correspondence to FERC or other outside entities. Klinge again observed that this makes work for Douglas P.U.D. and is counterproductive in terms of his time and that of others. Hevlin said that no one is limited in their communications with FERC. Feldmann made a plea for the members to work diligently within the committee to resolve issues, and choose appropriate battlefields for larger issues. If FERC becomes involved the issue is escalated to the point where lawyers become involved and the P.U.D. has to respond to FERC or others. Klinge asked the members to air problems first in the committee and attempt to resolve them there. The members noted that to formalize such an agreement would be beyond their authority. However, they agreed to proceed with a "gentlemen's agreement" that they would use the committee as their first resource to air problems with regard to the matters addressed in the Wells Settlement Agreement and attempt to solve them in the committee.

ATTENDANCE ROSTER
WELLS PROJECT COORDINATING COMMITTEE
MEETING OF MARCH 3, 1994

Name	Representing
Rick Klinge	Douglas County P.U.D.
Cary Feldmann	Power Purchasers
Tom Scribner	Yakama Indian Nation
Brian Cates	U.S. Fish and Wildlife Service
Rod Woodin	Washington Department of Fisheries and Wildlife
Bill Hevlin	National Marine Fisheries Service
Bob Heinith	Columbia River Intertribal Fish Commission
Richard Whitney	The Committee

WELLS PROJECT COORDINATING COMMITTEE
MEETING April 6, 1994
SUMMARY[1]

Agreements Reached
1. The committee approved the protocol for brood stock collection for spring chinook on the Methow River. The committee will meet again on May 10 to consider new deadline dates for decisions on collection levels that are to be based on run size updates.

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The Wells Project Coordinating Committee met by telephone conference call at 2:00 P.M. April 6, 1994. Participating in the call were Bill Hevlin, NMFS; Tom Scribner and George Lee, Yakama Indian Nation; Rod Woodin Bob Bugert, Craig Busack and Bob Jateff, WDF&W; Chuck Peven and Steve Hays, Chelan County P.U.D., Brian Cates, U.S. Fish and Wildlife Service; Rick Klinge, Douglas County P.U.D., and Richard Whitney for the committee.

1. **Protocol for Taking Spring Chinook Brood Stock in the Methow.** Bugert had distributed a draft protocol in advance of the meeting. He raised questions about the appropriate stock to use for the brood stock source. He recommended that no brood stock be taken until the appropriate stock is identified. Woodin asked about the use of volunteers from the channel, as was done in 1993. Bugert suggested that scales of fish from the channel could be read to identify hatchery fish. Those could be taken to the Winthrop Hatchery. Others could be released into the river, as a salvage operation. Klinge wondered who would do that. Bugert suggested Bob Jateff. Klinge expressed a concern about Jateff working for the neighbor. Jateff responded that the channel is different this year than it was last year. Beaver have constructed a dam in the channel. He doubts that fish will be attracted in the same numbers as last year. Last year we tried to attract them with river water. We will not do that this year. Bugert asked whether the committee had any problem with a proposal for no Methow production this year. Klinge responded that Scribner had proposed collection of eggs from dewatered sections of the river. Bugert responded that he would prefer to evaluate the feasibility of that this year. If it appears to be feasible then we could do it on a full scale in 1995. There is a question whether the eggs would be hardened and ready to move. Concern was expressed about the predicted low run size and the implications for collection of brood stock. Bugert pointed to the provision that if the run size is less than 100 fish in a given sub-stock (i.e. Twisp, Chewack, Methow, individually), then no brood stock would be taken from that substock. Woodin pointed out that the hatchery record is good, so that it could be argued that at some low level of abundance, we should take all of the fish. Jateff pointed out that the trap only takes about 25% of the run. Woodin noted that the proposed protocol would prohibit the take of fish before May 23. He asked whether this presents a problem. Bugert said that up to then, they could take up to 50% of the run. There would be a chance then, after holding the

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1. Prepared by R. Whitney

fish, to return them to the river if it appeared to be necessary or desirable. Woodin suggested that it looks like the run might be early.

There was a discussion of the provisions of the draft protocol. Hevlin expressed a concern that not many fish should be taken into the hatchery. Craig Busack offered an analysis indicating that when a population is small, there is a higher probability of further depression of population size if the hatchery has a much higher survival rate. Bugert further noted there is a higher likelihood of inbreeding depression with small populations. The proposed protocol is worded to indicate no more than 50% of the run should be taken. If the run size is higher than expected, then we could shoot for less than 50%. The ideal number is 25 pairs as a minimum. If this amounts to 25% of the total population perhaps they should be released into the river. The best procedure is to take either a large percentage of the run or a small percentage. Jateff indicated that the take last year was 640,000 eggs from 3 stocks. He noted that the target of 675,000 eggs does not seem to be achievable. The water supply is available, but there is not enough space in the containers. Woodin asked whether more tanks could be made available. Jateff said that was conceivable. Bugert said that if the run proves to be stronger, the intention would be to drop back from the proposed 50% take. Hevlin commented that he could not support taking 50 out of 100 fish that return. Intuitively, he feels it would not be easily explained to the public. He suggested taking one-third as an alternative. Woodin observed that with the given trapping facilities we would be fortunate to take one-third. Bugert observed that hatchery survival rates would reduce the likelihood of losing a particular genotype. Busack noted that it is an issue of risk. He thought one-third might be an acceptable number. Hevlin proposed that if there are 100 fish the take should be 30. If it is above 100 then we could take 50%. Bugert observed that the trap is selective due to effects of flow. Klinge commented that the runoff will probably come in a big rush, bringing the fish, then they will taper off. The deadline in the protocol is June 30. It might be that the flow would not allow fish to move up until June 15. Busack offered the opinion that the best procedure might be to take a maximum of 25 pairs and allow at least 100 fish to pass upstream. Hevlin suggested there be a 30% take and a minimum of 70 fish above the weir. Jateff suggested that we take every fish as we go. Then if there are extra fish, some would be returned. It is hard to sex them to know when you have a pair.

Bugert suggested that the committee should meet again on May 10 to set a revised "drop dead" date. The committee agreed.

WELLS PROJECT COORDINATING COMMITTEE
MEETING APRIL 29, 1994
SUMMARY[1]

Agreements Reached
1. Spring chinook forecasts shows extremely poor returns for 1994. A decision to forego the spring chinook telemetry study for the Methow basin will wait until May 6, 1994. A conference call of the WCC (WCC 94-6) has been scheduled for 10:00 AM to decide.

2. Broodstock collection of spring chinook for the Methow Supplementation Program may be dropped. Further discussion on this will occur on Friday, May 2, 1994.

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A meeting of the Wells Coordinating Committee was held by Conference call on April 29, 1994 at 10:00 AM. Participants were Bob Bugert, Washington Department of Fish & Wildlife; Bob Heinith, Columbia River Inter-Tribal Fisheries Commission; Bill Hevlin, National Marine Fisheries Service; Jerry Marco, Colville Confederated Tribes; Tom Scribner, Yakama Indian Nation; Rod Woodin, Washington Department of Fish & Wildlife; and Rick Klinge, Douglas PUD. The purpose of the meeting was to discuss the spring chinook telemetry study and brood collection at Methow Hatchery in light of the projected spring chinook returns.

1. Bob Bugert projected mid-Columbia runs to be 500 - 700 spring chinook at Tumwater and about 600 spring chinook into the Methow River. Bugert speculated that of the Methow fish, 450 will be wild and 150 hatchery origin. Bob Heinith said Inter-Tribes' position is fish should not be radio tagged nor collected for broodstock. Rod Woodin mentioned the telemetry work in the Snake River was canceled on Wednesday. Bill Hevlin recommended that we consider using the effluent channel at Methow for collecting some brood. Rick Klinge said that while these fish would not be used in the Methow Program, possibly they could be used in the Winthrop Hatchery. This may reduce transferring outside stocks in for this hatchery. Rod said the WCC was rejected brood collection from the effluent channel in 1994 because a high proportion of these fish are from the Winthrop Hatchery. These fish are not desirable for supplementing native stocks. Bugert said that a large beaver pond has developed in the effluent channel and would require considerable work to reopen the channel in order to attract adult spring chinook. While positive in intent, Bugert felt the effort would generate a drop in the bucket of needs for the National facility. Rod Woodin expressed pessimism of any surplus eggs in the system. Bugert felt that a decision on broodstock collection could wait while the run develops in the mid-Columbia.

A decision on the fate of the telemetry work would also wait. Rick Klinge expressed concern that if we only collect 10% of the wild fish at Wells to radio tag, we may see less than a dozen fish encounter the traps at Twisp and Chewuck. This would not give enough data on behavior at the traps. The 120 tagged fish was felt to be a low number of test fish. A decision on how to proceed on the telemetry work and brood collection would be revisited in a week when more data was available on run strength. The members decided to have another conference call on Friday, May 6 at 10:00 AM to decide on the telemetry study in the Methow.

2. **Okanogan Sockeye** Bill Hevlin said gate well dipping at Rocky Reach Dam has collected many salmon and mostly sockeye. Rick Klinge said historical

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[1] Prepared by R. Klinge in R. Whitney's absence.

information shows that steelhead are the major species passing Wells at this time. Jerry Marco said that Colville Tribes will be operating a screw trap near the outlet of Lake Osoyoos. They will watch to see if large numbers of sockeye appear to be migrating down the river. There is an agreement between the managers of water in British Columbia and Washington State to release flows in the Okanogan River to help stimulate the sockeye migration. If the migration is currently under way, this may be a good time to release some of that water. Rick Klinge cautioned to use the limited resource wisely. If the sockeye migration is underway, it is earlier than years past. Irrigation district staff at Zosel Dam have not seen juvenile sockeye build in front of the dam. Hevlin said water visibility was poor and it would be difficult to see juvenile sockeye at Zosel. There was discussion concerning how natural flows today were high due to some snow melt and rain from last week. Jerry Marco said flows out of Okanogan Lake were about 700 cfs and by the time the river reached Oliver, side flows added to the total to make 1200 natural flows.

Rod Woodin asked what was being learned from the fry sampling. Rick Klinge said Bruce Shepherd has sampled for fry from early March. High flows caused some premature emergence of sockeye fry from the gravel. When this was realized, flows were cut back. early on there was a large migration of white fish. The peak of the nerkid fry migration was April 18. There is a size break between sockeye and kokanee. Sockeye migrate in the middle of the river channel. This will help keep them free from irrigation entrainment. Also most of the movement is at night. Bob Heinith was interested if Bruce Shepherd was looking at the oxbow areas for sockeye fry? Rick said to date he had not. The Province has found small mouth bass in these areas in the past.

Woodin was concerned about an update of the net-pen program. Jerry Marco said an update is on the way. The sockeye were much smaller than anticipated. The mesh size of the nets ordered for fish at 60 fpp were too large for the fish at 200 fpp. A single net was ordered to handle the smaller fish in the lake. Klinge said it was unclear how the fish would respond to growth in the lake. The Cassimer Bar crew felt comfortable raising the fish close to smolt size by the end of May. A limited amount of the production at the lake given temperatures and endemic diseases would be the best way to proceed. Klinge said Dave Narver, B.C. Environment, expressed disappointment to the Okanogan County Planning Department about the sockeye net pen program. Narver felt there was not adequate environmental assessment of potential impacts from the project. A copy of this letter will be forwarded to the WCC.

WELLS PROJECT COORDINATING COMMITTEE
MEETING MAY 6, 1994
SUMMARY[1]

Agreements Reached

1. The committee agreed to terminate the radio tagging study of adult chinook in the Methow River, due to the small run size.

The meeting was held by telephone conference call at 9:00 A.M. May 6, 1994. Participating were Rick Klinge, Douglas P.U.D.; Cary Feldmann, Power Purchasers: Rod Woodin, WDFW; Bill Hevlin, NMFS; Brian Cates, U.S. Fish and Wildlife Service; Jerry Marco, Colville Confederated Tribes; Bob Bugert, Bob Jateff and Craig Busack, WDFW; Bob Heinith, CRITFC; Tom Scribner and Joel Hubbell, Yakama Indian Nation; and Richard Whitney, Chair.

1. **Radio Tagging Study**. The purpose of the meeting was to make a decision as to whether or not to proceed in 1994 with a study, using radiotelemetry, of adult chinook movements near the weirs on the Chewack and Twisp rivers. The concern was that early forecasts of run size indicated that few adults might be returning, and that as a result, the study might require use of a high proportion of those fish that would be present. After full discussion, the committee agreed to terminate plans for the radio tagging study.

2. **Brood Stock Protocol**. The committee also discussed proposals to modify the brood stock protocol with respect to the provision relating to how to proceed in case the run size is less than 100 fish in a given sub-stock, which now appears to be the situation. There were two points of view and the committee was unable to resolve the difference. The protocol approved on April 6, 1994 therefore remains in effect.

3. **Salvage of Eggs in Redds Susceptable to Dewatering**. Scribner pointed out that spawning ground surveys in the past had found redds in parts of the Methow and Twisp rivers that become dewatered. He suggested that a salvage operation be mounted, in view of the critical shortage of spawners. Bugert said that there is a need to define the location of the redds. Joel Hubbell offered the information that he has data going back to 1987. He has walked the sections of the river in November. The water level appeared to have dropped about 12 feet. He felt there was no way some of those redds could have water. Others were in shallow water where they would freeze solid. Klinge said that Douglas P.U.D. is supportive of efforts to salvage fish. Hubbell said he would prefer to take the adults before they spawn, because they are less fragile than the eggs. Last year there were 40 redds in that area and, in his opinion, all were lost. The adults could be taken to the hatchery immediately. Hevlin wondered whether fish could be driven out of those areas. Hubbell said it amounts to about 5 miles of river. Perhaps fish could be netted out of pools. Bugert said he would like to talk to the hatchery managers about the idea. Hubbell agreed that was a good idea.

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1. Prepared by R. Whitney

Scribner agreed to develop a written proposal for the committee to consider.

4. **Collection of Brood stock in the Hatchery Channel.** Rick Klinge proposed that fish that enter the hatchery channel be used as a source of brood stock for the supplementation projects. He noted that a decision was not required immediately, but asked the committee to think about it and consider it at a later date. Bob Jateff reported that close to 100 fish came into the channel last year. 65% were hatchery fish. He could operate there without too much trouble, but would need some kind of trap to keep fish from jumping up to the water box. There was no decision. The proposal will be considered again.

WELLS PROJECT COORDINATING COMMITTEE
MEETING May 25, 1994
SUMMARY[1]

Agreements Reached

1. The committee asked the chair to prepare a written analysis of the differences within the committee with respect to the proposed modification of the brood stock collection protocol for the Methow River. The committee was unable to agree on a modification of the protocol, but agreed to consult policy level persons within their agencies to resolve the difference.

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The Wells Project Coordinating Committee met by telephone conference call at 2:00 P.M. May 25, 1994. Participating in the call were Bill Hevlin, NMFS; Rod Woodin, John Kerwin, Bob Bugert and Craig Busack, WDF&W; Bob Heinith, CRITFC; Tom Scribner, Yakama Tribe; Brian Cates, U.S. Fish and Wildlife Service; Rick Klinge and Mike Erho, Douglas County P.U.D.; Cary Feldmann, Power Purchasers; and Richard Whitney for the committee.

1. **Evaluation Plan for Methow Hatchery.** Bob Heinith asked about the status of the evaluation plan. Mike Erho said that he and Bob Bugert had met to discuss it. He is developing the draft based on that meeting. He recognizes the importance of the plan and will do the best he can to get it out soon.

2. **Modification of Protocol for Taking Chinook Brood Stock in the Methow.**

A. Use of Fish Entering the Channel at the Hatchery. Bugert said that WDFW is now willing to consider taking for brood stock fish that enter the channel at the hatchery. He stressed the fact that WDFW does not want to set a precedent with this proposed modification of the protocol. However, they have concluded that any fish that wanders into the hatchery channel is locally adapted. Busack indicates they may be alright from a genetic standpoint. Things are so bad this year that we need to do whatever we can to assist the fish. WDFW had planned to take samples for genetic analysis this summer, but it now appears there may not be enough fish to develop a definitive answer. Bugert indicated that if the committee does approve taking fish from the channel, then WDFW will need help gearing up to do it. Klinge said that if the committee approves the plan, then Douglas P.U.D. will proceed with vigor to assist in implementing it. There was a discussion of what might be expected this year compared to last year. Hevlin asked whether any effects would be expected downstream. Jateff said the only effects would be right in the channel itself. Erho said that if the committee decides to do it, Douglas P.U.D. will write up a proposal. Hevlin wanted to be sure that no effort was made to attract fish in there that would not normally enter the channel. There was a discussion of the logistical arrangements for holding the fish that would be caught. The committee then approved the plan to take brood stock from the channel, and asked Douglas P.U.D. to prepare a written proposal. All the fish that enter the channel will be used.

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1. Prepared by R. Whitney

B. **Proposed Modification of the Brood Stock Collection Protocol in the Methow River.** Bugert reviewed a draft protocol he had distributed in advance of the meeting. A copy is attached. There was a discussion of the provisions of the draft protocol. Basically, WDFW has rethought the provision in the protocol that specifies no fish will be taken for brood stock if the run is smaller than 100 fish. The proposal at hand suggests taking up to 20 fish in the Twisp and 20 in the Chewack. Hevlin said that NMFS will not agree to any collection of fish from the Twisp or Chewack because there is no indication that the hatchery helps, the taking of fish from this small population would violate genetic principles, and reducing the numbers of fish would make it more difficult for spawners to find each other. Bugert offered information that the survival rate from egg to smolt stage in the hatchery is 85 to 90 %. In the wild it is 8 to 10%. There was further discussion of the issue. Hevlin had not changed his mind since the previous meeting. The other members were ready to approve the proposed modified protocol. A number of alternatives were considered, but agreement could not be reached. Several members felt that the situation was critical and required some action.

There was a discussion of using the dispute resolution process spelled out in the Settlement Agreement. Woodin referred to it. It did not fit our situation, where a speedy determination on a biological or policy issue was required. Scribner suggested using the dispute resolution process available in U.S. v Oregon and Washington. Members were reluctant to bring this matter into a different legal arena. There was a suggestion that the committee itself resolve the matter by agreeing to submit the question to one or more disinterested experts. It was pointed out that if the entities represented on the committee were to agree to abide by the recommendation of the expert or experts, it would be necessary to obtain approval from the Directors or administrative heads of the entities. It then became clear that the issue would have to be explained to them. That being the case, the committee came to the conclusion that the Directors or other administrative heads might as well be the ones to make the decision, since it is basically a policy decision in the final analysis. The committee therefore asked the chair to prepare, in writing, an impartial analysis of the situation, explaining the differences. This will be used in discussions with those higher-ups. A copy is attached.

3. **Proposal to Salvage Fish From Dewatered Redds.** Scribner had distributed a proposal to salvage fish before they spawn in areas likely to be dewatered. He asked the committee members to study it and provide him with comments in a week.

MEMORANDUM

To: Wells Project Coordinating Committee

From: Dick Whitney, Chairman

Date: May 26, 1994

Subject: Resolution of Dispute over Brood Stock Collection in the Methow

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During the meeting of the Wells Project Coordinating Committee by telephone conference call on May 25, 1994, the committee asked me to outline the differences that were expressed on whether or not, considering the exceptionally low numbers of spring chinook expected in the run into the Methow River this year, there should or should not be brood stock removed from the run to be used for supplementation projects.

Background. In a telephone conference call in April, 1994 the committee approved a protocol for collection of spring chinook brood stock for the supplementation projects on the Methow River. The protocol that was approved included a provision that if the run size turned out to be less than 100 fish, there would be no take of brood stock.

Issue. As the run developed, it became apparent that the run into the Methow will indeed be less than 100 fish. Some of the members began to rethink this 100 fish provision, on the basis that at some low level of salmon abundance it becomes more rather than less justifiable to rear some in the hatchery in order to take advantage of higher survival rates from egg to smolt, estimated as 85 to 90% in the hatchery compared to 8 to 10% in the wild. Craig Busack, geneticist with the WDFW has provided an analysis of potential genetic effects at these low population levels, and recommends in favor of modification of the protocol to rear a portion of the run in the hatchery. He observed that any disadvantageous genetic effects observed could be undone with proper protocols in the future. On the other hand there is concern by some representatives in the committee about the possible effects of "domestication" on fish reared in the hatchery, and a concern about possible effects of removal of a portion of the spawning population on the ability of the ramaining fish to spawn successfully, as well as other possible effects on spawning success.

Actions. The committee has met by telephone conference call twice in May to discuss proposals for modification of the brood stock collection protocol. The committee has been unable to agree on a modification. At the May 25 meeting the committee discussed possible methods for dispute resolution on this issue. All parties agree that the low run size calls for emergency measures and there is a need for a prompt decision, but there are two points of view on what those measures should be. There is insufficient scientific evidence available on the questions raised to make it possible to develop a purely technical analysis and decision. Therefore, the representatives agreed to raise the issue to a policy level. [This is the only time in the 4 years of the committee's life, and in the 15 years of life of the mid-Columbia Coordinating Committee that the committee has been unable to either resolve a difference or live with the results of the difference.]

Positions.

1. Washington Department of Fisheries and Wildlife has proposed modifying that part of the protocol that says if the run is less than 100 fish there will be no take of brood stock, to a provision that says brood stock will be taken by capture of one-fourth of the run up to a maximum of 20 fish at each of the traps on the Twisp and Chiwack Rivers. This WDFW provision is also favored by Douglas County P.U.D., the Columbia River Intertribal Fish Commission, the Yakama Indian Nation, and the Power Purchasers.

2. The National Marine Fisheries Service has proposed proceeding with the protocol that was approved in April, and further that neither of the traps be operated for any purpose, so that there would be minimal disturbance of natural spawning. National Marine Fisheries Service is the proponent of this position.

Relief. The committee representatives, out of their concern for the spring chinook in this emergency situation are requesting policy guidance on this matter. The basic question is, when run sizes are as low as observed in the case of spring chinook this year, should some fish be removed as brood stock for supplementation projects or should the fish be left to spawn naturally?

DRAFT (23 May 1994)

METHOW SPRING CHINOOK SALMON HATCHERY
1994 BROODSTOCK COLLECTION PROTOCOL

Background

Methow Fish Hatchery (FH) was designed to propagate three spring chinook salmon stocks, from the Methow, Chewuch, and Twisp rivers. At this time, the production goal for each stock is 250,000 yearlings at 15 fish per pound. Broodstock required to meet this goal is 190 spawners (95 ♂ and 95 ♀) per stock, based upon a fecundity of 4,400 and 1:1 sex ratio. Assuming an 80% prespawning survival, 238 salmon need to be collected for full production. An alternative production goal may be initiated however, which would be based upon a supportive breeding strategy rather than an absolute numerical goal.

Methow River: The only acceptable founder population for the Methow stock are spawners upstream of Foghorn Dam. There currently is no means to collect these broodstock. The Methow FH outfall channel, which has flows up to 20,000 L\min, attracts salmon. In 1993, the hatchery crew collected 99 of these salmon for Methow production in an attempt to establish a founder population. Scale pattern analysis however, indicated that 67% of these appeared to be of hatchery origin, most likely from Winthrop FH. Collection of nonlocal hatchery stock is not consistent with the Methow FH goal, therefore the outfall channel will not be used for broodstock collection.

Chewuch River: Broodstock are collected at a trap on the Fulton irrigation diversion dam on the Chewuch River, which has had variable trap efficiency. Broodstock collections began in 1992, when 33 salmon were trapped, of which 20 were retained. Based upon redd count expansions, about 10% of the spawners was collected. In 1993, 186 salmon were trapped, and 110 were retained, comprising about 30% of the spawning population.

Twisp River: Broodstock are collected at a floating weir facility on the Twisp River. It has had a low trap efficiency. In 1992, 71 salmon were captured; 30 of which were retained for broodstock. An undetermined, but presumably large number of salmon passed the weir in moderately high flow. It appears that over 300 salmon spawned in the Twisp River in 1992, based upon redd count expansions. Based upon this estimate, the hatchery crew trapped 25% of the spawning population, and retained 10% or less for broodstock. In 1993, hatchery staff trapped 70 salmon and retained 42, which appears to be about 25% of the spawners, based upon redd count expansions.

Historical Escapement

The recent ten-year average Wells Dam counts for spring chinook salmon is 2,274 (adults and jacks). For the period 1987-1993, the distribution of redds is 45.7% mainstem Methow River and tributaries, 27.6% Chewuch River, and 26.7% Twisp River. Escapement to these streams (based on spawning ground surveys in index areas) appears to be quite variable. This variation should be considered in yearly broodstock collection plans; fewer fish should be collected in years of low abundance. The 1994 escapement to the Methow Basin is expected to be a record low. The TAC predicted final Wells Dam run size as of this date is 115 spring chinook salmon; individual stream escapements will therefore be 30 to 50 salmon.

DRAFT (23 May 1994)

Action Plan

No salmon from the mainstem Methow River will be collected for Methow FH production in 1994. Salmon from the Twisp and Chewuch rivers will be collected in a manner that represents the demographic character of each run, yet reduces passage problems or handling. No more than 20 salmon will be collected per stream.

Twisp River: The weir panels will be deployed in May and June. During this time, all salmon that enter the trap will be collected, on the assumption that roughly one fourth of the run enters the trap. The panels will be removed in July through September, but the trap will be operated on a continual basis through the duration of spawning. Fish will be passed upstream if it appears more than 20 will enter the trap over the course of the season. A sentry will monitor the weir for salmon which may have difficulties in passage.

Chewuch River: The trap on the Fulton Dam steep pass will be maintained daily. All salmon that enter the trap during May and June will be collected for broodstock, which presumably will be one fourth of the run. Some fish will be passed upstream if it appears more than 20 will enter the trap in May and June. The trap will then be kept open in July, August, and September, but will be checked daily to ensure that salmon are passing the trap without difficulties. Some salmon may be collected during this late period, depending upon trap efficiency, sex ratio, and run size.

Scale samples from the broodstock will be taken during inoculation. If the scale pattern indicates a salmon is hatchery-origin, it will be transferred to Winthrop FH. Likewise, adipose-clipped salmon will be taken to Winthrop FH. Logistics of this transfer will be decided by the hatchery managers. Fertilization methods will be determined in late summer when a firm estimate of broodstock size and sex ratio is known.

WELLS PROJECT COORDINATING COMMITTEE
MEETING August 18, 1994
SUMMARY[1]

Agreements Reached

1. The committee appointed a subcommittee, consisting of Larry LaVoy, and Bob Bugert, WDFW, to develop a work plan for conducting a spawning ground survey for sockeye in the Okanogan River in 1994 that would not depend on funding from Douglas County P.U.D.

2. The committee appointed a subcommittee of Rick Klinge and Bob Heinith to communicate with Canadian governmental agencies in order to discover their interests and concerns related to the Committee's interest in enhancement of sockeye in Lake Osoyoos, and to arrange a time when representatives of those Canadian agencies can meet with the committee to discuss joint interests.

The meeting was held by telephone conference call at 1:00 P.M. August 18, 1994. Participating were Rick Klinge, Douglas, County P.U.D.; Jerry Marco, Colville Confederated Tribes; Cary Feldmann, Power Purchasers; Rod Woodin, Bob Bugert and Larry Lavoy, WDFW; Brian Cates, USFWS; Bill Hevlin, NMFS; Bob Heinith, CRITFC; and Richard Whitney, Chairman.

1. **Update on Brood Stock Collection:** The committee asked Bob Bugert for a progress report on collection of brood stock. He reported that for summer chinook at Wells Dam, as of August 17, there have been 612 collected, (490 adults and 112 jacks) to date. There have been 924 adults and 10 jacks that were volunteers at the Wells Hatchery ladder and trap. A total of 3,981 (3,645 adults and 336 jacks) have been counted past the dam. Therefore, collection for brood stock amounts to about 15% of the run. The goal for collection is 700 adults, along with 2,000 as the goal for dam passage. It therefore appears that the goals will be met. At this time it is estimated that 4,000 will pass the dam. Collection will continue until the 700 adults are collected or until August 28th, whichever comes first. It appears that they will obtain from the volunteers enough eggs for the Rocky Reach program. The might need to close the ladder to the hatchery in order to prevent taking more than are needed. In the Methow, they have 9 females and 8 males, in the Twisp 4 females and 1 male, and in the Chewack 5 females and 5 males. They have not transferred any fish to the Winthrop National Fish Hatchery. Brian Cates reported that the Winthrop Hatchery has 21 fish to date. Bugert resumed with information that to date there has been no spawning observed in the Twisp. The weir was removed yesterday, as agreed by the committee.

2. **Okanogan, Sockeye Piliot Program.** Jerry Marco reported that they have been collecting adults three days a week at Wells Dam since July 18. Collection of sockeye has proceeded in conjunction with the WDFW collection of

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1. Prepared by R. Whitney

summer chinook at the left bank ladder at Wells Dam. CRITFC has taken scale samples of sockeye at the same time. They have collected 141 sockeye, which is half the goal. The count at Wells Dam is 1,615. They apparently missed a sequence of days when large numbers of fish came through. They are injecting the adults with erythromycin, so they are being marked individually. Condition of the fish is mixed. In previous years they have been able to sort out injured fish, but could not afford that luxury this year because of the scarcity of fish. They have lost 10 fish so far. Klinge offered information that a thermograph located at the lower end of Lake Osoyoos showed a temperature of 81 F at the end of July. CRITFC personnel measured 73 F in the river, so it is possible that some fish moved up the river. However, measurements of oxygen showed only 2 ppm, which would not support salmon.

3. **Okanogan Spawning Ground Survey.** Klinge said that as the RFP for the spawning ground survey in the Okanogan was being studied, concerns developed within Douglas P.U.D. about Canadian opposition that was expressed during the permitting process before the Okanogan County Commission. The Commission delayed their decision in order to obtain input from the Canadians. The Canadians were opposed to the net pen operation in Lake Osoyoos. Douglas P.U.D. is concerned, as a matter of policy, that we might be proceeding with a project that will end up dead because of Canadian opposition. It was hard to justify the spawning ground survey. Another complication with the RFP was that it included estimates of kokanee spawning. Douglas P.U.D. was informed that Canadian law requires that where any study is proposed on fish being managed by a Canadian governmental agency, that agency is required to conduct the study. The inclusion of kokanee in the survey would put it under this requirement. We need to spell out how far the Canadians are willing to go with us. Douglas P.U.D. is willing to proceed with the pilot project with sockeye rearing. But the fry emergence and spawning survey are not seen as critical needs for projects now underway. Rod Woodin expressed the opinion that the spawning ground survey is of critical importance in evaluating the success or failure of the pilot sockeye program. Klinge agreed that would be true in 1997, when the first adult returns are expected. Jerry Marco observed that Canadian opposition had come from British Columbia Department of Environment. He wondered what the position of the Canadian Department of Fisheries and Oceans is on the subject. Klinge believed that DFO had left the matter up to BC Environment. Jerry observed that DFO representatives had attended meetings dealing with management of Lake Osoyoos and seemed quite interested in plans for enhancement. He wondered if we might just be reacting to BC Environment, when there are other interest in Canada. He noted that the Native American Bands were quite desirous of developing a viable sockeye run into Lake Osoyoos. Klinge agreed there is a need to include other Canadian entities. Woodin pointed out that it is unfortunate that we don't have our sockeye evaluation plan or our enhancement plan available. He has a feeling that the plan would identify a need for this information, but without having it in hand, he is unable to cite a place in the plan. Hevlin expressed the opinion that the spawning ground information would be useful in estimating survival of the 1,600 fish that have passed Wells Dam. Water conditions at the mouth of the Okanogan River have been identified in previous surveys as potential barriers to safe passage of adult spawners. There is a critical question how many might actually succeed in getting upstream. In his talks with the Canadians, they have expressed opposition to introduction of sockeye smolts, but have supported measurement of environmental parameters. They

were quite interested in how fry were washed out of the gravel by early water releases for irrigation. Klinge noted that Larry LaVoy of WDFW will be assessing spawning escapement with a one-day survey. This should provide an idea of how many fish get into the area. In any case, it is now too late in the process to be able to proceed with a contract.

Woodin expressed dismay. He felt that through the committee process, the members had been led to believe that study was going forward. Now it appears to be too late for anybody to do it. He felt that the committee should have been notified early enough that an alternative could be developed. Hevlin also expressed his disappointment, as did Heinith when he came on the line. Hevlin felt that the data would be useful and will be missed.

The committee explored possible alternatives. Larry LaVoy was asked to provide input. He said that the Canadians are sensitive about outsiders handling their fish. However, WDFW has conducted visual surveys in Canada without marking or handling fish and has encountered no objections. Woodin offered the idea that there are ways to estimate escapement without marking fish. LaVoy said he would have to look into that. He thought it might be feasible to conduct several consecutive surveys, if manpower were available. Committee members offered help as volunteers. The committee agreed to work together to develop and conduct the best survey possible under the circumstances. Larry LaVoy and Bob Bugert were appointed as a subcommittee to communicate with the members as to their ability to participate, and to develop a written work plan to estimate spawning escapement of sockeye in the Okanogan River.

4. **Communications with Canadians.** Klinge pointed out that beyond the immediate concern is a larger question about how Canadian interests could affect the Committee's program. The committee agreed. Klinge and Heinith were appointed as a subcommittee to communicate with the Canadians to find out what their interests and policies are, and to arrange a session with them and the full committee during one of our Wells Project Coordinating Committee meetings this fall.

5. **Future of the Foghorn Project.** Klinge said he will write a memo describing some options for operations at Foghorn, now that the matter with OWL is past us. This will provide a basis for discussion in the committee.

WELLS PROJECT COORDINATING COMMITTEE
MEETING OCTOBER 5, 1994
SUMMARY[1]

Agreements Reached

1. The committee decided December 5, 1994 would be the deadline for comments on the draft evaluation plan.
2. The committee designated Klinge, Heinith and Bugert as a subcommittee to confer with the Canadians on the issue of sockeye enhancement planning.
3. Comments on the plan for modifying the Foghorn Dam are due November 15, 1994.
4. The committee approved the proposal of WDFW to take brood stock for steelhead out of the east ladder at Wells Dam.

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The meeting was held on October 5, 1994 at the West Coast Sea-Tac Hotel in conjunction with the meeting of the mid-Columbia Coordinating Committee.. The agenda followed was mailed along with the meeting notice on September 22, 1994. Those in attendance are listed on the attached roster.

1. Spawning Ground Survey, Okanogan River. Bob Bugert reported on the schedule for committee participation in the spawning survey. They will be counting live and dead salmon. No fish will be handled. There will be 7 surveys over five weeks. The escapement over Wells Dam has been very low. Woodin commented that this is a critical year to be doing the survey. Bugert has contacted Bruce Shepard in B.C. and they have acknowledged his communication. Jerry Marco suggested contacting the Okanogan Band in B.C..

2. Cassimer Bar Sockeye. Jerry Marco reported that a written report will be available soon that will include data on brood stock numbers and the dates they were taken. There have been a total of 141. Prespawning mortality has been 11%, compared to 30% last year. New vinyl raceways have helped. They found ripe fish last week and took eggs on Friday. The second take will be Monday. Chuck Peven reported that Chelan P.U.D. is funding genetic studies of sockeye by Fred Utter.

Rick Klinge added information from Jack Rensel on the net pens in Lake Osoyoos. They found that fish in the pens were feeding on natural zooplankton. Measurements in the southern basin showed oxygen levels down to zero. The temperature reached 25-25 degrees. He will forward the report from Jack as soon as it is available.

3. Methow Chinook Brood Stock. Bob Bugert reported from the Chewack there have been 6 females and 4 males taken. The egg take is 19,000. From the Methow there were 9 females and 8 males, and an egg take of 36,000. On the Twisp there were 4 females, 1 male and 16,000 eggs. Joel Hubbell provided spawning counts as follows: Chewack 27, Twisp 32, Methow 64, Early Winters 4. There were a total of 400 last year. The count at Wells Dam was 252. Hevlin asked about the fish rescue effort. Hubbell said they had moved 6 to

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1. Prepared by R. Whitney

The committee designated Klinge, Heinith and Bugert as a subcommittee to confer with the Canadians.

7. Trap at Foghorn. Klinge expressed relief that the situation with OWL is behind us. Construction at Foghorn Dam will begin in the summer of 1995. However, the trap is still a question in his mind. It would be only one-fourth mile from the current collection location in the hatchery channel. He wonders what the gains would be of providing an additional site that close. Douglas' current plan is to do all of the work except install the trap. Woodin commented that this would be 180 degrees out of phase with the evaluation plan. Where we are currently collecting fish, we do not get natural fish. Until we try to trap we won't know whether there is a difference in hatchery/wild composition at the two locations. Bugert pointed out that the collection channel requires modification in order to provide a sorting capability. Klinge thought that the channel was serving the purpose. Bugert agreed except that it would need to be modified to allow for sorting of hatchery and wild fish. There was a discussion of the numbers of fish expected. Woodin noted that less than 10% of the fish volunteered into the channel. Less than half were wild fish. Bugert said that Winthrop Hatchery will collect volunteers and share them with the Methow Hatchery. Erho observed that with improvements in the dam at Foghorn we might still see few fish using the ladder, let alone the trap in the ladder, since the dam is not a barrier to fish. He felt that we should wait and see what the fish do, and build the trap later if it appears to hold some promise. Klinge said he would go back to Douglas P.U.D. and look into the possibility of providing a temporary trap in the ladder. In the meantime, comments on the plan are due November 15, 1994.

8. Other

Steelhead Brood Stock Collection. Woodin reported that WDFW is in the process of collecting steelhead brood stock at Wells Dam. The goal is 600 fish. They have 259. Of these, 77% are 1 salt fish, so the egg take will probably be low. They want to be able to trap the east ladder at Wells Dam to get more fish. Those taken on the west side are volunteers, which are low in number so far. They propose operating in the east ladder 2 or 3 days per week, taking only fish that show an adipose fin clip. They would expect to collect about 20 fish per day. The committee discussed the proposal and approved it.

Communications to FERC. Heinith expressed concern that after arriving at what he thought was an agreement on this subject, Douglas P.U.D. still wrote to FERC, with a letter critical of what he had done. Klinge responded that he had explained to Heinith when this matter first came up that whenever an issue of compliance with FERC orders is involved, the P.U.D. feels that they must respond to FERC. The Chair offered to assist in breaking the cycle.

Next Meeting. The committee adjourned without setting a date for a meeting to follow. They will wait until an agenda develops.

ATTENDANCE ROSTER
WELLS PROJECT COORDINATING COMMITTEE
MEETING OCTOBER 5, 1994

NAME	REPRESENTING
Joel Hubbell	Yakama Indian Nation
Rick Klinge	Douglas County P.U.D.
Mike Erho	Douglas County P.U.D.
Steve Hays	Chelan County P.U.D.
Dick Nason	Chelan County P.U.D.
Chuck Peven	Chelan County P.U.D.
Dennis Rohr	mid-Columbia P.U.D.s
Brian Cates	U.S. Fish and Wildlife Service
Cary Feldmann	Power Purchasers
Lance Smith	NMFS
Bill Hevlin	NMFS
Jerry Marco	Colville Confederated Tribes
Bob Bugert	WDFW.
Bob Pearce	NMFS
Gustavo Bisbal	NWPPC
Jim Ruff	NWPPC
Tracey Steig	HTI
Bob Heinith	CRITFC
Stuart Hammond	Grant County P.U.D.
Stephen Brown	Grant County P.U.D.
Richard Whitney	The Committee

WELLS PROJECT COORDINATING COMMITTEE
MEETING MINUTES, 15 DECEMBER 1994

Agreements reached:

1) The JFP agreed to support Douglas PUD in development of an adult trap in the fishway at Foghorn Dam, and agreed that no request will be made by any agency or tribe in the future for an additional trap site or structure to collect Methow stock adults.

2) The Wells Coordinating Committee (WCC) established an *ad hoc* group to work with Canadian authorities on development of an Okanogan sockeye enhancement plan.

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Douglas County P.U.D.

A. Wells Dam

1. Squawfish control at Wells tailrace

Klinge distributed a proposal (Attachment A) to the committee for removal of squawfish from the tailrace of Wells Dam and at the outfall to Wells Fish Hatchery (FH). This work is proposed to be done in 1995. The committee discussed the feasibility of doing this work in a cooperative venture with the other public utility districts. Refer to minutes of the MCCC meeting (MID-COL 94-14) for details of the discussion.

2. 1995 bypass operation

Prior to the meeting, Klinge distributed the proposed 1995 bypass operation, which he said was essentially the same as the 1994 operations. No comments were made.

B. Wells FH status report

Klinge called upon Bugert to give a report on the 1994 broodstock management at Wells FH. Bugert said that eggtake needs were met for the Wells, Eastbank, and Rocky Reach hatchery programs. He noted that, based upon preliminary analysis of coded-wire tag recoveries, extensive gene flow is occurring between the Wells and Eastbank programs. Despite all efforts to control this flow, it appears to be an ongoing phenomenon, yet this may have no deleterious effect on the viability of these populations. He said the incidence of the causative agent for bacterial kidney disease in the broodstock was quite low--only 21 females had detectable levels of the antigen, based upon the ELISA technique. The WDFW may propose transfer of the progeny of these females to Winthrop FH, operated by USFWS. Cates said this proposal is being considered by USFWS.

C. Methow FH

1. Foghorn trap plans

Klinge said Douglas PUD is prepared to negotiate an amendment to its agreement with USFWS and WDFW on renovation of the fishway at Foghorn Dam. This amendment would include funding for installation of a trap in the fishway. Klinge said the district needs verification from the JFP that the trap design, as proposed by FishPro, is acceptable. Also, the district will require an assurance from the JFP that no further actions will be made by any agency or tribe represented in the Settlement Agreement to seek an alternative trap site or structure to collect Methow stock adults. The trap is required under Paragraph IV.D.2 (c)(iii)(a). After some deliberation, the JFP agreed to this stipulation.

Klinge emphasized the importance of proper coordination between Winthrop FH (operated by USFWS) and Methow FH (established under the Wells Settlement Agreement). He stated that the district's decision to proceed with development of a trap at Foghorn Dam further demonstrates its commitment to developing a cooperative arrangement between the two hatcheries.

2. Comments on Methow Evaluation Plan

Klinge called upon Erho to discuss the draft Methow Evaluation Plan. Erho said comments have been received from all parties except the Colville Tribes. Marco said comments will be provided by the end of December. Erho said the plan was, in general, well received. As to be expected, the significant hurdle for adoption of the plan is to resolve the relationship between the Methow and Winthrop hatcheries, which operate under separate and conflicting legal requirements. Cates assured the committee that USFWS will work to resolve these differences, given the constraints under the U.S. *v* Oregon Agreement. Scribner said he will work within that arena to achieve resolution. Erho said that the next draft, to be submitted in February, will incorporate the comments of the committee.

D. Okanogan Sockeye

1. Comments on CRITFC Enhancement Plan

The WCC discussed the comments on the Columbia River Intertribal Fish Commission (CRITFC) Enhancement Plan, which were provided by Puget Power and Douglas PUD. Both parties expressed concern over the plan's technical merit, nebulous goals, and lack of coordination with the Canadian authorities. Bugert suggested an *ad hoc* group be developed to continue work on the CRITFC plan and to resolve these problems. The WCC appointed Klinge, Cates, Marco, Bugert, and a CRITFC representative to this group. Heinith will notify the group of that representative.

Heinith distributed a letter on behalf of the JFP (Attachment B) recommending to Douglas PUD they continue biological monitoring of Okanogan sockeye. Klinge said Douglas PUD will provide a comment in the January meeting.

2. Cassimer Bar status report

Marco gave a status report on the 1994 brood sockeye at Cassimer Bar. He said only 141 adults were collected, because of the poor run strength to Wells Dam (1,665) in 1994. Less than 40% of the collected adults were female, and the adults suffered a high mortality (about 20%); the cause of the mortality was not known. The hatchery currently has 67,000 eyed eggs on station. There was no positive detections of IHN in the adults, hence egg segregation is not required.

Marco reported that a student from Eastern Washington University requested 288 sockeye in 1995 for physiological studies. The WCC was reluctant to supply these salmon when the run is depressed, and suggested the student use Baker River stock. Feldman said he could arrange this transfer.

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The next meeting of the Wells Project Coordinating Committee is set for 25 January 1995.

ATTENDANCE LIST

Bill Hevlin	National Marine Fisheries Service
Cary Feldman	Puget Power Company
Tom Scribner	Yakama Indian Nation
Bob Heinith	Columbia River Intertribal Fish Commission
Rod Woodin	Washington Department of Fish and Wildlife
Mike Erho	Private consultant
Rick Klinge	Douglas PUD
Brian Cates	U.S. Fish and Wildlife Service
Jerry Marco	Colville Confederated Tribes
Bob Bugert	Washington Department of Fish and Wildlife

ATTACHMENTS

Attachment A: 1995 Wells Project squawfish removal proposal

Attachment B: Letter from CRITFC to Douglas PUD on recommended studies for Okanogan sockeye

MEMBERSHIP LIST OF THE

WELLS COORDINATING COMMITTEE

1994

APPENDIX - N

APPENDIX

1994 MEMBERSHIP LIST

OF

WELLS COORDINATING COMMITTEE

Mr. Ron Boyce
Oregon Department of Fish and Wildlife

Mr. Brian Cates
U. S. Fish and Wildlife Service

Mr. Carey Feldmann
Puget Power Company

Mr. Bob Heinith
Columbia River Inter-Tribal Fisheries Commission

Mr. Bill Hevlin
National Marine Fisheries Service

Mr. Rick Klinge
Public Utility District No. 1 of Douglas County

Mr. Jerry Marco
Colville Confederated Tribes

Mr. Tom Scribner
Yakama Indian Nation

Dr. Richard R. Whitney
Wells Coordinating Committee Chairman

Mr. Rod Woodin
Washington Department of Fisheries

THE LONG TERM SETTLEMENT AGREEMENT

FOR THE

WELLS HYDROELECTRIC PROJECT

APPENDIX - O

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Public Utility District No. 1 of Douglas County, Washington	)))	Project No. 2149 Docket No. E-9569

SETTLEMENT AGREEMENT

This Settlement Agreement is entered into this 1st day of October, 1990, by the Public Utility District No. 1 of Douglas County, Washington (the PUD), Puget Sound Power & Light Company, Pacific Power and Light Company, the Washington Water Power Company, Portland General Electric Company (collectively the Power Purchasers), the Washington Department of Fisheries, the Washington Department of Wildlife, the Oregon Department of Fish and Wildlife, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Confederated Tribes and Bands of the Yakima Indian Nation, the Confederated Tribes of the Umatilla Reservation, and the Confederated Tribes of the Colville Reservation (collectively the Joint Fishery Parties).

I. GENERAL

A. PURPOSE AND SCOPE

1. This Agreement establishes the PUD's obligations with respect to the installation and operation of juvenile downstream migrant bypass facilities and measures; hatchery compensation for fish losses; and adult fishway operation at least until March 1, 2004, as described in subsection I.C. For purposes of the Wells Project, these measures, in conjunction with existing hatchery

Agreement.

5. For purposes of this Agreement, except under subsections VI.B, VII.B and E, VIII.B and D, the Power Purchasers collectively will be a single Party. For all purposes under this Agreement, except under subsections VI.B, VII.B and E, VIII.B and D, the Power Purchasers shall participate through a single representative, whom they will designate from time to time.

B. <u>DURATION</u>

The term of this Agreement shall commence on the date of execution by all Parties and shall continue for the term of the current license for the Wells Project, plus the term of any annual licenses which may be issued after the current license has expired.

C. <u>MODIFICATIONS TO THE AGREEMENT</u>

1. Notwithstanding subsection I.B, at any time after March 1, 2004, any Party may request all other Parties to commence negotiations to modify the terms and conditions of this Agreement in whole or in part. Any such modification shall be subject to FERC approval, except that the Parties may agree to implement on an interim basis, pending FERC approval, any measure not requiring prior FERC approval. No Party shall file a petition with FERC pursuant to subsection I.C.2 to modify this Agreement without first presenting the proposed modification to all Parties and allowing a reasonable opportunity to negotiate, not to exceed 90 days without consent of all Parties.

2. Subject to the limitation stated in the above subsection, at any time after March 1, 2004, any Party to this Agreement may:

both, that might have arisen during the period March 7, 1979, through March 1, 2004.

5. Notwithstanding any other provision of this subsection I.C, any Party may participate in any legislative or administrative proceeding dealing with fish protection or compensation issues provided, that, consistent with this subsection, no Party shall advocate or support the imposition of fish protection, mitigation, or compensation measures at the Wells Project that are different from or in addition to those required by this Agreement until after March 1, 2004.

6. The Parties intend that this subsection I.C shall apply to each and every provision of this Agreement, and therefore the terms of this subsection are hereby incorporated by reference into and shall apply to every other provision of this Agreement as if set out fully in each such provision.

D. RESOLUTION OF DISPUTES

1. Any dispute between the Parties concerning compliance with this Agreement shall be referred for consideration to the Wells Project Coordinating Committee (the Coordinating Committee) established under Section V. The Coordinating Committee shall convene as soon as practicable following issuance of a written request by any Party. All decisions of the Coordinating Committee must be unanimous. In the event the Coordinating Committee cannot resolve the dispute within fifteen (15) days after its first meeting on a dispute, it will give notice of its failure to resolve the dispute to all Parties. Thereafter, if the dispute qualifies

Party that expedited review is requested. Responsive statements shall be filed and served within forty (40) days of the mailing of the notice. The Decisionmaker shall set a date for submission of any briefing, affidavits or other written evidence and a further date for hearing of oral evidence and argument. Except by agreement of all Parties involved in the dispute, the hearing shall be held not later than seventy (70) days after the date of mailing of the requesting Party's notice or as soon thereafter as the Decisionmaker shall be available. The hearing shall be held in Seattle, Portland or any other location agreed upon by the Parties, or mandated, upon a finding of special circumstances, by the Decisionmaker. The Decisionmaker shall decide all matters presented within fifteen (15) days of the hearing or as soon thereafter as possible.

4. All decisions under the expedited review process shall be effective upon issuance and pending appeal, if any. Nothing in this subsection I.D shall limit or restrict the right of any Party to petition the FERC for de novo review of any decision under the expedited review process. All such appeals shall be in accordance with the FERC's Rules of Practice and Procedure.

5. The Parties may agree to refer any issue subject to expedited review to a third party Decisionmaker other than someone within FERC for processing pursuant to this subsection or as otherwise agreed by the Parties.

B. BYPASS SYSTEM

The PUD will continue to implement a program of controlled spill using five (5) bypass baffles at the Wells Project to meet the criteria set out in subsections II.C, D, and E.

C. NORMAL BYPASS OPERATIONS CRITERIA

1. No turbine will be operated during the juvenile migration period unless the adjacent bypass system is operating according to the following criteria.

2. The five (5) bypass system bays will be Nos. 2, 4, 6, 8, and 10. Operation of the turbines will be in pairs with the associated bypass system bays, as follows:

Turbines Operated	Bypass Bays Operated
1 and/or 2	2
3 and/or 4	4
5 and/or 6	6
7 and/or 8	8
9 and/or 10	10

(For example, if turbines 1, 5, and 6 are operating, bypass systems 2 and 6 will be operating.)

3. At least one bypass will be operating continuously throughout the juvenile migration period, even if no turbines are operating.

4. The bypass systems and spillgates will be operated in configuration K of the 1987 bypass system report (bottom spill, 1 foot spill gate opening, 2,200 cfs, vertical baffle opening) for all bypass system bays.

E. BYPASS PERFORMANCE CRITERIA

1. At a minimum, bypass system operations will be provided as described in subsections II.B, C, and D for the entire juvenile migration period as defined in the annual operations plan under subsection II.F, and subject to the provisions of subsection II.F.3.

2. Bypass operations as described in subsections II.B, C, and D are intended to provide fish passage efficiency (FPE) of at least eighty percent (80%) for the juvenile spring migration, and FPE of at least seventy percent (70%) for the juvenile summer migration. For purposes of this Agreement, FPE is expressed by the following formula:

Where A = Sum of daily migrants successfully passed by the device during the spring or summer migration

and B = Sum of daily migrants passing through the turbine unit intakes during the same migration

$$FPE = \frac{A}{A + B} \times 100$$

3. If bypass operations under subsections II.B, C, and D do not meet the minimum FPE levels specified in subsection II.E.2, the PUD will modify those operations by implementing one or more of the following measures:

(a) Change in configuration or addition of lights or other physical changes.

(b) Change in "normal operation" under subsection II.C to operation of five bypass system bays at forecast flow of 120 Kcfs.

dates from facilities above Wells and previous passage monitoring data. The plan will contain predicted dates for the beginning and end of the juvenile migration period; criteria for identifying the beginning and end of the spring and summer runs; and procedures for bypass operations within the constraints of subsections II.B, C, D, and E, including dates for installation and removal of spill baffles, dates for run time monitoring, and criteria for initiation and cessation of bypass operations. If unanimous agreement cannot be reached within the Coordinating Committee regarding all items in the plan, disagreements will be resolved by expedited dispute resolution under subsection I.D.

2. A Bypass Team will be established composed of one representative each for the Party fishery agencies, the Party tribes, and the PUD.

3. Notwithstanding the provisions of subsections II.F.1 and 2 above, the Bypass Team may agree to relax the operations and performance criteria of subsections II.C and E for a period between the end of the juvenile spring migration and the beginning of the juvenile summer migration. Such a modification can only be made with the agreement of all of the members of the Bypass Team, and will be limited to one or more of the following measures:

(a) Less than continuous 24-hour operation of bypass systems.

(b) Fewer than one bypass system operated for two adjacent turbines operated.

(c) Less than 1 foot spill gate slot opening.

operational changes are made to the bypass systems, additional FPE evaluation under a new or amended plan will be required to provide at least three consecutive years of evaluation after completion of the changes.

2. It is the goal of evaluations under the plan to be able to determine FPE within plus or minus five percent (5%) at the ninety-five percent (95%) confidence level. If the FPE point estimates are equal to or greater than eighty-five percent (85%) for the spring run and seventy five percent (75%) for the summer run, then the accuracy of plus or minus ten percent (10%) at the ninety percent (90%) confidence level is acceptable. If the FPE point estimate for the spring run is between eighty (80) and eighty-five (85) percent, or the FPE point estimate for the summer run is between seventy (70) and seventy-five (75) percent, the PUD will implement one of the following actions:

(a) Take the necessary steps to achieve a FPE accuracy of plus or minus five percent (5%) at the ninety-five percent (95%) confidence level, or

(b) Take steps outlined in subsection II.E.3 to increase the FPE point estimates to eighty-five percent (85%) and seventy-five percent (75%) for the spring and summer runs, respectively.

3. The PUD will fund a biometrician or statistician selected by unanimous agreement of the Coordinating Committee to review the draft plan to ensure that the plan meets the objectives of subsections II.H.1 and 2, and to review results developed under the plan.

2. Lower jet (30-inch diameter) will operate only when the low level fixed orifice entrance is open.

3. Three 24-inch diameter jets (at elevations 700, 708, and 717 msl) will each be discharging when tailwater reaches that level.

E. STAFF GAUGE AND WATER LEVEL INDICATOR CRITERIA

Staff gauge and water level indicators will:

1. Be located upstream and downstream of all entrances, and at convenient locations for viewing along ladder.

2. Be located upstream and downstream of adult fishway exit trashrack.

3. Be readable at all water levels and be kept clean.

4. Be checked against panel board water surface readings to insure proper adjustment of water level sensing equipment.

F. TRASHRACK CRITERIA

1. Visible buildups of debris will be cleaned immediately from picketed leads near counting stations, and from trashracks at adult fishway exits.

2. The staff gauges upstream and downstream of the adult fishway exit trashrack will be monitored for water surface differential, which will reflect buildup on submerged trashrack. The trashrack will be cleaned immediately if the differential reading is greater than 0.3 feet.

G. MONITORING AND EVALUATION OF ADULT PASSAGE

1. In 1990, the PUD, in consultation with the Joint Fishery Parties, will develop a study plan to determine the extent of adult

rearing, and adult holding; and acclimation facilities in the tributaries above Wells Dam for final rearing and release.

A. PRODUCTION PLAN

1. The Joint Fishery Parties have developed the Production Plan to define the requirements of hatchery-based compensation under this Agreement. The Production Plan describes juvenile rearing and release requirements, including species mix and target release sizes; and related broodstock requirements under subsection IV.D.

2. The Production Plan will be reviewed annually by the Joint Fishery Parties, and may be modified by the Joint Fishery Parties in consultation with the PUD. Modifications to the Production Plan may include changes to the species mix and rearing and release strategies as required to accommodate the Joint Fishery Parties' management needs. Modifications to the Production Plan will not require an increase in the rearing capability of the Program beyond that required to satisfy Phases One and Two of the Production Plan as shown in subsections IV.A.3(a) and (b) or Phases Three and Four of the Production Plan to be determined as shown in sections IV.A.3(c) and (d). The Production Plan and any modifications thereto will be consistent with guidelines and procedures developed under the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program.

3. The Production Plan is comprised of four phases of hatchery-based compensation as described below. It also includes related broodstock requirements under subsection IV.D.

about 10/pound; and 6,500 pounds of zero-age summer chinook juveniles at about 40/pound.

(c) Phase Three

Phase Three will begin as soon as practicable following Coordinating Committee approval of the results of the Wells Project juvenile mortality/survival study or no later than the third brood year after Coordinating Committee determination of the adjustments required and will consist of the following compensation elements:

(1) Except for steelhead, which shall remain at 30,000 pounds, adjust compensation requirement to reflect the difference between the juvenile mortality rate determined by the mortality/survival study under subsection IV.C.5 and the assumed mortality rate shown in Appendix A; and

(2) Adjust compensation requirement to reflect unavoidable and unmitigated adult losses, as determined by Coordinating Committee approved estimates from studies conducted under subsection III.G, and converted to juvenile production based on adult to smolt ratio estimates as described in Appendix B.

(d) Phase Four

Phase Four will begin at such time as the Coordinating Committee approved five-year rolling average estimate of juvenile run size, estimated as described in subsection IV.C.6 and Appendix A, increases to at least 110% of the 9,034,700 estimated juvenile migrant salmon production used to establish the Phase One and Phase Two compensation levels shown in subsections IV.A.3(a) and

Phase One production is initiated. Nothing in this Agreement will affect the annual production of 25,000 pounds of steelhead under the Oroville-Tonasket agreement between the PUD and the U.S. Bureau of Reclamation.

5. Facilities provided in the Program will consist of:

(a) Phase One

Phase One compensation facilities, including satellite facilities, shall be capable of rearing and releasing 57,200 pounds of salmon and 30,000 pounds of steelhead annually.

(b) Phase Two

Phase Two compensation facilities shall be capable of increased production to accommodate the Production Plan as described in subsection IV.A.3(b).

(c) Phase Three

Phase Three compensation facilities shall be capable of production levels to reflect the compensation adjustments which may be required as described in subsection IV.A.3(c).

(d) Phase Four

Phase Four compensation facilities shall be capable of production levels to reflect the compensation adjustments which may be required as described in subsection IV.A.3(d). Facilities for the required adjustments will be constructed by the PUD as soon as practicable and be operational no later than the third brood year following the Joint Fishery Parties request under subsection IV.A.3(d).

(a) The studies will involve marking a portion of the juvenile fish produced under subsection IV.B and will involve recoveries of juvenile and adult fish to estimate various parameters such as fish health, fishery contribution, survival, spawning time and spawning locations.

(b) The PUD will fund recovery efforts at Wells Dam and hatchery and tributary spawning areas above Wells Dam. Existing recovery operations, currently funded through different sources, will be utilized to the extent possible. Approved studies may require the PUD's participation in funding a portion of other recovery efforts.

(c) The evaluations provide data necessary to determine the success of the Program to produce the intended compensation levels and the effectiveness of the Production Plan to meet management objectives.

(d) Evaluation of the Production Plan and Program effectiveness will be initiated in Phase One for all species in the Production Plan.

(e) To the extent that the Joint Fishery Parties elect to modify the Production Plan, the PUD will fund studies to evaluate the modifications. The studies will be mutually agreeable and are intended to evaluate only the changes called for in the modification. The studies will be consistent with the provisions of Section V, Coordinating Committee.

(f) The PUD will fund an analysis of annual fish production and adult contribution to harvest and escapement to be conducted

1. Salmon Criteria

(a) Adult Holding

(i) Density not to exceed one (1) fish per ten (10) cubic feet of space.

(ii) Flow must be at least one (1) gallon per minute per 20 pounds of fish.

(b) Juvenile Rearing

(i) Density not to exceed 0.75 pounds of fish per cubic foot of rearing space for yearling chinook to a size of 10 fish per pound. Maximum density is achieved at release date. The density through out the rearing period is proportionately lower and directly related to fish size.

(ii) Pond or raceway loading rate not to exceed 6.0 pounds of fish per gallon of water per minute inflow for yearling chinook at a size of 10 fish per pound. Maximum loading rate is achieved at release date. The loading rate throughout the rearing period is proportionately lower and directly related to fish size.

(iii) Density for sockeye juveniles in net pens not to exceed 0.33 pounds of fish per cubic foot of rearing space.

(iii) Protection from mammalian and avian predators must be provided.

2. Salmon Guidelines

(a) Water Temperatures

(i) Egg incubation - no greater than 55°F nor less than 38°F.

(ii) Fry starting - 48-52°F.

(iii) Juvenile rearing - not to exceed 52°F.

(iv) Adult holding - not to exceed 55°F.

(b) Release Size, Time, and Location

(i) Yearling spring chinook - 15 fish/pound in late April.

(ii) Yearling summer chinook - 10 fish/pound in late April.

(iii) Subyearling summer chinook - 40 fish/pound in June.

(iv) Subyearling sockeye - 25 fish/pound in June.

(v) Juvenile fish will be acclimated and released in tributaries above Wells Dam.

(c) Adult Brood Stock

(i) Sufficient adults of the appropriate species and stocks will be trapped and held to meet the egg requirements for each phase of salmon production.

(ii) Fifty percent (50%) of the adults trapped will be females and it is assumed there will be minimize delay of non-target species and individual fish.

3. Steelhead Criteria

The goal for this program is to use the existing facilities including well and river water, raceways, rearing ponds, house, shop, freezer, office, etc., in the manner they are being used now. Most of the following criteria and guidelines fit the existing program.

(a) Adult Holding

(i) Density not to exceed 2.5 pounds of fish per cubic foot of water.

(ii) Flow must be at least one gallon per minute for 3.3 pounds of fish.

(b) Juvenile Rearing

(i) Density: Calculated density limit not to exceed Pipers density formula: W= D x V x L where

W = Permissible weight in pounds.

D = Density index (.25 for raceways and .03 for rearing ponds).

V = Useable volume in container in cubic feet.

L = Fish length in inches.

ii) Water flow: Calculated flow should not allow weight to exceed Pipers flow formula:

W= F x L x I where

W = Permissible weight in pounds.

must not stop release of fish in local watersheds.

(ii) Reuse water not acceptable for egg incubation.

(iii) Reuse water normally acceptable (unless disease problem) for adult holding.

(iv) Effluent water from egg incubation will require treatment for fish diseases.

(v) Adult holding and juvenile rearing water may have to be treated for disease pathogens.

(d) General

(i) Facilities must have reasonable capability to provide for isolation and treatment of diseased fish.

(ii) Protection from mammalian and avian predators must be provided.

4. Steelhead Guidelines

(a) Water Temperatures

(i) Egg incubation: 38°F to 55°F

(ii) Fry starting: 48°F to 54°F

(iii) Juvenile Rearing not to exceed 57°F

(iv) Pre-smolt not to exceed 54°F

(v) Adult holding not to exceed 54°F

(b) Release age, time, size and location

(i) Released as yearlings

(ii) April 10 to May 10 at six to the pound.

B. USE OF COMMITTEE

The Coordinating Committee will be used as the primary means of consultation and coordination between the PUD and the Joint Fishery Parties in connection with the conduct of studies and implementation of the measures set forth in this Agreement and for dispute resolution pursuant to subsection I.D. All study designs and modifications to study designs will be subject to agreement by all Parties.

C. STUDIES AND REPORTS

1. All studies and reports prepared under this Agreement will be available to all Parties as soon as reasonably possible. Draft reports will be circulated through Coordinating Committee representatives for comment, and comments will either be addressed in order or made an appendix to the final report.

2. All studies will be conducted following accepted techniques and methodologies in use for similar studies in the Columbia Basin. All studies will be based on sound statistical design and analysis.

3. Fish passage efficiency tests will be conducted using hydroacoustic means and direct capture methods for species identification.

VI. JOINT FISHERY PARTIES' RESPONSIBILITIES

A. LIMITATION OF MID-COLUMBIA PROCEEDING

The Joint Fishery Parties agree to join with the PUD to request that the FERC terminate the Mid-Columbia proceeding insofar

C. STIPULATION OF ADEQUACY

The Joint Fishery Parties stipulate that the performance of the PUD's responsibilities under this Agreement constitutes adequate fish protection and full compensation for all fishery losses caused by the Wells Project at least until March 1, 2004. It is further stipulated that this Agreement satisfies any obligations of any Party relating to the adequacy of fish protection and compensation for fish losses caused by the Wells Project, and arising under applicable laws and regulations, including but not limited to the Federal Power Act, the Pacific Northwest Electric Power Planning and Conservation Act, and the Electric Consumers Protection Act of 1986, at least until March 1, 2004. This Agreement shall not otherwise affect the rights of any Party except as expressly covered by this Agreement.

D. FISH AND WILDLIFE PROGRAM

The Joint Fishery Parties stipulate that the performance of the PUD's responsibilities under this Agreement shall constitute full compliance with the applicable provisions of the Northwest Power Planning Council's 1987 Fish and Wildlife Program, at least until March 1, 2004. The Joint Fishery Parties stipulate that the PUD shall receive full credit for its hatchery production in meeting any requirements that may be established as a result of implementation of Section 203 of the Council's Program.

E. LIMITATION ON REOPENING

The Joint Fishery Parties shall not invoke or rely upon an reopener clause set forth in any license applicable to the Well connection with this Agreement shall not be considered a waiver with respect to any subsequent default or matter.

D. ENTIRE AGREEMENT -- MODIFICATIONS

All previous communications between the Parties hereto, either verbal or written, with reference to the subject matter of this Agreement are hereby abrogated, and this Agreement duly accepted and approved, constitutes the entire agreement between the Parties hereto, and no modifications of this Agreement shall be binding upon any Party unless executed or approved in accordance with the procedures set forth in subsection I.C.

E. BENEFIT AND ASSIGNMENT

This Agreement shall be binding upon and inure to the benefit of the Parties hereto and their successors and assigns provided, no interest, right or obligation under this Agreement shall be transferred or assigned by any Party hereto to any other Party or to any third party without the written consent of all other Parties, except by a Party:

(a) To any person or entity into which or with which the Party making the assignment or transfer is merged or consolidated or to which such Party transfers substantially all of its assets; or

(b) To any person or entity that wholly owns, is wholly owned by or is wholly owned in common with the Party making the assignment or transfer.

held by the U.S. Fish and Wildlife Service (FWS), and subject to full or partial recall by FWS for any reason. The PUD shall not obtain legal title or ownership of the FWS water right.

3. To the extent that the utilization of water does not occur or is recalled or returned to FWS, the PUD and WDF shall use their best efforts to acquire an alternative source of water that meets applicable State requirements for water rights in order to satisfy obligations under this Agreement.

4. The PUD agrees to cooperate with WDF to secure the necessary permits in order to construct and provide for the operation of the proposed Methow River hatchery. The hatchery will be designed and constructed with the capability of installing pump-back facilities for returning the flow to the point of diversion.

5. If hatchery and/or river water supply requirements dictate the need for installation of a pump-back scheme, the PUD shall install and WDF shall operate the pump-back facilities.

VIII. REGULATORY APPROVAL

A. FERC ORDERS

All Parties agree to join in the filing of an offer of settlement with the FERC based on this Agreement and to request that the FERC issue appropriate orders approving the settlement. All Parties shall refrain from seeking judicial review of the FERC orders approving this Agreement.

B. PERFORMANCE CONTINGENT ON APPROVAL

Performance of all Parties' obligations under this Agreement

F. ACTION FOR NONCOMPLIANCE

Notwithstanding any other provision of this Agreement, any Party may seek relief arising solely from noncompliance with this Agreement by any Party; provided, all requests for specific performance of any provision of this Agreement shall be filed with the FERC pursuant to subsection I.D.

IN WITNESS WHEREOF, the Parties have executed this Agreement the day and year first written above.

of juvenile migrant salmon entering Wells reservoir are:

Spring Chinook	=	1,504,400
Summer Chinook	=	2,913,300
Sockeye	=	4,617,000
Total	=	9,034,700

b. The total project mortality at Wells, including reservoir mortality, was estimated to be 14%. Applying this mortality rate to the population estimates in Item 1 above results in the following estimates of juvenile migrants killed by species:

Spring Chinook	=	210,600
Summer Chinook	=	407,900
Sockeye	=	646,400
Total loss	=	1,264,900

3. Derivation of Production Plan

a. The Phase I compensation Production Plan and Program is an initial step in production which is not intended to provide full compensation for juvenile migrant losses. The lack of full compensation is due to the experimental nature and developmental aspects of the sockeye Production Plan and Program.

b. To accommodate logistic and per-unit cost factors in Phase I development, about 225,000 (15,000 pounds) spring chinook were substituted for 231,000 sockeye.

15,000 lbs. of Summer Chinook @ 10/lb.

6,500 lbs. of Summer Chinook at 40/lb.

APPENDIX B

DETERMINATION OF RESPONSIBILITY FOR HATCHERY COMPENSATION

For each year of determination, calculate an average smolt output as follows:

1. Calculate a 5-year running average adult run (by species) for naturally spawned fish (Ays) as follows:

$$\bar{A}ys = \frac{Ay + Ay\text{-}1 + Ay\text{-}2 + Ay\text{-}3 + Ay\text{-}4}{5}$$

   Where Ay is the total adult count for each species at Wells minus the hatchery escapement for the species in year y; Ay-1 = the same in the previous year (y-1) and so on.

2. Multiply Ays by the average expected adult to smolt production factor Kys for each species, where Kys is calculated as follows:

   a. Spring Chinook:

   Ksp = 0.94 (Wells Dam to spawner survival) x 0.50 (sex ratio) x 5000 (eggs/female) x 0.10 (av. survival to smolt) = 235

   b. Summer Chinook:

   Ksu = 0.94 x 0.50 x 5000 x 0.30 = 705

WELLS PHASE IV THEORETICAL CALCULATION EXAMPLE

NATURAL PRODUCTION

DATA USED IN EXAMPLE CALCULATION OF NATURAL PRODUCTION

Adult Count	Ay	Ay-1	Ay-2	Ay-3	Ay-4	5 Year Average
Spring Chinook	3,000	2,200	3,100	5,000	2,900	3,240
Summer Chinook	2,400	2,800	3,700	4,000	4,700	3,520
Sockeye	40,000	20,000	35,000	15,000	30,000	28,000

Ay = Wells Count Minus Hatchery Escapement for Year Y

Ksp = Calculated Spring Chinook Smolts

Ksu = Calculated Summer Chinook Smolts

Ksoe = Calculated Sockeye Smolts

Spring Chinook $\bar{A}y$ $= \frac{Ay + Ay\text{-}1 + Ay\text{-}2 + Ay\text{-}3 + Ay\text{-}4}{5}$

$= \frac{3000 + 2200 + 3100 + 5000 + 2900}{5}$

$= 3240$

Summer Chinook $\bar{A}y$ $= \frac{Ay + Ay\text{-}1 + Ay\text{-}2 + Ay\text{-}3 + Ay\text{-}4}{5}$

$= \frac{2400 + 2800 + 3700 + 4000 + 4700}{5}$

$= 3520$

Sockeye $\bar{A}y$ $= \frac{Ay + Ay\text{-}1 + Ay\text{-}2 + Ay\text{-}3 + Ay\text{-}5}{5}$

$= \frac{40,000 + 20,000 + 35,000 + 15,000 + 30,000}{5}$

$= 28,000$

Ksp, su, soc = Adult/redd factor x sex ratio x eggs/female x eggs to smolt survival x dam count minus hatchery return

= 585,000

Twisp Accl. Pond = $\frac{400,000 + 400,000 + 400,000 + 250,000 + 200,000}{5}$

= 330,000

Sockeye Net Pens* = $\frac{200,000 + 200,000 + 200,000 + 150,000 + 100,000}{5}$

= 170,000

*Need Adjustment Factor For Survival To Migration

Average Total Hatchery Smolts

Winthrop	=	1,100,000
Methow	=	585,000
Twisp	=	330,000
Net Pens	=	170,000
		2,185,000

Average Total Hatchery/Natural Smolts
(5 Year Average for Years Y-4, Y-3, Y-2, Y-1 and Y)

Natural	=	7,779,000
Hatchery	=	2,185,000
Total	=	9,964,000

PHASE IV DETERMINATION

Base Number Smolts Used for Initial Compensation = 9,034,700

Calculated Average Natural + Hatchery Smolts in Years Y-4, Y-3, Y-2, Y-1 and Y = 9,964,000

Calculated Average Natural + Hatchery Smolts Minus Base Number Smolts = 929,300

Difference Between Base Number Smolts and Calculated Natural + Hatchery Smolts X Wells Project Mortality Rate = 929,300 X .14

= Additional Smolts Possible Under Phase IV 130,102

FOR PUBLIC UTILITY DISTRICT NO. 1
OF DOUGLAS COUNTY, WASHINGTON:

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Commissioner

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Commissioner

____
Commissioner

FOR PUGET SOUND POWER & LIGHT COMPANY:

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FOR PACIFIC POWER & LIGHT COMPANY:

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FOR THE WASHINGTON WATER POWER COMPANY:

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FOR PORTLAND GENERAL ELECTRIC COMPANY:

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FOR THE WASHINGTON DEPARTMENT
OF FISHERIES:

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FOR THE WASHINGTON DEPARTMENT
OF WILDLIFE:

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FOR PUBLIC UTILITY DISTRICT NO. 1
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FOR THE WASHINGTON DEPARTMENT
OF FISHERIES:

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FOR THE WASHINGTON DEPARTMENT
OF WILDLIFE:

Ray Ryan 6/11/90
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FOR THE OREGON DEPARTMENT OF
FISH AND WILDLIFE:

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FOR THE NATIONAL MARINE
FISHERIES SERVICE:

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FOR THE U.S. FISH & WILDLIFE SERVICE:

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FOR THE CONFEDERATED TRIBES AND BANDS
OF THE YAKIMA INDIAN NATION:

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FOR THE CONFEDERATED TRIBES
OF THE UMATILLA INDIAN RESERVATION:

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FOR THE CONFEDERATED TRIBES
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