US Army Corps
of Engineers®
Walla Walla District

FINAL

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

APPENDIX B

Resident Fish

February 2002

FEASIBILITY STUDY DOCUMENTATION

	Document Title
Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement	
Appendix A (bound with B)	Anadromous Fish Modeling
Appendix B (bound with A)	Resident Fish
Appendix C	Water Quality
Appendix D	Natural River Drawdown Engineering
Appendix E	Existing Systems and Major System Improvements Engineering
Appendix F (bound with G, H)	Hydrology/Hydraulics and Sedimentation
Appendix G (bound with F, H)	Hydroregulations
Appendix H (bound with F, G)	Fluvial Geomorphology
Appendix I	Economics
Appendix J	Plan Formulation
Appendix K	Real Estate
Appendix L (bound with M)	Lower Snake River Mitigation History and Status
Appendix M (bound with L)	Fish and Wildlife Coordination Act Report
Appendix N (bound with O, P)	Cultural Resources
Appendix O (bound with N, P)	Public Outreach Program
Appendix P (bound with N, O)	Air Quality
Appendix Q (bound with R, T)	Tribal Consultation and Coordination
Appendix R (bound with Q, T)	Historical Perspectives
Appendix S*	Snake River Maps
Appendix T (bound with R, Q)	Clean Water Act, Section 404(b)(1) Evaluation
Appendix U	Response to Public Comments

*Appendix S, Lower Snake River Maps, is bound separately (out of order) to accommodate a special 11 x 17 format.

The documents listed above, as well as supporting technical reports and other study information, are available on our website at http://www.nww.usace.army.mil/lsr. Copies of these documents are also available for public review at various city, county, and regional libraries.

STUDY OVERVIEW

Purpose and Need

Between 1991 and 1997, due to declines in abundance, the National Marine Fisheries Service (NMFS) made the following listings of Snake River salmon or steelhead under the Endangered Species Act (ESA) as amended:

- sockeye salmon (listed as endangered in 1991)
- spring/summer chinook salmon (listed as threatened in 1992)
- fall chinook salmon (listed as threatened in 1992)
- steelhead (listed as threatened in 1997).

In 1995, NMFS issued a Biological Opinion on operations of the Federal Columbia River Power System (FCRPS). Additional opinions were issued in 1998 and 2000. The Biological Opinions established measures to halt and reverse the declines of ESA-listed species. This created the need to evaluate the feasibility, design, and engineering work for these measures.

The Corps implemented a study (after NMFS' Biological Opinion in 1995) of alternatives associated with lower Snake River Dams and reservoirs. This study was named the Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study). The specific purpose and need of the Feasibility Study is to evaluate and screen structural alternatives that may increase survival of juvenile anadromous fish through the Lower Snake River Project (which includes the four lowermost dams operated by the Corps on the Snake River—Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams) and assist in their recovery.

Development of Alternatives

The Corps' response to the 1995 Biological Opinion and, ultimately, this Feasibility Study, evolved from a System Configuration Study (SCS) initiated in 1991. The SCS was undertaken to evaluate the technical, environmental, and economic effects of potential modifications to the configuration of Federal dams and reservoirs on the Snake and Columbia Rivers to improve survival rates for anadromous salmonids.

The SCS was conducted in two phases. Phase I was completed in June 1995. This phase was a reconnaissance-level assessment of multiple concepts including drawdown, upstream collection, additional reservoir storage, migratory canal, and other alternatives for improving conditions for anadromous salmonid migration.

The Corps completed a Phase II interim report on the Feasibility Study in December 1996. The report evaluated the feasibility of drawdown to natural river levels, spillway crest, and other improvements to existing fish passage facilities.

Based in part on a screening of actions conducted for the Phase I report and the Phase II interim report, the study now focuses on four courses of action:

- Existing Conditions
- Maximum Transport of Juvenile Salmon

- Major System Improvements
- Dam Breaching.

The results of these evaluations are presented in the combined Feasibility Report (FR) and Environmental Impact Statement (EIS). The FR/EIS provides the support for recommendations that will be made regarding decisions on future actions on the Lower Snake River Project for passage of juvenile salmonids. This appendix is a part of the FR/EIS.

Geographic Scope

The geographic area covered by the FR/EIS generally encompasses the 140-mile long lower Snake River reach between Lewiston, Idaho and the Tri-Cities in Washington. The study area does slightly vary by resource area in the FR/EIS because the affected resources have widely varying spatial characteristics throughout the lower Snake River system. For example, socioeconomic effects of a permanent drawdown could be felt throughout the whole Columbia River Basin region with the most effects taking place in the counties of southwest Washington. In contrast, effects on vegetation along the reservoirs would be confined to much smaller areas.

Identification of Alternatives

Since 1995, numerous alternatives have been identified and evaluated. Over time, the alternatives have been assigned numbers and letters that serve as unique identifiers. However, different study groups have sometimes used slightly different numbering or lettering schemes and this has led to some confusion when viewing all the work products prepared during this long period. The primary alternatives that are carried forward in the FR/EIS currently involve the following four major courses of action:

Alternative Name	PATH[1/] Number	Corps Number	FR/EIS Number
Existing Conditions	A-1	A-1	1
Maximum Transport of Juvenile Salmon	A-2	A-2a	2
Major System Improvements	A-2’	A-2d	3
Dam Breaching	A-3	A-3a	4

[1/] Plan for Analyzing and Testing Hypotheses

Summary of Alternatives

The **Existing Conditions Alternative** consists of continuing the fish passage facilities and project operations that were in place or under development at the time this Feasibility Study was initiated. The existing programs and plans underway would continue unless modified through future actions. Project operations include fish hatcheries and Habitat Management Units (HMUs) under the Lower Snake River Fish and Wildlife Compensation Plan (Comp Plan), recreation facilities, power generation, navigation, and irrigation. Adult and juvenile fish passage facilities would continue to operate.

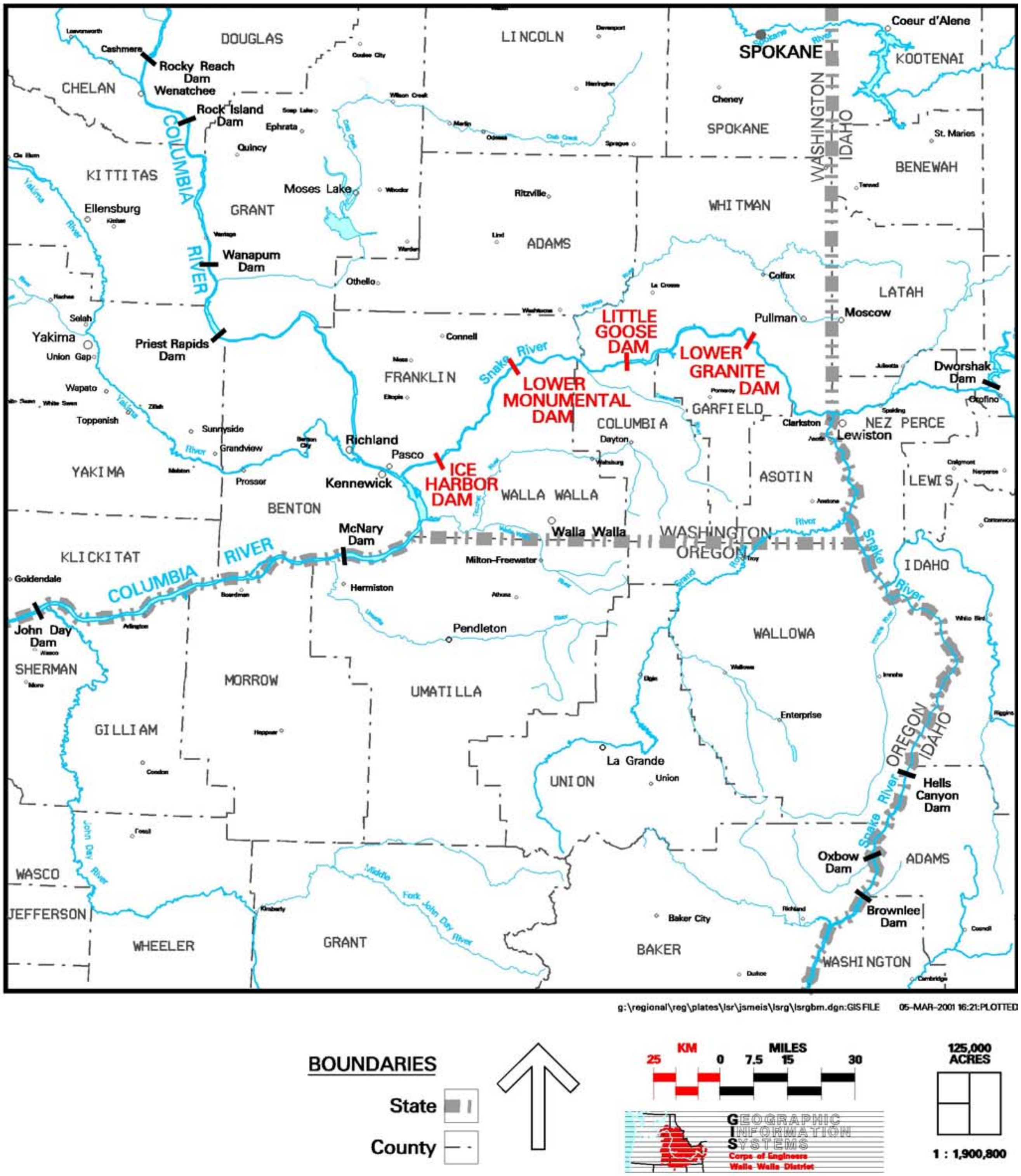
The **Maximum Transport of Juvenile Salmon Alternative** would include all of the existing or planned structural and operational configurations from the Existing Conditions Alternative. However, this alternative assumes that the juvenile fishway systems would be operated to maximize fish transport from Lower Granite, Little Goose, and Lower Monumental and that voluntary spill would not be used to bypass fish through the spillways (except at Ice Harbor). To accommodate this maximization of transport, some measures would be taken to upgrade and improve fish handling facilities.

The **Major System Improvements Alternative** would provide additional improvements to what is considered under the Existing Conditions Alternative. These improvements would be focused on using surface bypass facilities such as surface bypass collectors (SBCs) and removable spillway weirs (RSWs) in conjunction with extended submerged bar screens (ESBSs) and a behavioral guidance structure (BGS). The intent of these facilities would be to provide more effective diversion of juvenile fish away from the turbines. Under this alternative, an adaptive migration strategy would allow flexibility for either in-river migration or collection and transport of juvenile fish downstream in barges and trucks.

The **Dam Breaching Alternative** has been referred to as the “Drawdown Alternative” in many of the study groups since late 1996 and the resulting FR/EIS reports. These two terms essentially refer to the same set of actions. Because the term drawdown can refer to many types of drawdown, the term dam breaching was created to describe the action behind the alternative. The Dam Breaching Alternative would involve significant structural modifications at the four lower Snake River Dams, allowing the reservoirs to be drained and resulting in a free-flowing yet controlled river. Dam breaching would involve removing the earthen embankment sections of the four dams and then developing a channel around the powerhouses, spillways, and navigation locks. With dam breaching, the navigation locks would no longer be operational and navigation for large commercial vessels would be eliminated. Some recreation facilities would close while others would be modified and new facilities could be built in the future. The operation and maintenance of fish hatcheries and HMUs would also change, although the extent of change would probably be small and is not known at this time.

Authority

The four Corps dams of the lower Snake River were constructed and are operated and maintained under laws that may be grouped into three categories: 1) laws initially authorizing construction of the project, 2) laws specific to the project passed subsequent to construction, and 3) laws that generally apply to all Corps reservoirs.



g:\regional\reg\plates\lsr\jsmeis\lsrg\lsrgbm.dgn:GIS FILE 05-MAR-2001 16:21:PLOTTED

LOWER SNAKE RIVER
Juvenile Salmon Migration Feasibility Study

REGIONAL BASE MAP

US Army Corps
of Engineers®
Walla Walla District

Final
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

---

Appendix B
Resident Fish

Produced by
Normandeau Associates, Inc. and
University of Idaho

Produced for
U.S. Army Corps of Engineers
Walla Walla District

February 2002

FOREWORD

Appendix B was prepared by Normandeau Associates, Inc. and the University of Idaho in conjunction with the U.S. Army Corps of Engineers' (Corps) study team. This appendix is one part of the overall effort of the Corps to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input and comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the FR/EIS and appendices; therefore, not all of the opinions and/or findings herein may reflect the official policy or position of the Corps.

CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

BOR	Bureau of Reclamation
BPA	Bonneville Power Administration
BRD	Biological Resources Division
BRZ	boat-restricted zone
CAR	Coordination Act Report
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CPUE	catch per unit effort
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
fps	feet per second
FL	fork length
flip lips	spillway flow deflectors
FR/EIS	Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement
GBT	gas bubble trauma
IDFG	Idaho Department of Fish and Wildlife
KAF	thousand acre-feet
kcfs	thousand cubic feet per second
kg/ha	kilogram per hectare
kg/km	kilogram per kilometer
km	kilometer
m	meter
m^3/s	cubic meters per second
MAF	million acre-feet
MOP	Minimum Operating Pool
MW	megawatt
NEPA	National Environmental Policy Act
NGVD	National Geodetic Vertical Datum
NMFS	National Marine Fisheries Service
NPPC	Northwest Power Planning Council
ODFW	Oregon Department of Fish and Wildlife
ppm	parts per million
rkm	river kilometers
RM	river mile
SOR	System Operation Review
TDG	total dissolved gas
TL	total length
USFWS	U.S. Fish and Wildlife Service

ENGLISH TO METRIC CONVERSION FACTORS

To Convert From	**To**	**Multiply By**
LENGTH CONVERSIONS:		
Inches	Millimeters	25.4
Feet	Meters	0.3048
Miles	Kilometers	1.6093
AREA CONVERSIONS:		
Acres	Hectares	0.4047
Acres	Square meters	4047
Square Miles	Square kilometers	2.590
VOLUME CONVERSIONS:		
Gallons	Cubic meters	0.003785
Cubic yards	Cubic meters	0.7646
Acre-feet	Hectare-meters	0.1234
Acre-feet	Cubic meters	1234
OTHER CONVERSIONS:		
Feet/mile	Meters/kilometer	0.1894
Tons	Kilograms	907.2
Tons/square mile	Kilograms/square kilometer	350.2703
Cubic feet/second	Cubic meters/sec	0.02832
Degrees Fahrenheit	Degrees Celsius	(Deg F –32) x (5/9)

Executive Summary

The purpose of the resident fish appendix to the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS) is to clearly identify and describe the potential effects of various alternative actions on resident fish. This appendix explores the current status of the resident fish community, comprised of both native and introduced fish. Those aspects of each alternative that could impact resident fish are explained, and the biological consequences of each alternative on the fish community are discussed. Resident fish are an important ecosystem component and currently provide recreational opportunities in the reservoirs of the lower Snake River from close to Tri-Cities, Washington, upstream into Idaho, but also negatively interact with juvenile salmonids.

A considerable amount of scientific literature and data was reviewed for this appendix. Most site-specific references resulted from work conducted at the University of Idaho. Much of that information, especially for those species that prey upon juvenile salmonids or are considered important to recreational fisheries, represents the bulk of available, current data. Additional sources consulted for data and information were the fisheries management agencies of Washington, Idaho, and Oregon. Federal agencies that conducted studies of resident fish and provided information included the U.S. Army Corps of Engineers (Corps) and the U.S. Geological Survey, Biological Resources Division, Cook, Washington. An annotated bibliography of the most relevant publications reviewed for this appendix is attached as Annex A.

ES.1 The Reservoirs and Their Habitats

Four dams impound more than 96 percent of the lower Snake River. The four reservoirs constructed include, from upstream to downstream, Lower Granite, Little Goose, Lower Monumental, and Ice Harbor. Each of the reservoirs formed by dams share similar length, surface area, depth, and other morphometric characteristics. Surface areas range from 2,667 to 4,057 hectares (6,590 to 10,025 acres), and mean depths range from 14.6 to 17.4 meters (48 to 57 feet). The impounded reach receives inflow from three major tributaries—the Clearwater, Palouse, and Tucannon rivers.

The Snake River reservoirs conform to a typical longitudinal impoundment gradient composed of three macrohabitat types, or reaches. The tailwater section is the most riverine and extends from immediately below a dam about 8 km (5 miles). The uppermost portion of Lower Granite Reservoir is also more riverine, but is not a tailwater since there is no impoundment immediately upstream. Impoundment of Lower Granite Reservoir is considered to extend upstream almost to Asotin, Washington, on the Snake River arm and close to the Potlatch Corporation in the Clearwater River arm at Lewiston, Idaho. A mid-reservoir reach represents the largest section of each impoundment and is a transition area from the lotic (riverine) character of the tailwater to more lake-like (lentic or lacustrine) conditions closer to the dam. The reach immediately above a dam is the forebay.

Each macrohabitat can contain up to several habitat types, termed mesohabitats. A sampling scheme developed during initial Snake River impoundment research in Little Goose Reservoir identified these mesohabitats as tailwater, upper shoal, lower shoal, lower embayment, gulch, and deepwater. Tailwaters, upper and lower shoals, and deepwater reaches represent main channel habitats. Embayments and gulches represent off-channel areas. Main channel velocities typically decrease with distance downstream from a tailwater. Gulches and embayments have little or no current velocity and are usually considered standing water habitats. Embayments surveyed by the Corps generally were steep-sided and ranged from 0.04 to 4.7 hectares (0.1 to 11.6 acres) in size. Nearly 50 percent of a lower Snake River reservoir's surface area is comprised of deepwater habitat, while shallow-water habitat may be less than 10 percent.

Reservoir substrates are generally embedded in fines and variable in composition; substrate size decreases with distance downstream from a dam. Larger-sized substrates along the north shorelines of the reservoirs are due primarily to riprap placement after parallel road or railroad relocation. Although little characterization of substrates has occurred in Lower Monumental and Ice Harbor reservoirs, a greater occurrence of fines would be expected due to older age and longer depositional history.

ES.2 Lower Snake River Resident Fish

Eighteen native and 17 introduced species comprise the current ichthyofauna of the lower Snake River reservoirs. As a result of recent action by the American Fisheries Society, the northern squawfish was renamed the "northern pikeminnow." The latter name is utilized throughout this appendix. The white sturgeon is a state species of concern in Idaho. Bull trout are listed as a threatened species and are occasionally seen in the lower Snake River.

Current information on the relative abundance of resident fish in the lower Snake River reservoirs suggests that fish community structure is generally similar among reservoirs. Initial fisheries sampling was conducted seasonally in each of the four lower Snake River reservoirs, with the most extensive sampling in Little Goose Reservoir, in 1979 and 1980. Bridgelip sucker, redside shiner, largescale sucker, smallmouth bass, and northern pikeminnow were the age one and older fish in highest relative abundance, based on sampling with multiple gear types in Little Goose Reservoir. These five species accounted for about 80 percent of all fish sampled in 1979 and 1980. All of these fish except smallmouth bass are native species in the Snake River. Less abundant species were a mixture of native and introduced fish. Chiselmouth, another native cyprinid species, was moderately abundant in the lower Snake River reservoirs, while native peamouth, sculpins, and white sturgeon were less abundant. Introduced crappies, yellow perch, and sunfish other than smallmouth bass were highly abundant in off-channel habitats. Other introduced fish such as catfish and bullheads were present, but in lower abundance. Non-migratory salmonid fish were generally rare, seasonal in occurrence, and typically associated with a tributary confluence.

Relative abundance of fish varied among habitats sampled. In general, introduced centrarchid fish were more abundant in lentic backwater habitats, while native suckers and redside shiners were more abundant in the more lotic upreservoir stations (e.g., tailwater and upper shoal). A tendency also existed to have higher abundance of selected introduced species in the older downstream reservoirs, including channel catfish, largemouth bass, and carp. In contrast, non-native smallmouth bass, pumpkinseed, and white crappie were more abundant in upriver reservoirs.

Recent updated information on the relative abundance of selected species has resulted from research on Snake River predator-prey interactions. The Oregon Department of Fish and Wildlife determined that smallmouth bass density was highest in mid-reservoir and forebay reaches, opposite that of channel catfish and northern pikeminnow that were found mostly in mid-reservoir and tailwater reaches, particularly tailrace boat-restricted zones (BRZs). Further, smallmouth bass and channel catfish displayed opposing density gradients; smallmouth bass relative abundance was highest in

Lower Granite Reservoir, whereas relative abundance of channel catfish was highest in Ice Harbor Reservoir. A sport reward program that pays bounties for angler-caught northern pikeminnow has apparently reduced northern pikeminnow relative abundance. Recent sport fishing catches on the lower Snake River reservoirs also generally reflect the most recent trends in relative abundance for most species found with sampling gears.

In spite of the recent information on the relatively high-profile species (i.e., predators), the overall similarities in community composition and relatively limited information on specific fish abundance of most species in each reservoir suggest that the four lower Snake River reservoirs should be treated as one reservoir system. Analysis of expected impacts will be based on examination of the characteristic fish communities in the forebay, tailrace, mid-reservoir, and specific backwater/embayment habitats common to all reservoirs in the system. This type of analysis will facilitate subsequent descriptions of expected impacts to reservoir fish communities for the various alternatives under consideration.

Six species or congeners have been identified for individual treatment as ecologically key, or important, species. The native northern pikeminnow, for example, is important in predator-prey dynamics of the reservoirs and is the focus of population reduction efforts via a sport reward program that pays bounties for removal of large individuals. Largescale and bridgelip suckers are native species that were highly abundant throughout the reservoirs during comprehensive sampling efforts in 1979 and 1980. White and black crappie, smallmouth bass, and channel catfish represent introduced species that are highly sought by sport anglers throughout the reservoir system. Smallmouth bass and channel catfish also have been the focus of predator-prey investigations, along with northern pikeminnow. White sturgeon is a native species that has declined in abundance due to continued harvest, isolation, and loss of flowing water habitats by dams.

All of the ecologically key species are spring or summer spawners. Suckers and white sturgeon may spawn earliest, beginning in April, whereas channel catfish generally spawn the latest, in July. In general, the native suckers, northern pikeminnow, and white sturgeon are more tolerant of water velocities in rearing habitats, whereas introduced smallmouth bass, channel catfish, and particularly crappie, are not. As adults, smallmouth bass, northern pikeminnow, and channel catfish are highly piscivorous, and are sustained by crayfish. White and black crappie are smaller as adults, and eat a varied diet that also includes fish. White sturgeon are primarily benthivorous, including crayfish, but will also eat fish. In contrast, largescale and bridgelip sucker eat primarily diatoms, filamentous algae, and smaller benthic invertebrates.

Substantially less information exists about local populations of other fish in the lower Snake River reservoirs. Many, such as native chiselmouth, peamouth, redside shiner, and sculpins are main channel species that contribute to trophic relationships as prey. Sport anglers also catch introduced fish such as bluegill, pumpkinseed, yellow perch, and brown bullhead in off-channel areas.

ES.3 Spawning Temperature Summary

One of the key environmental variables that will serve as a limiting factor in the ability of the members of the resident fish community to successfully adapt to new riverine or impoundment conditions is water temperature. The seasonal Snake River hydrograph typically experiences peak flows in May and/or June from spring rains and snowmelt. Dry or wet springs or accelerated or delayed snow melt creates highly variable inter-annual spring runoff, which in turn, plays a major role in the overall timing of the water temperature regimen and the summer thermal maxima experienced by lower Snake River fish. High temporal variability in water temperature may have a profound effect on the spawning success of lower Snake River resident fish, particularly non-native species. Spawning temperature ranges and time frames for native and introduced resident fish, including site-specific data where available, show that spawning may extend from April into August at water temperatures from 8 to 26°C (46 to 79°F).

Water temperatures were monitored in the forebay area of Lower Granite Reservoir by recording thermographs for several recent years. These data show that a major source of variability imposed on the spring-summer temperature regime experienced by resident fish during spawning periods is the cooling effect of augmentation flows released from upstream reservoirs (e.g., Dworshak Reservoir) to enhance juvenile salmonid smolt outmigration. These effects are particularly notable during 1994, a low-flow year. Three episodes of rapidly declining water temperatures were evident in mid-May, mid-June, and nearly the entire month of July into August. Two similar episodes occurred in June 1995, a year representative of average runoff.

Flow augmentation can affect spawning and growth of Snake River fish in several ways. Attainment of spawning temperatures may be delayed substantially, growing seasons may be shortened, and optimum temperatures for growth may never be achieved. Theoretically, these conditions contribute to variable year-class strength, although the effects of accelerated, delayed, or depressed spawning and growth temperatures on resident fish have proven difficult to isolate to date.

ES.4 Gas Bubble Trauma

Air is entrained by the plunging action of spilled water at Snake River Dams, creating supersaturated water in tailraces, stilling basins, and downstream reaches. Although dissolved gas concentrations and impacts on anadromous salmonids have been studied extensively, effects on Snake River resident fish are poorly documented. Generally, resident fish are considered more tolerant of high dissolved gas concentrations than salmonids. Resident fish may also reduce their exposure to supersaturated water by occupying deeper portions of affected areas.

Most studies that have examined Snake River resident fish for evidence of gas bubble trauma have reported a low incidence rate. However, one study, which also included a portion of the Columbia River, reported rates of 72 percent and 85 percent for angler-caught smallmouth bass and northern pikeminnow, respectively. However, no studies have provided evidence of effects at the population level.

ES.5 Entrainment of Resident Fish

Only limited evidence of the numbers and species composition of resident fish entrained through lower Snake River Dams has been compiled. The principal source of information was data collected by Corps biologists at juvenile facility separators at the dams.

Largescale and bridgelip sucker, channel catfish, and common carp were the most common fish tallied at juvenile separators, whereas juvenile crappie were common in some years. Peamouth were also relatively common. Although data exist that could provide clues to entrainment of primarily juvenile fish, no analyses have been conducted. The issue of entrainment effects on resident fish populations has not been addressed previously in the lower Snake River, although fish populations appear to be at saturation levels and, therefore, superficially do not appear to be affected by entrainment losses/gains.

ES.6 Resident Fish Predation on Juvenile Salmonids

Impoundment construction has created conditions that enhance predation on juvenile salmonids. Dams physically funnel migrating fish into upstream forebays and provide a concentrated supply of migrating fish in relatively restricted tailwater areas. Impoundments have also slowed migration speed and improved water clarity, two factors that increased the likelihood of predation.

Many studies have documented predation on juvenile salmonids. The principal predators in lower Snake River reservoirs are northern pikeminnow, smallmouth bass, and channel catfish. Other species such as crappie and yellow perch also consume juvenile salmonids. Several conclusions of these studies are as follows:

- Predation is highest in tailwaters and forebays where juveniles are more concentrated.
- Annual differences in predation magnitude or intensity may be due to annual variations in flow. Predation seems highest in low flow years and lowest in high flow years.
- Predation intensity is likely higher on subyearling than yearling chinook or juvenile steelhead. Yearling chinook and juvenile steelhead migrate earlier when water temperatures are cooler and turbidity is higher. Subyearling chinook rear in the reservoirs and migrate when water temperatures are higher and turbidity lower. Feeding intensity is higher in warmer water when metabolic demands of predators are higher. Similarly, predation is enhanced by clearer water as these predators are largely visual feeders.
- Salmonid consumption increases with predator size.
- Predator size is correlated with prey size. Larger predators can consume a wider size range of juvenile salmonids.
- Salmonid consumption by smallmouth bass may exceed 100,000 juveniles per season per reservoir. Most of these are likely subyearling chinook salmon.
- Predation by northern pikeminnow is believed to be lower than a decade ago due to population reductions by scientific sampling and a sport reward program.
- Native non-salmonid fish contribute little to the food base of these fish predators.

ES.7 Habitat Use Guilds of Snake River Resident Fish

The native and introduced resident fish in the lower Snake River occupy aquatic habitats according to their respective habitat preferences. Fish are currently distributed according to reservoir habitat conditions. Those with lotic (riverine) preferences generally inhabit the tailwaters and upper reservoir areas in higher abundance. Others with lacustrine (lake-like) preferences are more likely to be found in slower mid-reservoir areas or forebays or in off-channel sites like embayments. To assist with predicting future fish community structure, native and introduced resident fish were assigned to habitat-use guilds. The guild approach simplifies analysis by grouping fish with similar habitat preferences. The selection of guilds was based on the expected development of riverine habitats following dam removal, if that alternative were selected. Each guild is described below.

- Riffle/rapids guild—comprises fish that prefer higher velocities (includes largescale sucker and sculpins).
- Upper pool guild—members inhabit transitional habitats with moderate velocities between rapids and the slower, main portion of pools (includes mostly native fish such as bridgelip and largescale sucker, chiselmouth, northern pikeminnow, and non-native smallmouth bass adults).
- Mid/lower pool guild-shallow—members inhabit slower, shallower portions of pools, such as pool margins (includes mostly native fish such as bridgelip and largescale sucker, redside shiner, peamouth, juvenile northern pikeminnow, and non-native smallmouth bass juveniles and adults).
- Mid/lower pool-deep—members prefer the deeper portions of pools that have generally slower velocities (includes native fish such as white sturgeon and northern pikeminnow, and non-native channel catfish and smallmouth bass).
- Slough/backwater guild—comprised of fish that prefer standing water habitat. Included are all non-native fish such as sunfish, bullheads, crappie, common carp, yellow perch, and juvenile smallmouth bass, plus native juvenile northern pikeminnow.

Most native fish occurred in guilds with higher velocities, whereas most introduced fish were included in guilds with slower velocities, including standing water. Fish regarded as habitat generalists such as smallmouth bass, northern pikeminnow, and largescale sucker were included in multiple guilds.

Assignment to a guild was largely based on velocity preferences. Velocity also dictates substrate composition. Thus, those habitats with higher velocities will contain larger substrate such as boulders and cobble. Slower velocity habitats shall comprise variable proportions of smaller particles such as gravel, sand, and silt.

ES.8 Alternatives Analysis

Eight alternatives are under consideration in this appendix. The operational and structural modifications associated with each alternative are grouped into three major pathways: the existing condition pathway, including the existing condition alternative; the major system improvements pathway; and natural river drawdown. The existing condition pathway continues current operational practices. The major system improvements pathway includes five alternatives, each with an emphasis on surface collection and bypass systems. Under the drawdown pathway, the four lower Snake River Dams would be removed. Since all the potential modifications are not expected to affect resident fish, this analysis focuses only on those measures most likely to affect resident fish populations.

ES.9 Total Dissolved Gas Improvements

Spillway flow deflectors (flip lips) installed at all dams have proven effective in reducing total dissolved gas (TDG) in the lower Snake River. Relative to salmonids, however, the effects of variable gas supersaturation on resident fish are poorly documented. Additional refinements or measures being considered to reduce TDG include reconfiguration of existing flip lips, raising the stilling basin floor elevation (limits plunging effects), and passing excess water by methods other than spill.

ES.10 Spill Requirements

Spilling water at lower Snake River Dam spillways is designed to reduce salmonid smolt passage through turbines by bypassing fish through the spillway, a presumably safer route. Spill increases TDG in the tailwaters and main portions of the reservoirs and potentially affects the resident fish utilizing these habitats. Because of concerns for high TDG in unregulated spill, among other concerns, spill is currently regulated to a target percentage of spring (all dams) or summer (Ice Harbor only) instantaneous flow and is to not exceed a target TDG cap concentration. The gas cap in reservoir forebays is now set at 115 percent of saturation, and in tailraces is equal to 120 percent of saturation. In addition to affecting TDG in the reservoirs, spill also may affect the numbers of fish entrained through project turbines.

ES.11 Flow Augmentation

Flow augmentation has been implemented to speed passage of salmonid smolts through the lower Snake River reservoirs or at hatchery release locations. Flow augmentation is provided during the salmonid smolt outmigration period from April through August. Flow augmentation can provide a significant increase in spring flows in below-average water years and improve summer flows and moderate summer water temperatures in most-water years. Flow augmentation in years prior to 1991 was intended only to speed smolt passage. More recently, augmentation flows, particularly those from Dworshak Reservoir, have extended into summer and have provided cooling of warm reservoir water temperatures.

Three options for flow augmentation are under consideration for the lower Snake River. For most alternatives, provision of the 427 KAF from the Hells Canyon complex and Dworshak Reservoir as called for in the 1995 and Supplementary 1998 Biological Opinions would continue. Other options include provision of an additional 1.0 million acre-feet from upstream storage, or elimination of flow augmentation.

ES.12 Natural River Drawdown

The Snake River Dams are to be breached by removing the earthen embankments from August to December. Simultaneous reductions in water levels will be achieved by passing water through modified turbine structures used as low level outlets, yielding controlled flow conditions to minimize downstream impacts. The number of years required to achieve drawdown of the entire reach is unclear at this time, but, regardless, the long-term effects would not change. Dam removal will produce 225 km (140 miles) of unimpounded river, but upstream dams and reservoirs (Brownlee, Dworshak) will continue to regulate flows for flood control and power production and will continue to block access to historic spawning areas.

ES.13 Expected Riverine Habitats

A 1934 bathymetry and habitat data set was utilized to model and qualitatively predict some common attributes of riverine habitats expected to develop at a representative summer flow level after dam removal. The attributes include gradient, depth, substrate composition, water velocities, and surface areas of selected habitats.

The modeled data indicate there will be no steep rapids and relatively few long pools in the restored river. The average gradient was estimated at 0.53 m/km (2.81 feet/mile), and little variation in gradient among river reaches is expected.

Riverine habitat following drawdown will comprise about 39 percent of the aquatic habitat currently available in the reservoirs. Approximately 90 percent of the remaining wetted area will be relatively swift-flowing, with modeled velocities exceeding 0.6 m/second (2.0 feet/second). In fact, river velocities in about 30 percent of the restored reach are expected to exceed 1.5 m/second (5.0 feet/second). The amounts of moderate to slow velocity habitat will be severely restricted. Most reduced velocity habitats will exist in narrow bands along channel edges, or in occasional island complexes and backwaters.

Most of the restored river will be less than 4.3 m (14 feet) deep at moderate summer flows, with deeper mid-channel areas of 7.6 m (25 feet) or more. Three reaches will exceed 15.2 m (50 feet) in depth. Substrates will be variable among reaches and predominantly gravel-sand or cobble-gravel, with bedrock-cobble substrates in areas with higher river currents. Occasional island complexes occur throughout and will be relatively more abundant in the Ice Harbor reach than elsewhere. Riparian zones will contain 25 percent or more coverage of riprap to protect existing parallel roads, railroads, and bridges.

ES.14 Predicted Impacts

ES.14.1 Alternative A-1: Existing Condition

The existing condition alternative means the reservoirs would remain in place, and flow augmentation (427 KAF) would continue. No specific short-term effects will be detectable in resident fish populations. Any long-term effects will likely be due to continued flow augmentation, and these effects are most likely to be seen among fish requiring warmer water for spawning in Lower Granite Reservoir due to potential cooling from Dworshak reservoir releases. Species that could be affected include smallmouth bass, other centrarchids (sunfish), and channel catfish. The cumulative effects of this alternative would be continued reservoir aging and deposition of finer substrates in low-velocity areas.

ES.14.2 Alternative A-2: Existing Condition/Maximize Transport of Juvenile Salmon

Increased transport of juvenile salmonids under current structural and operational conditions may be achieved by limiting spills and passing more fish through bypass and collection systems. This could potentially expose more resident fish to turbine entrainment, although detection of the effects would be difficult since resident fish entrainment is largely unassessed. Other potential long-term and cumulative effects would be similar to those for Alternative A-1.

ES.14.3 Alternative A-2a: Major System Improvements/Maximized Transport of Juvenile Salmon

Alternative A-2a is designed to maximize juvenile salmonid transport and increase fish survival by improvement of bypass structures, principally surface collection systems. Also, spillway basin floor elevations may be increased to further limit TDG. Reduction in TDG may improve conditions for resident fish, but other structural changes associated with surface collection are unlikely to appreciably affect resident fish. Other long-term and cumulative effects related to reservoir aging and cooling due to flow augmentation would be similar to Alternative A-1.

ES.14.4 Alternative A-2b: Major System Improvements/Minimized Transport of Juvenile Salmon

Structural changes to be implemented under Alternative A-2b are similar to those for Alternative A-2a; operationally, however, spills would be maximized to encourage in-river migration of juvenile salmonids. Higher spills may reduce turbine entrainment of resident fish, but foster elevated TDG. Other potential long-term and cumulative effects due to flow augmentation and reservoir aging are similar to those described for previous dam-in-place alternatives.

ES.14.5 Alternative A-2c: Major System Improvements/Adaptive Management

Adaptive management recognizes that future technologies may offer additional structural and operational improvements that could increase survival of juvenile salmonid outmigrants. Long-term and cumulative impacts of this alternative, based on current knowledge, are expected to be similar in scope to the dam-in-place effects discussed above. However, future management options that may be developed to enhance juvenile salmonid survival would most likely be detrimental to the resident fish communities.

ES.14.6 Alternative A-6a: Major System Improvements/In-River Migration, and Additional 1.0 MAF Flow Augmentation

Alternative A-6a is designed to create a more lotic reservoir system with structural changes designed to guide more juvenile salmonids into bypass systems. Potential alterations to the resident fish communities by this alternative may be the most significant among all dam-in-place alternatives due to increasing flow augmentation. The principal short- and long-term effects would be higher flows and river velocities through the reservoirs that may enhance the native fish component of the resident fish community and hinder spawning and production of introduced resident fish. However, since the 1.0 MAF additional flow augmentation is expected to come from upper Snake River storage and have no capacity for cooling, there is potential to offset by dilution some of the negative aspects of Dworshak Reservoir releases. Tripling flow augmentation volumes through the reservoirs may also keep smaller sediment particles suspended longer, thus delaying the sediment buildup that accompanies reservoir aging.

ES.14.7 Alternative A-6b: Major System Improvements/In-River Migration with Zero Flow Augmentation

Major system improvements with maximum in-river juvenile migration, but no flow augmentation, have a very low long-term potential to alter the resident fish community. Any changes may result from an accumulation of low-flow years where temperatures are allowed to warm without the interruptions and cooling due to flow augmentation. Such years would enhance production by the introduced component of the resident fish community. High-flow years would still occur, however, and high flows would continue to favor production of native resident fish. Cumulatively, less flow through the reservoirs may accelerate sediment deposition and reservoir aging.

ES.14.8 Alternative A-3: Natural River Drawdown

All four lower Snake River Dams would be breached under this alternative, and approximately 225 km (140 miles) of impounded water would revert to riverine condition. Flows would still be regulated by upstream projects, however, although flows from many major tributaries are unregulated. Flow augmentation (427 KAF) would continue.

ES.14.8.1 Short-term/Transition Period Effects

The initial impact to resident fish will be a progressive draining of backwaters, sloughs, and mitigation ponds that may strand and result in eventual loss of substantial numbers of fish. Losses will be highest for juvenile fish that favor these habitats such as crappie, largemouth bass, sunfish, bullheads, and yellow perch, and in the more downstream reservoirs where more of these habitats occur. Losses of crayfish would be substantial in the dewatered areas. Channel velocities will increase, and lead to erosion and transport of accumulated silt deposits. The high turbidities may decrease fish feeding efficiency and growth. The exposed banks will continue to erode accumulated silt according to the amount of precipitation received, especially during the initial spring following drawdown.

ES.14.8.2 Long-term Effects

The resident fish community would eventually revert toward one that is more representative of historical fish assemblages, including higher native cyprinid, cottid, and catostomid components. These fish include chiselmouth, peamouth, redside shiners, sculpins, and suckers. Riverine specialists such as white sturgeon and speckled dace would also increase in abundance. In contrast, a greatly reduced introduced-fish community (e.g., sunfish, yellow perch, and crappie) would result from restricted abundance of preferred lacustrine habitats. Since no historical data on pre-impoundment fish communities were available, the current resident fish community of the unimpounded Snake River upstream from Asotin, Washington, was used as a model to estimate potential changes in biomass. Standing crops kilograms/hectares (kg/ha) of resident fish would increase to about 1.7 times that currently found in the reservoirs. Most of the increase would be due to more suckers, chiselmouth, and white sturgeon. However, biomass of predators such as northern pikeminnow, channel catfish, and smallmouth bass should decrease on a linear scale kg/kilometer (kg/km).

Continued flow augmentation will likely influence resident fish, particularly if releases exert cooling effects after flows have subsided in summer. The effects would be felt by resident fish as potentially shorter or interrupted growing seasons and reduced primary and secondary productivity that subsequently can impact food supply. The cooling effects may also be magnified due to smaller river volumes compared to the large reservoirs.

The habitats occupied by resident fish in a restored lower Snake River may largely be driven by velocities. Smallmouth bass, northern pikeminnow, and channel catfish prefer slow to moderate current. Since the amount of riverine habitat with slow to moderate velocity is expected to be fairly restricted, these species will also make use of cover objects where available. These include large boulders for smallmouth bass and northern pikeminnow and woody structure for catfish. In contrast, white sturgeon favor moderate to fast water and should be found in deeper mid-channel areas.

ES.14.9 Impacts to Key Species

ES.14.9.1 Smallmouth Bass

Current research indicates similar to higher estimates of abundance of smallmouth bass in the flowing waters upstream of Lower Granite Reservoir compared with those in the reservoir. Smallmouth bass standing crop (kg/ha) will likely increase after drawdown, although on a linear scale, biomass (kg/km) will decrease. However, a major factor may be the influence of flow augmentation on Snake River water temperatures. Frequent cooling releases may retard reproduction and growth, resulting in reduced over-winter survival of young.

ES.14.9.2 White and Black Crappie

White and black crappie populations would certainly decrease due to severe habitat loss of low velocity areas.

ES.14.9.3 Largescale and Bridgelip Sucker

Suckers are habitat generalists that would be expected to increase in abundance following drawdown. Perhaps food-limited in the reservoirs, their principal food items (diatoms and algae) are expected to increase in an unimpounded river.

ES.14.9.4 Northern Pikeminnow

Limited data suggest that northern pikeminnow standing crop (kg/ha) will be higher in an unimpounded river, but that biomass on a linear scale (kg/km) will decrease. A major factor may be whether the sport reward program is continued following drawdown. This program has reduced northern pikeminnow abundance in the reservoirs.

ES.14.9.5 White Sturgeon

The white sturgeon will benefit from the lotic habitats found in an unimpounded lower Snake River. Recruitment to reservoirs downstream of Lower Granite will improve, as habitats for spawning and rearing would no longer be isolated. White sturgeon should also benefit from the long-term higher abundance of crayfish, a preferred food, in a lotic system.

ES.14.9.6 Channel Catfish

Channel catfish standing crop may remain similar or increase slightly in a restored lower Snake River. Channel catfish may benefit from an expected increase in crayfish abundance. However, the restored section will be subject to cooling flows from Dworshak Reservoir that do not affect the portion of the Snake River above Asotin that was used as a guide to predict future abundance. Since optimum water temperatures are higher for channel catfish than for most other resident species, flow augmentation may affect channel catfish more than other fish.

ES.15 Anticipated Predation on Juvenile Salmonids After Drawdown

The standing crop of significant predators on juvenile salmonids, including smallmouth bass, northern pikeminnow, and channel catfish, is expected to be higher after drawdown. Ultimately, the factors that will limit these species will be suitable rearing habitat, including water temperatures, and, for northern pikeminnow, continuation of the sport reward program.

Several factors may alter the susceptibility of juvenile salmonid prey, particularly yearling chinook and juvenile steelhead. River turbidities are expected to be higher during spring runoff, limiting the ability of sight feeders to locate prey. Juvenile salmonids will be moving faster through the unimpounded river and will not be concentrated in specific areas (i.e., forebays and tailwaters) during outmigration. Predation would likely continue to be high on subyearling chinook, however, as they migrate later when turbidities will be reduced and water temperatures have warmed. Thus, the metabolic demands of the predators are higher, and visibility is better, and predators and prey are in closer proximity as river volumes contract.

In summary, dam-in-place Alternatives A-1, A-2, A-2a, A-2b, A-2c, and A-6b would result in little or no detectable changes to the resident fish communities. The other dam-in-place alternative, A-6a, could result in changes to resident fish communities favoring native species as a result of increased reservoir velocities due to higher flow augmentation volumes. The dam removal alternative, A-3, would result in highly altered resident fish community structure that would strongly favor native fish.

1. Introduction

1.1 Purpose

The purpose of the resident fish appendix to the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement is to clearly describe effects of potential alternative actions on resident fish. Resident fish are those that are not obligated to migrate to the ocean to complete their life cycle. The resident fish appendix will present available scientific data and analyses that describe the current status of resident fish populations and will discuss the biological consequences of the different alternatives for the long-term structural and operational configuration of the lower Snake River, part of the Federal Columbia River Power System (FCRPS). This appendix, along with public input, will form part of the basis for the U.S. Army Corps of Engineers' (Corps) decision on which alternative will be selected for implementation.

1.2 Scope

The resident fish appendix will describe the effects of a set of alternatives on the resident fish fauna that has developed during more than three decades of impoundment of the lower Snake River. Resident fish stocks provide significant recreation opportunities in the lower Snake River, and certain species are important in predator-prey dynamics affecting anadromous salmonid survival. Although linked, issues related to resident fish are deemed of secondary importance to those affecting ESA-listed anadromous fish resources, specifically salmonids.

The lower Snake River, for the purposes of this appendix, is considered to extend from the Columbia River confluence near Pasco, Washington, upstream to Asotin, Washington (Figure 1-1). McNary Dam on the Columbia River impounds the Snake River immediately downstream of Ice Harbor Dam. The lower Snake River impoundments also include a short section of the lower Clearwater River in Idaho near Lewiston. These river reaches will be influenced by adoption of any of the various alternatives under consideration by the Corps.

1.3 Appendix Organization

The resident fish appendix is organized as follows:

1. The site-specific sources consulted for the biological data and other data needed to address the potential alternatives are described in Section 2.0.
2. A thorough summary of the key biological attributes of the lower Snake River resident fish communities in the reservoirs, as well as summaries of certain physical processes that affect all reservoir fish, are provided in Section 3.0.
3. The actions embedded in each alternative that are most likely to affect resident fish, and the full range of expected impacts to resident fish, are discussed in Section 4.0.
4. A brief summary comparing the alternatives is provided in Section 5.0.
5. A list of literature consulted, both site-specific and general, is provided in Section 6.0.

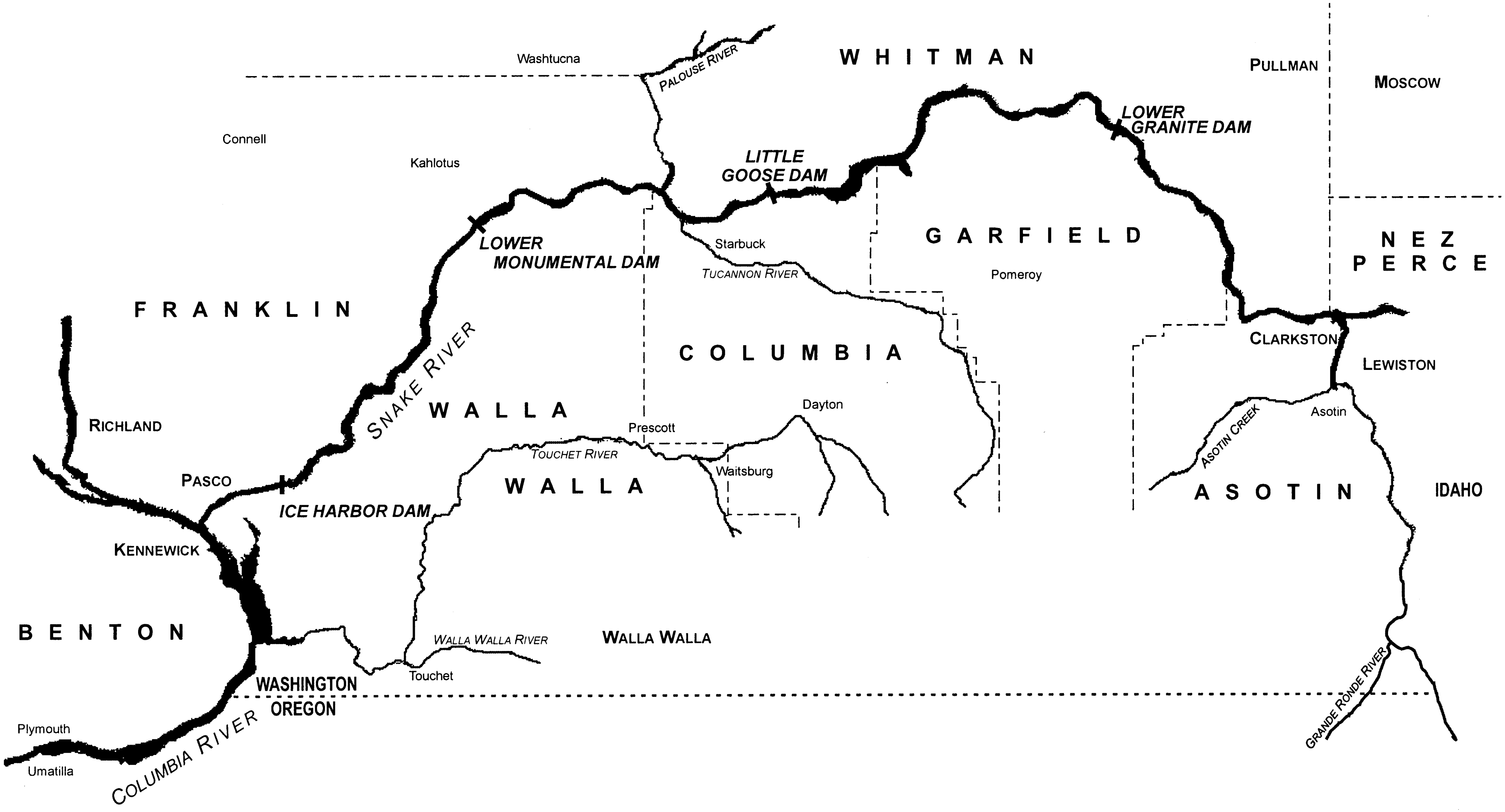


Figure 1-1. Location Map of Hydro Dams and Reservoirs on the Lower Snake River and the Mid-Snake River Upstream of Asotin, Washington

2. Information Sources for Resident Fish

2.1 Information Sources

Work conducted by researchers at the University of Idaho represents the single, largest source of technical information on historical and current status of lower Snake River resident fish. Comprehensive investigations of the warm water fisheries that developed in the four reservoirs were initiated in 1979 (Bennett et al., 1983), shortly after completion of the impoundment of Lower Granite Reservoir in 1975. Much of that information, particularly for those species of little interest to sport anglers or not believed to influence successful passage of anadromous salmonid smolts, represents the most current information available.

Subsequent to that compilation, more focused studies on various aspects of Snake River resident fish ecology in the reservoirs were conducted by the University of Idaho. All were reviewed as appropriate for this appendix. Additionally, commercial literature search services (e.g., Absearch) were consulted for relevant published papers. Personnel within the fisheries management agencies of Washington, Idaho, and Oregon were asked to provide relevant reports and information on Snake River resident fish. Personnel with the U.S. Geological Survey, Biological Resources Division, Cook, Washington, were asked to provide any available data on Snake River resident fish. Corps biologists at each Snake River Dam were also queried for information and reports. The goal was to compile the best available science on resident fish in the lower Snake River as possible to develop a comprehensive description of their current status.

2.2 Development of Annotated Bibliography of Snake River Resident Fish

Each report, thesis, or publication reviewed for this appendix that contained relevant, site-specific information on resident Snake River fish is listed as a citation in the Annotated Bibliography. In addition, some references that describe the methodologies used in the alternatives analysis are included. Each annotation contains a brief description of the contents, results, or conclusions of the reference. The review included reports and peer-reviewed papers reporting on more than two decades of research. The Annotated Bibliography prepared in support of this appendix is located in Annex A.

3. Existing Resident Fish and Habitats – Affected Environment

The following subsections describe the lower Snake River reservoirs, some of their physical characteristics and attributes, and the habitats used by the various resident fish species, as well as summarizing the available distribution, abundance, and selected life history information on resident fish that use these habitats. Site-specific data are emphasized where available. Additional subsections summarize available data on resident fish spawning temperature requirements, entrainment of resident fish through or over the dams, gas bubble trauma investigations, and predation by resident fish on juvenile salmonids. Finally, a framework based upon a habitat-use guild system is proposed to assist in predicting the potential impacts of the various alternatives on the reservoir resident fish communities.

3.1 Lower Snake River Reservoirs

The four dams on the lower Snake River impound more than 96 percent (216 kilometers [135 miles]) of the Snake River in Washington from Asotin to the confluence with the Columbia River at Pasco (Figure 1-1). Also impounded is the lower 6 kilometers (3.7 miles) of the Clearwater River in upper Lower Granite Reservoir. The remaining length (about 9.7 kilometers [6.0 miles]) of the Snake River below Ice Harbor Dam forms the uppermost reach of McNary Reservoir (Lake Wallula) on the Columbia River. The entire reach lies within a canyon cut through the Columbia plateau. The physical characteristics of each reservoir were summarized in Bennett et al. (1983), and all reservoirs generally share similar morphometry (Table 3-1). Lower Granite is the longest reservoir, whereas Little Goose has the largest surface area. Mean depth ranges from 14.5 to 17.4 meters (48 to 57 feet); Ice Harbor Reservoir is the shallowest. Three major tributaries enter this section. The Clearwater River joins the Snake River in upper Lower Granite Reservoir (Figure 3-1), and the Palouse and Tucannon rivers join near the midpoint of Lower Monumental Reservoir (Figure 1-1).

3.2 Reservoir Habitat Conditions

3.2.1 Available Habitats in Snake River Reservoirs

Individual Snake River reservoirs are shown in Figures 3-1 through 3-4. The Snake River reservoirs conform to a typical longitudinal impoundment gradient composed of three macrohabitat types, or reaches (Hjort et al., 1981). The tailwater is the section immediately below a dam and is the most riverine in nature. The uppermost portion of Lower Granite Reservoir is also more riverine, but is not a tailwater since there is no impoundment immediately upstream. Impoundment of Lower Granite Reservoir is considered to end near Asotin in the Snake River arm and near the Potlach Corporation in the Clearwater River arm (Figure 3-2). A mid-reservoir reach represents the largest section of each impoundment and is a transition area from the lotic (riverine) character of the tailwater to the more lake-like (lentic or lacustrine) conditions nearer the dam. The reach immediately above a dam is the forebay. A sampling protocol described by Zimmerman and Parker (1995) assigned reach lengths of 6 kilometers (3.73 miles) each to a tailwater or forebay, but the length was likely a result of sampling considerations as opposed to defined differences in habitat. So designated, lower Snake River tailwaters and the upper reach of Lower Granite Reservoir comprised 5 to 15 percent of total reservoir area. Forebays formed a more uniform 13 to 18 percent of total reservoir area, and the remaining 67 to 72 percent is mid-reservoir (Zimmerman and Parker, 1995).

Table 3-1. Physical Characteristics of Lower Snake River Reservoirs, Washington and Idaho

	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
Normal pool elevation-m (ft) NGVD	134.0 (440.0)	164.0 (540.0)	194.0 (638.0)	225.0 (738.0)
Normal pool fluctuation-m	0.9	0.9	1.5	1.5
Reservoir length-km (miles)	51.4 (31.9)	46.2 (28.7)	59.9 (37.2)	62.8 (39.0)
Surface area-hectares (acres)	3,390.0 (8,375.0)	2667.0 (6,590.0)	4057.0 (10,025.0)	3602.0 (8,900.0)
Proportion of impounded reach-%	26.5	19.0	28.9	25.6
Maximum depth; flat pool-m (ft)	33.5 (110.0)	39.6 (130.0)	41.1 (135.0)	42.1 (138.0)
Mean depth; flat pool-m (ft)	14.5 (48.6)	17.4 (57.2)	17.2 (56.4)	16.6 (54.4)
Maximum width-m (ft)	1,609.0 (5,280.0)	1286.0 (4,220.0)	1432.0 (4,700.0)	1128.0 (3,700.0)
Mean width-m (ft)	610.0 (2,000.0)	579.0 (1,900.0)	518.0 (1,700.0)	6473.0 (2,110.0)
Major tributaries	None	Palouse R., Tucannon R.	None	Clearwater R.

Source: Bennett et al., 1983

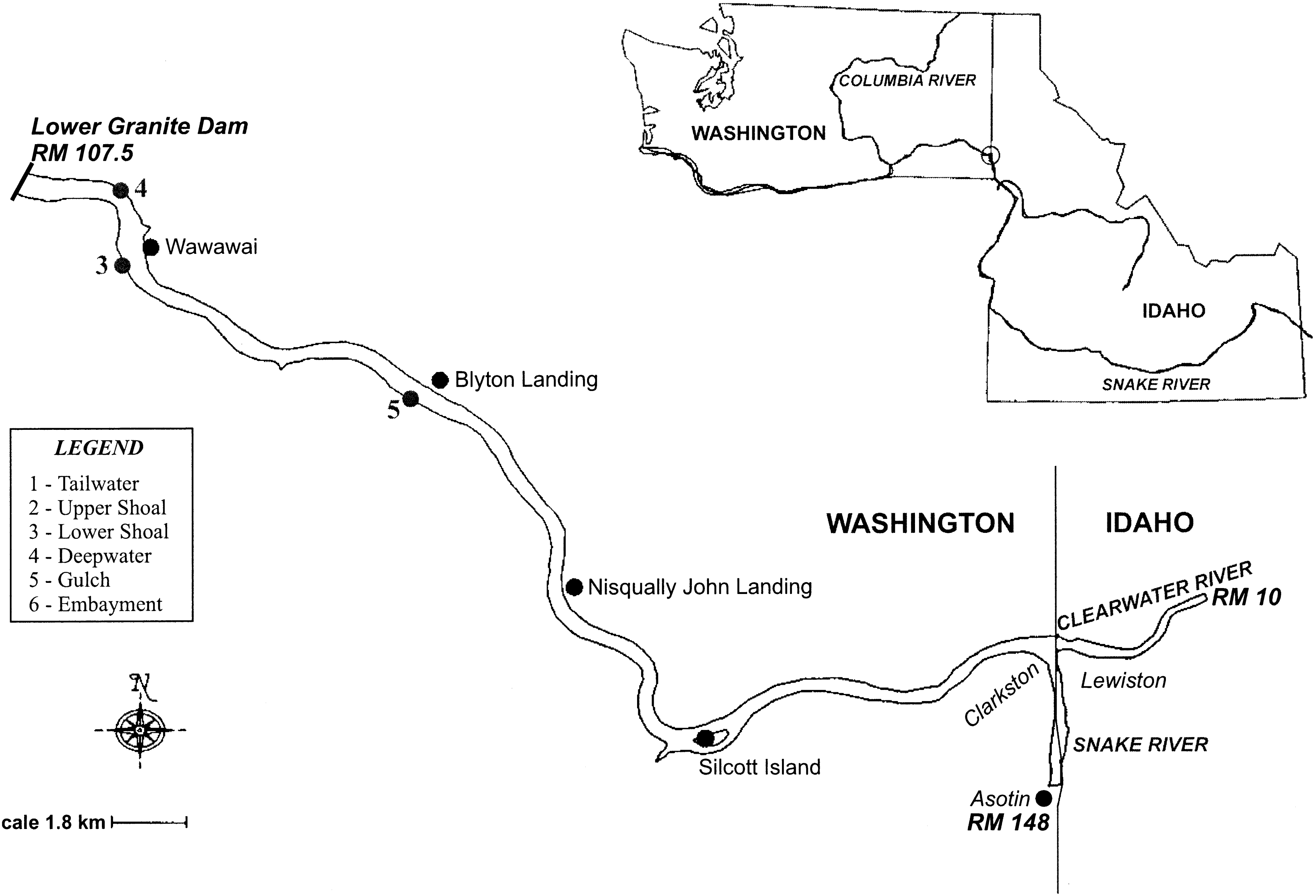


Figure 3-1. Lower Granite Reservoir, Snake and Clearwater Rivers, Washington-Idaho

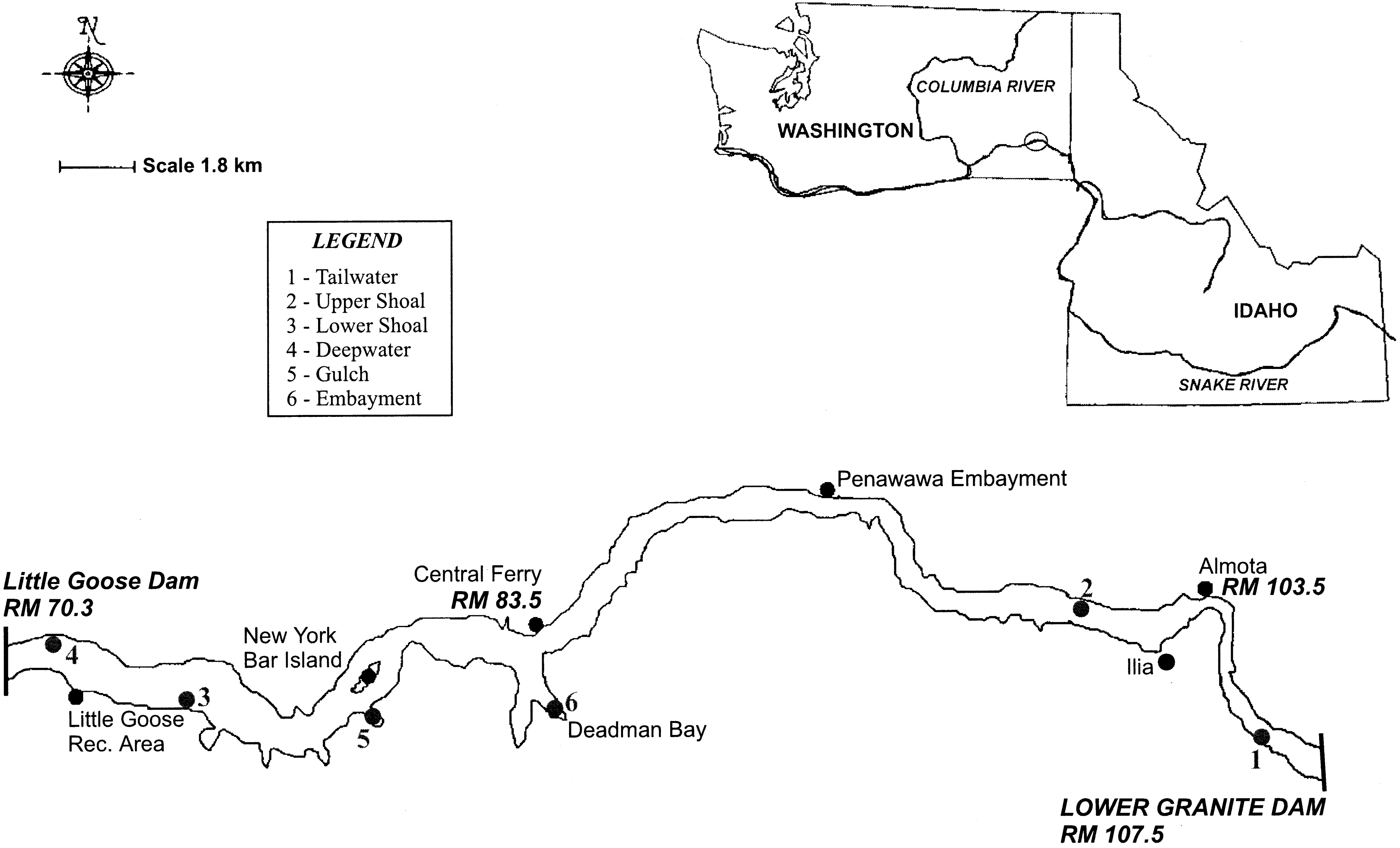


Figure 3-2. Little Goose Reservoir, Snake River, Washington

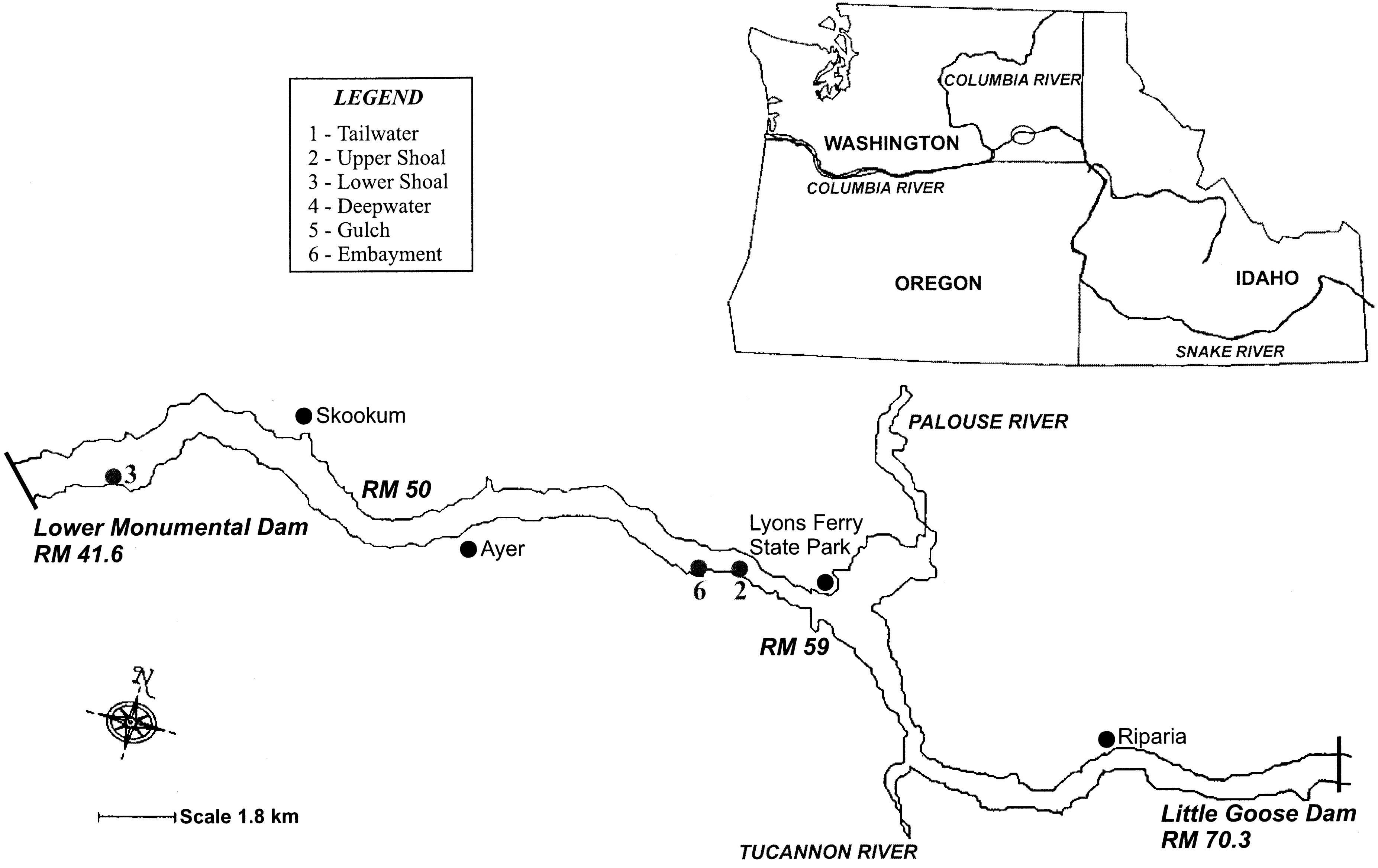


Figure 3-3. Lower Monumental Reservoir, Snake River, Washington

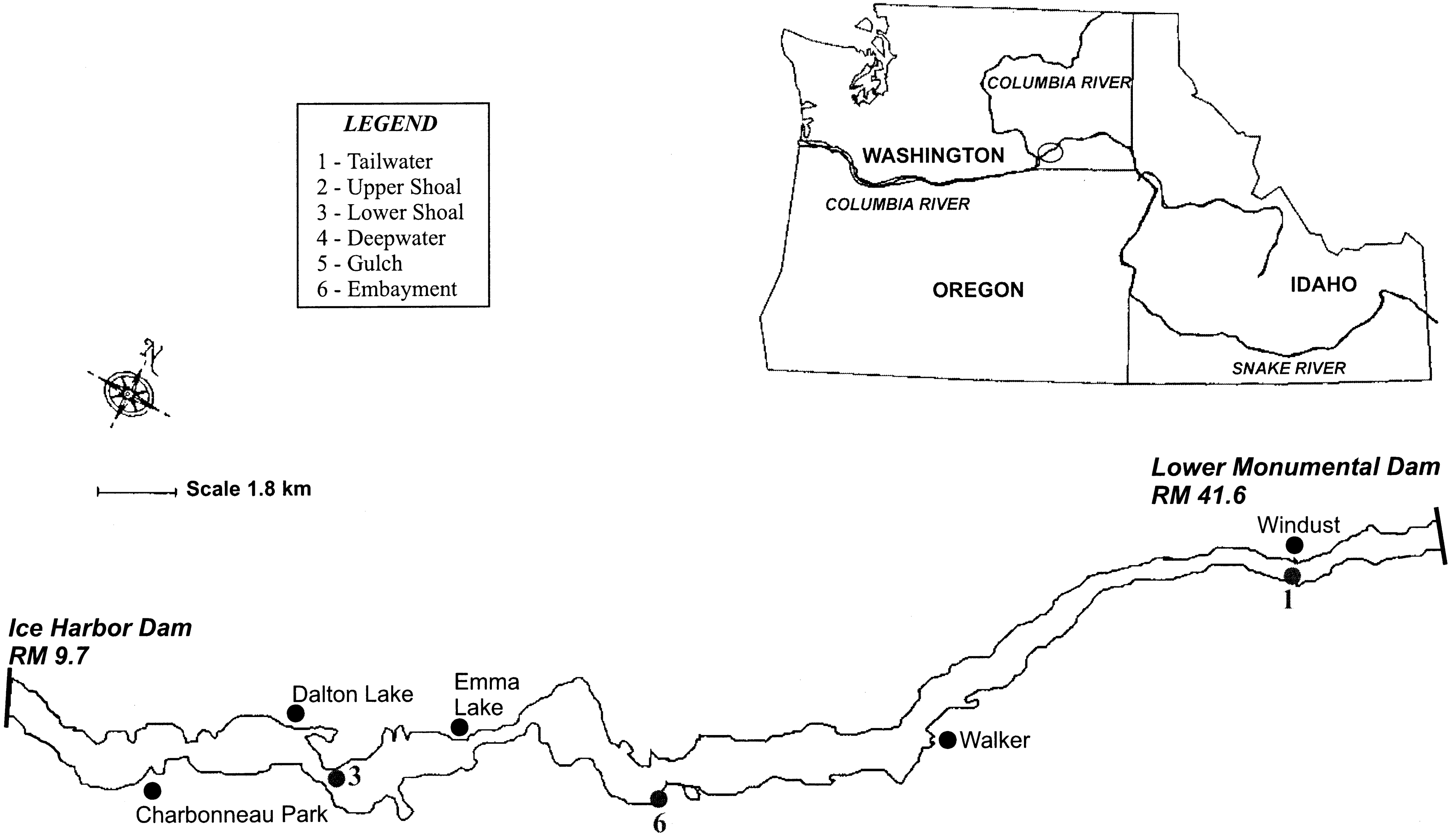


Figure 3-4. Ice Harbor Reservoir, Snake River, Washington

Each macrohabitat reach can contain up to several habitat types. The sampling scheme developed by Bennett et al. (1983) recognized six individual habitat classifications, or mesohabitats, that are described below. Six limnological characteristics of each mesohabitat in Little Goose Reservoir were summarized by Bennett et al. (1983) and are shown in Table 3-2. These attributes would be generally applicable for the respective habitats in all of the lower Snake River.

Tailwater-The highest water velocities in a reservoir (up to 7 meters/second [23 ft/sec]) were always found in the tailwater immediately below the dam. The uppermost area of a tailwater adjacent to the dam is the boat restricted zone (BRZ), which is variable in size but typically less than 1.0 kilometers (0.6 miles) long (Ward et al., 1995). Also included in a tailwater are protected areas with little or no current behind the lock chamber walls (most prominently below Lower Granite Dam) or adjacent to the earthen portion of a dam (e.g., below Little Goose Dam). Water current is typically negligible in these areas unless induced by spill. For example, under certain spill conditions, reverse eddy flows can occur below the earthen portion of Little Goose Dam. The bottom slope in a tailwater is moderate with relatively little littoral area and no macrophyte growth.

Upper shoal-Moderately sloped areas in the upper portion of a reservoir, but located below a tailwater. Upper shoal habitats have slower velocities and a greater littoral area than in a tailwater due to slightly shallower bottom slopes. As a result of slower velocities, these areas generally accumulate sediment by deposition. In Little Goose Reservoir, water velocities in spring were lower than 1.0 meters/second (3.3 ft/second), but higher than 0.3 meters/second (1.0 ft/second), and intermediate between tailwater velocities and those of more downstream habitats (Bennett et al., 1983).

Lower shoal-Moderately sloped areas up to 10 meters (33 feet) deep at 61 meters (200 feet) offshore, with water velocity less than 0.3 meters/second (1.0 ft/second). Macrophyte growth was sparse, averaging about 3.3 percent of sampled areas.

Lower Embayment-Relatively large, shallow (up to 4 meters [13 feet] deep) areas off the main river channel, and typically separated from the main reservoir by a road or railroad berm. No measurable water current occurs, and macrophyte growth can be extensive. In Little Goose Reservoir, the embayment sampled averaged 3.7 percent macrophyte coverage (Table 3-2). Increased siltation from small tributaries and reservoir maturity likely has led to more substantial macrophyte growth in recent years. Examples of embayments include Deadman Bay in Little Goose Reservoir (Figure 3-2) and Dalton and Emma lake in Ice Harbor Reservoir (Figure 3-4).

Gulch-Small to medium-sized, shallow (up to 4 meters (13 feet) deep), off-channel areas with no measurable current. These areas may also be thought of as coves, as they are not cut off from the main reservoir body by a berm. Macrophytes are typically present, and the littoral areas of gulch habitats are typically extensive due to shallow bottom slopes.

Deepwater-Steep sloped areas with little or no littoral zone, intermediate to no current (less than 0.3 meters/second [1.0 ft/second]), and up to 30 meters (98 feet) deep (as measured in Little Goose Reservoir by Bennett et al., 1983). Macrophytes are absent due to a negligible littoral zone.

Comprehensive fisheries sampling conducted by Oregon Department of Fish and Wildlife (ODFW) in 1991 and 1994 to 1996 in the lower Snake River reservoirs throughout the three macrohabitat reaches identified habitats only as "nearshore" and "offshore" (Zimmerman and Parker, 1995; Parker et al., 1995). Nearshore habitats were defined as those less than 12 meters (40 feet) deep within 46 meters (150 feet) of shore.

Table 3-2. Limnological Characteristics at Major Sampling Stations on Little Goose Reservoir, Washington

Limnological Characteristics	Lower Embayment	Lower Gulch	Deepwater	Lower Shoal	Upper Shoal	Tailwater
Maximum water depth (m)[a]	4.0	4.0	30.0	10.0	8.0	10.0
Littoral reach (m)[b]	29.0	42.0	3.0	10.0	12.0	6.0
Average slope of bottom (°)	4.0	4.0	27.0	9.0	8.0	12.0
Water velocity (m/second)	0.0	0.0	0-0.03	0-0.3	0-0.9	0-1.7
Aquatic macrophyte coverage (%)	3.7	11.8	0.0	3.3	9.7	0.0
Mean water transparency (m)						
Spring	0.7	1.1	1.2	1.2	1.1	1.1
Summer	1.0	2.1	2.2	2.2	2.0	1.9
Fall	1.4	2.8	3.1	3.1	2.5	2.4

a. Mean water depth 61 meters from shoreline

b. Distance which the littoral zone (<2 meters depth) extended in a perpendicular direction from the shoreline

Source: Bennett et al., 1983

Bennett et al. (1983) listed all habitats other than deepwater as having mean depths less than or equal to 10 meters (33 feet) within 61 meters (200 feet) of shore. Thus, the range of mesohabitats less than 10 meters (33 feet) deep sampled by Bennett et al. (1983) is represented within the nearshore habitats sampled more recently by ODFW.

Within the nearshore reservoir habitats, Bennett et al. (1983) defined the littoral area as 2 meters (6.6 feet) deep. Subsequent research in Lower Granite Reservoir redefined the littoral depth as 5 to 6 meters (16 to 20 feet), approximately the maximum depth of light penetration (David H. Bennett, University of Idaho, personal communication).

Snake River embayments between river kilometers (rkm) 95 to 145 (river miles [rms] 59 to 90) in Lower Monumental and Little Goose reservoirs were surveyed by Corps biologists in 1988 and 1989 (Kenney et al., 1989). Most of the 37 embayments surveyed were canyons and gulches cut off by railroad relocation when Little Goose Reservoir was filled. Most of these embayments remained connected to the main reservoirs by culverts. Others maintained a direct channel opening to the reservoir. The embayments ranged in area from less than 0.04 hectare (0.1 acre) to 4.7 hectares (11.6 acres), and were generally steep-sided. More than half of the embayments surveyed were greater than 6 meters (20 feet) deep, and 11 were 9 meters (30 feet) or deeper. Aquatic vegetation was generally sparse due to the steep slopes. Shallower embayments with more moderate slopes supported pondweed (*Potamogeton sp.*), cattails, and rushes. Although this survey documented these habitats for a 50 km (31-mile) portion of the reservoirs, similar embayments occur throughout the impounded reach.

3.2.2 Habitat Differences Among Reservoirs

The proportion of shoreline distance represented by the six mesohabitats in Little Goose Reservoir, as listed in Bennett et al. (1983), was as follows: deepwater equals 47.8 percent; upper shoal=14.8 percent; lower shoal=11.9 percent; embayment=9.4 percent; tailwater=8.6 percent; gulch=7.4 percent. Based on surface area estimates for the various macrohabitat reaches in Zimmerman and Parker (1995), proportionately more tailwater or upper reservoir (in Lower Granite Reservoir) habitat exists in each Snake River reservoir other than Little Goose. Similarly, Lower Monumental Reservoir had proportionately more deepwater habitat than Little Goose Reservoir, whereas Lower Granite and Ice Harbor reservoirs had proportionately less deepwater habitat. Relative to Little Goose Reservoir, both Ice Harbor and Lower Monumental reservoirs likely have more shallow water embayment and/or gulch habitat, whereas Lower Granite Reservoir has less.

3.2.3 Reservoir Substrates

Several studies have described the substrata in the lower Snake River reservoirs. Bennett and Shrier (1986) conducted the first known substrate analyses in Lower Granite Reservoir. They used a Ponar dredge to characterize the substrate at six stations. Substrate sizes were significantly different between shallow and deep waters, although silt was the predominant substrate class at each of the six study locations. Clay content of the substrate generally increased with distance downstream. Organic content was less than 5 percent.

In 1987, Bennett et al. (1988) surveyed the substrata in five shallow water areas of Lower Granite Reservoir by both systematic diving and Ponar dredge. Larger substrata were found near Wawawai (rm 109) in the lower portion of the reservoir than at other up-reservoir locations. A high degree of embeddedness was found for substrates less than 150 millimeters (6 inches) in diameter. Organic content ranged from 5.2 percent to 8.8 percent and overlapping confidence intervals suggested little difference in organic content among shallow water stations throughout Lower Granite Reservoir.

Dredge samples taken from various depths within the littoral zones of Lower Granite and Little Goose reservoirs were analyzed and summarized in Bennett et al. (1998). Although the samples were taken from "largely shallow shoreline areas," they were not keyed to specific mesohabitats as identified above (Section 3.2.1). Due to their shallow nature, however, sampled areas likely were shoal or embayment/gulch type habitats that had moderate to shallow bottom slopes.

Littoral substrata in Lower Granite Reservoir were classified as sand, sand-cobble, sand-talus, or rip-rap (Curet, 1994). Sampled areas on the north shoreline tended to be comprised of bottom particles greater than 25 millimeters (1 inch) in diameter. Most of the larger substrates were likely associated with rip-rap placed during parallel road and public access construction. South shore habitats tended to be comprised more of finer sands and silts. The south shore habitats are in reservoir areas less disturbed by anthropogenic activity. Shallow habitats in Little Goose Reservoir were classified as sand, cobble, talus, or rip-rap (Bennett et al., 1998). The north shoreline is largely rip-rap due to placement along the relocated parallel railroad. Finer grained sand and gravel habitats tended to occur more often along the south shore.

Dauble and Geist (1992) described substrata within the Snake River arm of Lower Granite Reservoir (upper reservoir) and the tailwater below Lower Granite Dam in Little Goose Reservoir during the 1992 experimental drawdown. Cobble substrate was highly embedded with sand and fines based on visual observations of exposed shoreline areas in upper Lower Granite Reservoir. Measured substrate composition at 16 shoreline transects in the upper 3 miles of Little Goose Reservoir was estimated at boulder-13.5 percent; cobble-40.3 percent; gravel-24.5 percent; sand-15.9 percent; and silt-5.9 percent. Cobble substrates were highly embedded except for the upper 0.8 kilometers (0.5 mile) of the tailwater in the BRZ immediately below Lower Granite Dam. A trend toward greater deposition of sand and fines was noted with distance below Lower Granite Dam. Gravel/cobble substrates on mid-channel islands 4.0 and 4.8 km (2.5 and 3.0 miles) below Lower Granite Dam were also highly embedded.

Additional investigations by Dauble et al. (1996) reported large substrata in the cobble to boulder size in the tailwaters of Lower Granite and Little Goose Dams on the lower Snake River. Gravel was generally free of sediments in the tailwaters, which the authors attributed to hydraulic events (e.g., spills and power releases).

Bennett et al. (1998) recently completed the most comprehensive survey of substrata in three of the lower Snake River reservoirs. Eighty-one Van Veen dredge samples were collected in total, three each at shallow, mid-depth, and deep locations in each of three sites in Lower Granite, Little Goose, and Lower Monumental reservoirs. Generally, the percentages of fine sediments (silts, clay, and organic material) increased from upstream to downstream in each of the reservoirs. Upstream sample locations were generally higher in sands, although coarse and fine gravels were collected from a shallow water site at RM 117 (rkm 188.4) in Lower Granite Reservoir. Substrata from the three depths were generally similar throughout the three reservoirs. Silt and sand accounted for most of the substrate composition.

Substrates were not otherwise classified in Lower Monumental or Ice Harbor reservoirs. Tailwater substrata, including the degree of embeddedness, are likely similar in composition to the more upstream tailwaters. Greater occurrence of fines, especially in down-reservoir areas such as gulch and embayment habitat, would be expected due to greater age and depositional history of these impoundments.

3.3 Resident Fish Species and Assemblages

3.3.1 Existing Resident Species and Status

Eighteen native species and 17 introduced fish comprise the current ichthyofauna of the reservoirs. A list of resident fish species compiled from several sources with common and scientific names is shown in Table 3-3. Of particular interest, the northern squawfish was renamed the "northern pikeminnow," a result of recent action by the American Fisheries Society (Nelson et al., 1998). The white sturgeon is a state species of concern in Idaho. Bull trout are listed as a threatened species in the Snake River Basin.

3.3.2 Historical and Current Distribution and Abundance

Current information on the relative abundance of resident fish in the Lower Snake River reservoirs suggests that fish community structure is generally similar among reservoirs (BPA, 1995). Bennett et al. (1983) conducted seasonal sampling in each of the four lower Snake River reservoirs and extensive sampling in Little Goose Reservoir in 1979 and 1980. Bridgelip sucker, redside shiner, largescale sucker, smallmouth bass, and northern pikeminnow were the age one and older fish in highest relative abundance, based on sampling with multiple gear types in Little Goose Reservoir (Table 3-4). These five species accounted for about 80 percent of all fish sampled in 1979 and 1980. All of these fish but smallmouth bass are native species in the Snake River. Species of lesser abundance were a mixture of native and introduced fish. Chiselmouth, another native cyprinid species, was moderately abundant in the lower Snake River reservoirs, while native peamouth, sculpins, and white sturgeon were less abundant. Introduced crappies, yellow perch, and some sunfish were highly abundant in off-channel habitats. Other introduced fish such as catfish and bullheads were present, but in lower abundance. Non-migratory salmonid fish were generally rare, seasonal in occurrence, and typically associated with a tributary confluence.

Relative abundance of fish varied among habitats sampled. In general, introduced centrarchid fish were more abundant in lentic backwater habitats while native suckers and redside shiners were more abundant in the more lotic up-reservoir stations (e.g., tailwater and upper shoal). For example, Bennett et al. (1983) reported that redside shiner and bridgelip sucker dominated the catch in the Lower Granite Dam tailwater of Little Goose Reservoir during 1980. These two species combined represented over 60 percent of the fish caught by multiple gear types. A tendency also existed to have higher abundance of selected species in the older downstream reservoirs. These species, all introduced, included channel catfish, largemouth bass, and carp. In contrast, non-native smallmouth bass, pumpkinseed, and white crappie were more abundant in upriver reservoirs. Bennett et al. (1983) also showed variation in abundance among similar habitats in different reservoirs. For example, the abundance of chiselmouth and northern pikeminnow was considerably higher at an embayment station in Lower Monumental Reservoir than in embayment habitat in either Little Goose or Ice Harbor reservoirs. Also, the abundance of chiselmouth was higher at main channel stations on Lower Monumental and Lower Granite reservoirs than in Ice Harbor Reservoir.

Table 3-3. Composite Resident Fish Species List and Sources of Data for the Lower Snake River

Common name*	Scientific name	Bennett et al. (1983)	BRD-ODFW (1991)	SOR (1995)
White sturgeon	***Acipenser transmontanus***	**X**	**X**	**X**
Rainbow trout	***Oncorhynchus mykiss***	**X**		**X**
Kokanee	***Oncorhynchus nerka***	**X**		**X**
Mountain whitefish	***Prosopium williamsoni***	**X**	**X**	**X**
Brown trout	*Salmo trutta*	X		X
Bull trout	***Salvelinus confluentus***		**X**	**X**
Chiselmouth	***Acrocheilus alutaceus***	**X**	**X**	**X**
Common carp	*Cyprinus carpio*	X	X	X
Peamouth	***Mylocheilus caurinus***	**X**	**X**	**X**
Northern pikeminnow	***Ptychocheilus oregonensis***	**X**	**X**	**X**
Longnose dace	***Rhinichthys cataractae***			**X**
Speckled dace	***Rhinichthys osculus***	**X**		**X**
Redside shiner	***Richardsonius balteatus***	**X**	**X**	**X**
Bridgelip sucker	***Catostomus columbianus***	**X**	**X**	**X**
Largescale sucker	***Catostomus macrocheilus***	**X**	**X**	**X**
Yellow bullhead	*Ameiurus natalis*	X		X
Brown bullhead	*Ameiurus nebulosus*	X	X	X
Channel catfish	*Ictalurus punctatus*	X	X	X
Black bullhead	*Ictalurus melas*	X	X	X
Tadpole madtom	*Noturus gyrinus*	X		X
Flathead catfish	*Pylodictus olivaris*	X		X
Mosquitofish	*Gambusia affinis*			X
Sandroller	***Percopsis transmontana***		**X**	**X**
Pumpkinseed	*Lepomis gibbosus*	X	X	X
Warmouth	*Lepomis gulosus*	X		X
Bluegill	*Lepomis macrochirus*	X	X	X
Smallmouth bass	*Micropterus dolomieui*	X	X	X
Largemouth bass	*Micropterus salmoides*	X		X
White crappie	*Pomoxis annularis*	X	X	X
Black crappie	*Pomoxis nigromaculatus*	X	X	X
Yellow perch	*Perca flavescens*	X	X	X
Walleye	*Stizostedion vitreum*			X
Prickly sculpin	***Cottus asper***	**X**		**X**
Mottled sculpin	***Cottus bairdi***	**X**		**X**
Piute sculpin	***Cottus beldingi***	**X**		**X**

*Bold type indicates native species.

Note: Bennett et al. (1983) reflects sampling by multiple gear types in the four reservoirs. BRD-ODFW (1991) reflects sampling by electrofisher and includes sampling in the unimpounded Snake River above Asotin, Washington. SOR (1995) is a compilation of data from various sources, including the Snake River below Ice Harbor Dam.

Table 3-4. Species Composition of Fish Collected with Multiple Gear Types in Lower Snake River Reservoirs during 1979 to 1980

	Lower Granite		Little Goose		Lower Monumental		Ice Harbor	
Species	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
White sturgeon	0	0.0	235	0.6	3	0.1	2	0.1
Mountain whitefish	2	0.1	39	0.1	2	0.0	10	0.3
Rainbow trout	4	0.1	172	0.4	22	0.5	6	0.2
Brown trout	0	0.0	1	0.0	0	0.0	0	0.0
Chiselmouth	310	10.0	1,456	3.6	408	8.7	99	2.6
Common carp	120	3.9	1,057	2.6	187	4.0	256	6.6
Peamouth	2	0.1	76	0.2	25	0.5	23	0.6
Northern pikeminnow	354	11.5	2,510	6.2	823	17.5	347	9.0
Speckled dace	0	0.0	4	0.0	0	0.0	0	0.0
Redside shiner	246	8.0	3,847	9.5	219	4.7	553	14.3
Bridgelip sucker	274	8.9	3,803	9.4	490	10.4	402	10.4
Largescale sucker	1,255	40.7	7,972	19.7	849	18.1	1,257	32.5
Yellow bullhead	15	0.5	240	0.6	22	0.5	1	0.0
Brown bullhead	36	1.2	629	1.6	31	0.7	20	0.5
Channel catfish	7	0.2	1,152	2.8	118	2.5	218	5.6
Tadpole madtom	0	0.0	72	0.2	1	0.0	1	0.0
Flathead catfish	0	0.0	0	0.0	0	0.0	2	0.1
Pumpkinseed	16	0.5	1,926	4.8	145	3.1	70	1.8
Warmouth	0	0.0	13	0.0	0	0.0	0	0.0
Bluegill	12	0.4	1,218	3.0	5	0.1	21	0.5
Smallmouth bass	218	7.1	2,104	5.2	301	6.4	106	2.7
Largemouth bass	0	0.0	61	0.2	0	0.0	31	0.8
White crappie	68	2.2	7,011	17.3	440	9.4	118	3.7
Black crappie	79	2.6	1,672	4.1	129	2.7	141	3.6
Yellow perch	68	2.2	3,046	7.5	396	8.4	145	3.7
Sculpins	0	0.0	201	0.5	80	1.7	38	1.0
Totals	3,086		40,517		4,696		3,867	

Source: Modified from Bennett et al., 1983

Although these differences in the fish community were apparent, overall similarities in relative abundance persisted as determined by correlation analysis (Table 3-5). The relative abundance of fish among reservoirs showed high similarities with correlations ranging from r=0.74 (Lower Granite and Little Goose reservoirs) to r=0.94 (Lower Granite and Ice Harbor reservoirs). This cursory analysis shows that from 54 to 87 percent of the variation in fish communities is accounted for by differences in reservoirs. These correlations are largely driven by the species in higher abundance among each of the reservoirs. A number of other fish were collected, but all were generally lower in abundance in each of the lower Snake River reservoirs. Because of the general similarities in fish community structure, we believe a more specific analysis by habitat best describes the fish within the lower Snake River reservoirs.

Table 3-5. Correlation Coefficients of Relative Abundance Among Snake River Reservoir Resident Fish Communities

	Little Goose	Lower Monumental	Ice Harbor
Lower Granite	0.74	0.80	0.94
Little Goose	1.00	0.81	0.78
Lower Monumental	0.81	1.00	0.76

Subsequent research has provided updated or refined estimates of relative abundance among reservoirs or among macrohabitat types for selected species deemed important in predator-prey relationships or sport fisheries. ODFW sampled fish with multiple gear types throughout the lower Snake River in 1991 and 1994 to 1996 as part of an investigation of predator dynamics, distribution, and abundance (Zimmerman and Parker, 1995; Ward and Zimmerman, 1997; Zimmerman and Ward, 1997). Reporting of results was limited to three piscivorous species. Smallmouth bass density (CPUE) in 1991 was reportedly highest in mid-reservoir and forebay reaches of Snake River reservoirs. Additionally, smallmouth bass relative abundance and density in Lower Granite Reservoir was more than twice that in other lower Snake River reservoirs, and density decreased in a downstream direction. Follow-up sampling in the upper reservoir reach of Lower Granite Reservoir showed a trend of decreasing abundance of smallmouth bass from 1994 to 1996, but other areas in Lower Granite Reservoir or other reservoirs were not sampled from 1994 to 1996 for comparison.

Trends in channel catfish abundance and density were generally opposite those for smallmouth bass. The density and relative abundance of channel catfish in Ice Harbor Reservoir were more than twice that in any other reservoir, and catfish were least abundant in Lower Granite Reservoir. Further, the highest density of channel catfish among reservoir macrohabitats was in mid-reservoir and tailrace reaches, especially in tailrace BRZs.

Northern pikeminnow density among reservoir macrohabitats was highest in tailrace BRZs. Density was highest in tailrace BRZs of Little Goose and Lower Monumental reservoirs (i.e., below Lower Granite and Little Goose Dams). Mid-reservoir densities were lower, but the overall abundance was higher due to the large size of mid-reservoir areas relative to other habitats. Comparable sampling during the 1994 to 1996 period in the tailraces of Lower Monumental and Little Goose reservoirs and upper reservoir habitats in Lower Granite Reservoir showed declines in abundance of northern pikeminnow greater than 250 millimeters (9.8 inches) due to operation of a sport reward program that paid bounties for removal of large-sized individuals by angling (Friesen and Ward, 1997).

Qualitative assessments of distribution and abundance within reservoir macrohabitats for other Snake River fish sampled by electrofishing during 1991 are shown in Table 3-6 (Tom Poe, U.S.G.S., B.R.D., unpublished data). Species such as chiselmouth, carp, northern pikeminnow, suckers, and smallmouth bass were widely distributed among reservoirs and habitats, and abundance of these species was reported as common in most locations. Only northern pikeminnow and suckers were recorded as abundant in some reservoir macrohabitats. Species either less abundant or more narrowly distributed included mountain whitefish, brown bullhead, pumpkinseed, bluegill, crappie, and yellow perch. Of these, all but mountain whitefish were most abundant in embayment or gulch habitats as reported in Bennett et al. (1983), which may illustrate the results of different sampling protocols or gear types.

Several species were mostly reported as rare (one or two individuals per collection) in 1991 samples. These included redside shiner, sandroller, bull trout, and sculpins. Bull trout was only reported above the reservoir influence in the mid-Snake river, but are also infrequently reported passing the dams. Sculpins and sandrollers are occasionally seen in stomach samples of reservoir predators, rather than in standard fisheries collections (David H. Bennett, University of Idaho, personal communication). Mosquitofish are only found in levee ponds in Lewiston (David H. Bennett, University of Idaho, personal communication).

More recently, the spatial trends in catch and catch rates among reservoirs determined by 1997 sport fishing surveys (Normandeau Associates et al., 1998a) corroborated trends in species density and abundance estimates for major Snake River predators as portrayed by Zimmerman and Parker (1995). For example, the highest smallmouth bass sport angling catches and catch rates occurred in Lower Granite Reservoir, whereas sport angling catch, harvest, and catch and harvest rates for channel catfish were highest in Ice Harbor Reservoir. The catch and catch rates of northern pikeminnow by anglers were highest in Lower Granite Reservoir, particularly in the more lotic Snake River arm of the upper reservoir.

Recent sport fishing catches may also illustrate recent spatial trends in distribution among reservoirs for several other species not targeted by specific management studies or activities. Sport catch and harvest of crappie were substantially higher in Little Goose Reservoir than in other reservoirs, especially in Ice Harbor Reservoir where crappie catch was nearly two orders of magnitude lower than in Little Goose Reservoir (Normandeau Associates et al., 1998a). Similarly, the white sturgeon sport catch was highest in Little Goose Reservoir. Yellow perch and sunfish (*Lepomis* spp.) sport catches were substantially higher in the downstream reservoirs, especially in Ice Harbor Reservoir. The sport catch of bullheads was highest in Lower Granite Reservoir.

In summary, recent documentation of the status of lower Snake River reservoir resident fish communities has focused primarily on a small group of species, mostly non-native, and that information on the current status of most native species (other than northern pikeminnow and white sturgeon) is lacking. Thus, the work by Bennett et al. (1983) shortly after the last reservoir was completed in 1975 represents the only quantitative information available on most resident fish that likely remain quite abundant and widely distributed. These species include largescale and bridgelip suckers, redside shiner, and other native cyprinids and cottids.

Table 3-6. Qualitative Relative Abundance Estimates of Resident Fish Determined by Electrofishing in Macrohabitats of Lower Snake River Reservoirs in 1991

	Ice Harbor			Lower Monumental			Little Goose			Lower Granite			Snake	Clearwater	Free-flowing
Species	**F**	**M**	**T**	**F**	**M**	**T**	**F**	**M**	**T**	**F**	**M**	**U**	**R. Arm**	**R. Arm**	**Snake R.**
White sturgeon			C						R				R		
Bull trout															R
Mountain whitefish	R			R	R	R			R	R		R	C	C	C
Chiselmouth	R	R	C	C	C	C	R	C	C	C	R	C	C	C	C
Common carp	C	C	C	C	C	C	C	C	C	C	R	C	C	R	C
Peamouth	R	C	C	C	C	C						R		R	
Northern pikeminnow	R	C	C	C	C	C	C	C	A	C	R	C	C	C	C
Redside shiner								R						R	
Suckers	C	C	A	C	C	C	C	C	C	C	C	C	A	A	A
Brown bullhead		R		R	R	C	C	R			R				
Channel catfish	R	C	R	R	C	C		C					R		
Sandroller					R										
Three-spine stickleback											R*				
Pumpkinseed	R	C	R	R	C			R			R	R		R	
Bluegill	C				R										
Smallmouth bass	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Crappies	C	C	R	R	C	C	R	C	R	R	R	R			
Yellow Perch	R	R	C	R	C	C	R	C	C					R	
Sculpins														R	

A=abundant (>25 individuals per collection)
C=common (>2-25 individuals per collection)
R=rare (1-2 individuals per collection)
*Questionable record
F=forebay; M=mid-reservoir; T=tailrace; U=upper reservoir
Source: USGS, Biological Resources Division, Cook, Washington

In spite of the recent information on the relatively high-profile species, the overall similarities in community composition and relatively limited information on specific fish abundance of most species in each reservoir suggest that the four lower Snake River reservoirs should be treated as one reservoir system with an analysis of the fish community inhabiting each of the principal macrohabitats in the reservoirs. Our analysis of expected impacts will be based on examination of the characteristic fish communities in the forebay, tailrace, mid-reservoir, and specific backwater/embayment habitats common to all reservoirs in the system. This type of analysis will facilitate subsequent descriptions of expected impacts to reservoir fish communities for the various alternatives under consideration.

3.3.3 Life History Information for Ecologically Key Species

Six species or congeners have been identified for individual treatment as ecologically key, or important, species. The native northern pikeminnow, for example, is important in predator-prey dynamics of the reservoirs (Ward et al., 1995) and is the focus of population reduction efforts via a sport reward program that pays bounties for removal of large individuals (Friesen and Ward, 1997). Largescale and bridgelip suckers are native species that were highly abundant throughout the reservoirs during comprehensive sampling efforts in 1979 and 1980 (Bennett et al., 1983). White and black crappie, smallmouth bass, and channel catfish represent introduced species that are highly sought by sport anglers throughout the reservoir system (Normandeau Associates et al., 1998a). Smallmouth bass and channel catfish also have been the focus of predator-prey investigations (Zimmerman and Parker, 1995; Ward and Zimmerman, 1997), along with northern pikeminnow. White sturgeon is a native species that has declined in abundance due to continued harvest and isolation and loss of flowing water habitats by dams. White sturgeon is a Species of Concern in Idaho (BPA, 1995).

The remaining resident fish are discussed in Section 3.3.4. Subsequent sections focus on physical habitat attributes or processes, including water temperature, gas supersaturation, and fish entrainment past the dams, that affect all the resident fish. A summary of research on predation by resident fish on juvenile salmonids is presented in Section 3.7. Finally, the resident fish were grouped into assemblages corresponding to assignment to one of several habitat-use guilds (see Section 3.8). Grouping by habitat-use guilds represents a method of assessing multiple species assemblages that share various habitat use attributes or characteristics. The guild approach simplifies analyses of large numbers of species and facilitates predictions of community responses to environmental change (Austen et al., 1994).

3.3.3.1 Smallmouth Bass

Smallmouth bass is one of the more abundant and widely distributed species in the lower Snake River reservoirs (Bennett et al., 1997) and an important sport fish (Normandeau Associates et al., 1998a). However, limited research has been conducted on the life history of smallmouth bass in the lower Snake River.

Two known estimates of the absolute abundance of smallmouth bass have been conducted in lower Snake River reservoirs. Anglea (1997) conducted multiple-census estimates during 1994 in Lower Granite Reservoir and reported 20, 911 bass greater than 174 millimeters (6.8 inches) (95 percent CI –17,092 to 26,197). Using an estimate of 0.47 percent survival, Anglea (1997) estimated that the population abundance of smallmouth bass greater than 70 millimeters (2.8 inches) in Lower Granite

Reservoir was 65,400 (95 percent CI –61,023 to 71,166). Standing crop was estimated at 0.75 kilogram/hectare (0.44 lb/acre) for bass greater than 199 millimeters (7.8 inches), and density was 3.4 smallmouth bass/hectare (1.4 bass/acre) throughout the entire reservoir. More recently, Naughton (1998) estimated the absolute abundance of smallmouth bass in the Lower Granite Dam tailwater (Little Goose Reservoir), the forebay, Clearwater River, and Snake River arms of Lower Granite Reservoir. He found that densities were highest for smallmouth bass greater than 174 millimeters (6.8 inches) in the forebay of Lower Granite Reservoir (12.7 bass/hectare), followed by the Clearwater River Arm (12.5 bass/hectare [5.1 bass/acre]). His estimates of standing crop compared closely to those of Anglea (1997).

Although absolute abundance has not been estimated for Lower Monumental and Ice Harbor reservoirs, studies by Zimmerman and Parker (1995) have shown that Lower Granite Reservoir supports the highest density and relative abundance of smallmouth bass among Snake River reservoirs. However, these estimates of abundance of smallmouth bass are generally lower than those reported by investigators for other geographical areas. For example, Paragamian (1991) reported densities of 2 to 911 smallmouth bass/ha (0.8 to 369 bass/acre) for 22 waters throughout Iowa, and Carlander (1977) reported densities no less than 16 smallmouth bass/ha (6.5 bass/acre). These findings demonstrate that smallmouth bass are comparatively low in abundance in lower Snake River reservoirs compared to other waters throughout their range.

The spawning season of smallmouth bass in lower Snake River reservoirs is generally later than reported elsewhere. Bratovich (1983) reported on the reproductive cycle of smallmouth bass from examination of gonads in Little Goose Reservoir in 1979 and 1980. The largest ovaries were measured in April, and the reported time of spawning based on ovarian condition was in May, June, and July. In contrast, Pflieger (1975) reported smallmouth bass spawning in Missouri as early as the first of April. Henderson and Foster (1957) observed smallmouth spawning in the Columbia River until the latter part of July. Bennett et al. (1983) suggested a spawning period of longer than 60 days, similar to that reported for Missouri (Pflieger, 1975).

Other observations suggest spawning largely occurs in June and July, based on attainment of suitable water temperatures of about 15.9°C (60.6°F) (Coble, 1975). Bennett et al., (1983) observed spawning to occur over a range of temperatures from 14 to 19.6°C (57 to 67°F), within the full range of water temperatures reported in the literature (12.8 to 26.7°C [55 to 80°F]); Henderson and Foster, 1957; Reynolds, 1965) for smallmouth bass. Others have reported spawning temperatures of 15 to 18.3°C (59 to 65°F) (Turner and McCrimmon, 1970; Coble, 1975; Pflieger, 1975; Coutant, 1975).

Habitat used for spawning is largely gravel substrate, highly abundant along the shorelines of the lower Snake River reservoirs. Substrate used by smallmouth bass for spawning in Little Goose Reservoir was similar to that reported in the literature (Bennett et al., 1983). All observed smallmouth bass spawning activity in Little Goose Reservoir was on low-gradient shorelines of sand and/or gravel, with 85 percent of spawning nests on gravel 6 to 50 millimeters (0.25 to 2.0 inches) in diameter. Spawning areas in Little Goose Reservoir were frequently found in gulch and embayment habitats in the lower reservoir. The areas were generally protected from direct wind and wave action with little to no perceptible current. In the upper reservoir, smallmouth bass nests were more commonly observed in shoal areas that were usually exposed to wind and wave action and/or higher water velocities. Differences in habitats used were attributed to the paucity of gulch and embayment habitats in the upper reservoir (Bennett et al., 1983).

Bennett and Shrier (1986) reported that smallmouth spawning nests were located in Lower Granite Reservoir from the confluence of the Snake and Clearwater rivers downstream nearly to Lower Granite Dam. Highest nest abundance was in the lower part of the reservoir where water velocities were lowest.

Fluctuating water levels and water temperatures may adversely affect smallmouth bass in Lower Granite Reservoir. Bennett et al. (1994) suggested from their research that cold upstream water releases from Dworshak Reservoir in 1991 and 1992 probably had only a minimal effect on smallmouth bass growth and survival and, consequently, year-class strength. However, operational water level fluctuations up to 1.5 meters (5 feet) in Little Goose Reservoir may affect the vertical distribution of spawning activity by smallmouth bass. Most spawning activity of smallmouth bass (and other centrarchid fish) occurs in water of 2 meters (6.6 feet) or less (Bennett, 1976). Most bass nests have been reported in water from 0.3 to 2 meters (1 to 6.6 feet) (Scott and Crossman, 1979; Coble, 1975), although smallmouth have been reported to spawn at depths of 6.7 meters (22 feet) in clear water (Trautman, 1981). The deepest smallmouth bass nests reported for Little Goose Reservoir were 5.3 meters (17.4 feet) (relative to full pool), although 84 percent were located at depths of 2 meters (6.6 feet) or less. In 1980, Bennett et al. (1983) found that 27 percent of all nests located were desiccated by fluctuating water levels in Little Goose Reservoir, although 75 percent of all spawning nests were located within the 1.5-meter (5-foot) fluctuation zone. Bennett et al. (1983) suggested that periods of high, stable water levels during the spawning season, followed by pronounced reduction in water levels, may have deleterious effects on the spawning success of smallmouth bass in Little Goose Reservoir. Vertical fluctuations of similar magnitude can also occur in Lower Granite Reservoir, whereas those in Lower Monumental and Ice Harbor reservoirs are about 0.5 meter (1.6 feet) lower (i.e., limited to about 0.9 meters [3 feet]). Spawning of smallmouth bass in the latter reservoirs has not been investigated.

Food items of smallmouth bass have been intensively examined in Little Goose and Lower Granite reservoirs. Bennett et al. (1983) found that smallmouth bass (n=484) consumed crayfish, fish, and terrestrial and aquatic insects in decreasing order of importance in Little Goose Reservoir during 1979 and 1980. Crayfish accounted for 72 percent by volume of the food items eaten and appeared in 64 percent of all bass stomachs. Fish consumed accounted for 25.4 percent by volume and were found in 32 percent of the smallmouth bass stomachs that contained food. Fish eaten were sculpin, white crappie, redside shiner, northern pikeminnow, catfish, bluegill, yellow perch, chinook salmon, bridgelip sucker, and pumpkinseed.

Anglea (1997) examined food items from over 4,000 smallmouth bass in Lower Granite Reservoir. Crayfish were consistently the dominant food item in Lower Granite Reservoir in 1995, although salmonids and other fish accounted for nearly 50 percent of the diet in the spring. He found that fish were the most important food item, by weight, from April to June 1994 and 1995, whereas crustaceans and insects increased in abundance after June. As others have reported, larger smallmouth bass consumed a higher proportion of fish. Crayfish were the most abundant food item by weight for smallmouth bass from 175 to 249 millimeters (6.9 to 9.8 inches), while finfish and crayfish were equally important for bass from 250 to 389 millimeters (9.8 to 15.3 inches). Fish were the dominant food item of smallmouths greater than 389 millimeters (15.3 inches).

Bennett and Naughton (1998) examined greater than 8,500 smallmouth bass stomachs from the tailwater, forebay, and Snake and Clearwater River arms of Lower Granite Reservoir in 1996 and 1997. They found that non-salmonid fish were the most abundant prey item by weight in the tailrace

(46.9 percent), tailrace BRZ (71.6 percent), forebay BRZ (51.5 percent), and Clearwater River arm in 1996. In contrast, during 1997, crayfish were clearly the dominant food item by weight in the tailrace (73.4 percent), tailrace BRZ (60.8 percent), forebay (58.8 percent), and Snake River arm (50.3 percent). Monthly differences in food items were low within study sites. From these findings, it is obvious that smallmouth bass in Lower Granite, Little Goose, and probably other lower Snake River reservoirs consume a large number of crayfish, similar to that reported in the literature for other river and lake systems.

The 1997 sport fishing catch (kept and released) of smallmouth bass was highest in Lower Granite (greater than 10,000 fish) and Little Goose (greater than 8,000 fish) reservoirs, while the sport harvest (kept only) of smallmouth bass varied more than fourfold among reservoirs (Table 3-7). Lower Monumental and Little Goose reservoirs yielded the largest smallmouth bass harvests (2,802 and 2,762 bass, respectively), whereas anglers in Ice Harbor Reservoir harvested less than 700 fish (Table 3-7).

Table 3-7. Estimated Sport Fishing Harvest of Selected Fish in Lower Snake River Reservoirs from April to November, 1997

	Lower Granite	Little Goose	Lower Monumental	Ice Harbor
Smallmouth bass	897	2,762	2,802	691
Crappie spp.	1,634	15,523	4,952	204
Channel catfish	228	5,654	1,789	5,607
Northern pikeminnow	1,512	161	256	102

Source: Normandeau Associates et al., 1998a

3.3.3.2 Black and White Crappie

Black crappie and white crappie are two of the more important sport fish in backwater habitats in the lower Snake River reservoirs (Knox, 1982; Normandeau Associates et al., 1998a). They are highly habitat-specific in the reservoirs and are chiefly limited to embayment areas off the main channel. The species co-occur throughout the reservoir system, but only in Little Goose Reservoir was there apparent dominance by white crappie (Bennett et al., 1983). The white crappie is more tolerant of turbidity and siltation than other centrarchid fish, although it is less competitive in clear waters (Carlander, 1977). Limited life history information has been collected on crappie, primarily in Little Goose Reservoir (Bennett et al., 1983).

Relative abundance of crappie has been determined for each of the lower Snake River reservoirs, and absolute abundance was determined for Deadman Bay in Little Goose Reservoir. Crappie ranged from about 20 percent of the fish community in Little Goose Reservoir to about 5 percent in Lower Granite Reservoir. Their relative abundance is directly related to habitats sampled during the abundance surveys. Crappie attain highest abundance in backwaters and, therefore, attained highest relative abundance in Little Goose Reservoir.

Bennett et al. (1983) conducted the only known population dynamics studies on crappie in lower Snake River reservoirs. A multiple-census population estimate in Deadman Bay found that white crappie was the most numerous species (Table 3-8). Density and biomass estimates for white crappie ranged from 158 to 200 fish/hectare (64 to 81 fish/acre) and 26.7 to 33.8 kilogram/hectare

Table 3-8. Estimates of Population Density (Number/Area) and Standing Crop (Biomass/Area) for Selected Centrarchid Fish in Deadman Bay, Little Goose Reservoir

Species	Minimum size (mm)	High Pool Level Population density (fish/ha)	High Pool Level Standing crop (kg/ha)	Low Pool Level Population density (fish/ha)	Low Pool Level Standing crop (kg/ha)
White crappie	200.0	158.0	26.7	200.0	33.8
Black crappie	200.0	21.0	4.2	27.0	5.3
Pumpkinseed	100.0	13.0	0.51	17.0	0.64
Bluegill	100.0	11.0	0.72	13.0	0.92

Source: Bennett et al., 1983

Note: Estimates are shown for Deadman Bay at high (53.8 hectares) and low (42.5 hectares) pool levels.

(23.8 to 30.2 lb/acre), respectively, while those for black crappie were about 85 percent less. Catches of black crappie were higher in the main channel areas of Little Goose Reservoir, while catches were higher for white crappie in backwaters.

Growth increments and condition factors of crappie from the lower Snake River reservoirs were similar or better than those for comparable geographical areas (Bennett et al., 1983). Growth increments were not significantly different among reservoirs, although growth of black crappie was slightly slower than that of white crappie. Differences in growth between white and black crappie were attributed to higher water temperatures in backwaters where white crappie predominate, as well as the greater consumption of fish by white crappie.

Food of white crappie in the lower Snake River reservoirs was similar to that reported in the literature. Cladocerans were the dominant food item of white crappie in the summer, and fish became more important in the fall in Little Goose and other lower Snake River reservoirs (Bennett et al., 1983). Dietary items of black crappie were similar to those of white crappie.

Time of spawning for crappie is typically later in the north than in the south (Hardy, 1978). Bratovich (1983) found white crappie in the lower Snake River reservoirs in spawning condition from June into August, similar to Nelson et al. (1967), who found the white crappie spawning season extended from mid-May through mid-July in Lewis and Clark Lake, Missouri River, on the Nebraska-South Dakota border. Hjort et al. (1981) reported white crappie spawning ranged from late May to late July in John Day Reservoir on the Columbia River. From late May to late July, water temperatures in the lower Snake River reservoirs ranged from 15.8 to 20.4°C (60 to 69°F) (Bennett et al., 1983). Published reports generally consider 16 to 21°C (61 to 70°F) optimal for white crappie spawning (Nelson et al., 1967; Siefert, 1968). Spawning times for black crappie in the lower Snake River reservoirs were June and July, compared to early May to mid-July in John Day Reservoir (Hjort et al., 1981). Water temperatures in the lower Snake River reservoirs during the time when black crappie were in spawning condition ranged from 15.8 to 19.6°C (60 to 67°F). These water temperatures were a little cooler than those generally reported suitable for black crappie spawning (19 to 20°C [66 to 68°F]); Scott and Crossman, 1979).

The most recent sport harvest data for crappie varied among reservoirs by more than two orders of magnitude. The largest harvest was in Little Goose Reservoir (15,523 fish), compared to an estimated 204 crappie harvested from Ice Harbor Reservoir (Table 3-7).

3.3.3.3 Largescale and Bridgelip Sucker

Suckers are the most abundant fish in the lower Snake River reservoirs (Bennett et al., 1983; 1987; 1990). Largescale suckers are about two times more abundant than bridgelip suckers in Little Goose and Lower Monumental reservoirs and two orders of magnitude higher in Lower Granite and Ice Harbor reservoirs. The high abundance of suckers throughout the reservoirs suggests that both species are habitat generalists. The greater overall abundance of largescale sucker relative to bridgelip sucker suggests that habitat requirements for bridgelip sucker might be somewhat narrower than for largescale sucker. Bridgelip sucker was classified as a mesotherm, with narrower temperature requirements than largescale sucker (*a eurytherm*), although their generalized distribution within a river continuum was similar (Li et al., 1987).

The seasonal distribution of suckers in Lower Granite Reservoir can be inferred from data presented by Bennett et al. (1993), although spring catches are dissimilar with findings in Little Goose

Reservoir (Bennett et al., 1983). Both species were primarily sampled in shallow waters in Lower Granite Reservoir during the spring of 1990. In 1980, however, captures of bridgelip sucker were highest in deepwater areas of Lower Granite Reservoir in the spring, while largescale suckers were more evenly distributed among deepwater areas and shallower shoal and gulch habitat. Both species were widely distributed throughout the water column in summer and fall based on gill net captures at deepwater stations. Bennett et al. (1983) also showed a tendency of both bridgelip and largescale suckers to move to the tailwaters of Lower Granite, Little Goose and Lower Monumental Dams in the fall.

Bennett et al. (1983) conducted the only known estimates of absolute abundance of suckers in the lower Snake River reservoirs. They estimated about 9,000 largescale suckers in Deadman Bay of Little Goose Reservoir in 1980, with a density of 172 fish/ha (70 fish/acre) and estimated standing crop about 156 kilograms/hectare (139 lb/acre).

Little information is available on the spawning of bridgelip or largescale suckers in the northwest. Dauble (1980) found that bridgelip suckers spawn from March to June, with most spawning in the Columbia River occurring during April. Water temperatures in the lower Snake River reservoirs that coincided with the presence of ripe bridgelip suckers ranged from 10.2 to 12.2°C (50.4 to 54°F) (Bennett et al., 1983). Dauble (1980) reported spawning from 6 to 13°C (43 to 55°F) in the Columbia River.

Bennett et al. (1983) found largescale suckers in spawning condition in May and June, similar to that reported by Scott and Crossman (1979) for British Columbia. MacPhee (1960) reported that largescale suckers spawn in the North Fork Payette River, Idaho, in mid-to late June, whereas Hjort et al. (1981) reported largescale sucker spawning from early May to early August in the lower Columbia River. Water temperatures in the lower Snake River reservoirs were 12.2 to 15.8°C (54 to 60°F) compared to 7.8 to 8.9°C (46 to 48°F) for stream-spawning largescale suckers in British Columbia (Scott and Crossman, 1979).

Food of suckers has been reported to be primary producers such as diatoms and filamentous green algae and benthic invertebrates (Carlander, 1977; Li et al., 1987). Bennett et al. (1983) conducted stomach analyses of bridgelip and largescale suckers and found predominantly diatoms and green and blue-green algae in the stomachs of each species. Macroinvertebrates were relatively minor food items. Few seasonal differences were found, although detritus and blue-green algae increased in abundance from spring to winter.

Anglers usually catch suckers only incidentally while fishing for other species. A few anglers, more typically in the mid-Snake River upstream of Asotin, catch suckers for bait for white sturgeon (Normandeau Associates et al., 1998b).

3.3.3.4 Northern Pikeminnow

The northern pikeminnow is a species of great interest in the Columbia River basin because of its predatory habits pertaining to downstream migrating juvenile salmonids (Poe et al., 1991). There has been substantial recent work detailing the food habits (Zimmerman and Ward, 1997), predatory role (Zimmerman and Ward, 1997), exploitation rates (Friesen and Ward, 1997), and population and growth parameters (Parker et al., 1995; Knutsen and Ward, 1997) for this important species in Snake River reservoirs. However, limited life history information exists relative to spawning and reproduction. Smith (1996) recently completed an analysis of the incidence of chiselmouth x northern pikeminnow hybrids in the lower Snake River. F1 hybrids are present in the system, with 33 percent of the hybrids having chiselmouth maternity and 67 percent having northern pikeminnow maternity. His work demonstrated how morphological characteristics could be used to assess accurate species identification.

The northern pikeminnow spawns from mid-May to late June in lower Snake River reservoirs (Bennett et al., 1983), somewhat earlier than reported by Hjort et al. (1981) for John Day Reservoir, Columbia River (June to August). In other areas, northern pikeminnow reportedly spawn from May to early July (Carl et al., 1959), both in lakes and tributary streams (Jeppson and Platts, 1959; Patten and Rodman, 1969). In Cascade Reservoir, central Idaho, Casey (1962) reported that northern pikeminnow spawn during June, with peak spawning activity in the latter part of June. Water temperatures at the time of spawning in Snake River reservoirs ranged from 14.0 to 20.4°C (57.2 to 68.7°F), similar to those reported by Casey (1962, 14.5 to 16.7°C [58.1 to 62°F]) and Stewart (1966, 18.0°C [64.4°F]).

Other than the time of spawning, little other information is available on spawning habits of northern pikeminnow in any of the Snake River reservoirs. Bennett et al. (1994) and Cichosz (1997) have emphasized the importance of the early rearing period to year-class strength and recruitment. Cichosz (1997) examined what factors limit the abundance of northern pikeminnow in Lower Granite Reservoir. He found that their abundance is probably determined in the egg-through-larval stage, although juvenile mortality is also important. Density independent factors were most important in controlling egg-through-juvenile survival. Timing of water temperature conditions was most important in predicting survival of northern pikeminnow. Survival was also positively related to growth.

Dresser (1996) examined the influence of habitat factors on fish assemblages in Lower Granite Reservoir. Through the use of multivariate analysis, he reported that the northern pikeminnow selected shallow, vegetated habitats with substrate sized less than 2.0 millimeters (0.08 inches). These findings were considerably different from those of Dupont (1994) who found that the northern pikeminnow in the Pend Oreille River, Idaho, selected rocky shorelines with deeper depths and higher water velocities. Dresser (1996) believed differences in selected habitats could be attributed to interactions with other species, particularly smallmouth bass. Smallmouth bass are not present in the Pend Oreille River. Habitat types occupied by the northern pikeminnow in the Pend Oreille River are occupied by smallmouth bass in Lower Granite Reservoir. Further, some evidence supports the hypothesis that predation on northern pikeminnow by smallmouth bass may account for differences in habitat use. Werner et al. (1997) reported that predation on small size classes may result in habitat segregation. Pollard (Idaho Department of Fish and Game, retired, personal communication, Portland, Oregon) observed that the abundance of northern pikeminnow decreased following the introduction of smallmouth bass into Anderson Ranch Reservoir, Idaho. He further suggested that similar habitats inhabited by the northern pikeminnow in Brownlee Reservoir, Idaho, were void of them following the introduction of smallmouth bass. Since most northern pikeminnow collected by Dresser (1996) were 120 to 250 millimeters (4.7 to 9.8 inches), and the smallmouth bass ranged in length from 100 to 520 millimeters (3.9 to 20.5 inches), his explanation seems plausible.

The influence that northern pikeminnow have on downstream migrating salmonids has been a concern for over a decade in the Columbia River system. A number of studies have been conducted to investigate northern pikeminnow predation in the lower Snake River reservoirs. Chandler (1993) provided the initial quantification of actual predation on downstream migrating salmonids in Lower Granite Reservoir. Chandler (1993) found that salmonids were the most abundant food item (by weight) consumed by northern pikeminnow during spring from 1987 to 1991. Crayfish were second in importance. Year-to-year variation in salmonid consumption was high. Ward et al. (1995) found that northern pikeminnow abundance and consumption of salmonids were higher in the lower Columbia River than in the Snake River. Among Snake River habitats sampled, the consumption index was higher in the Lower Granite Reservoir forebay and in tailwaters of Ice Harbor, Lower Monumental, and Little Goose reservoirs. Ward et al. (1995) correlated biological characteristics of northern pikeminnow populations and found a significant correlation only of density with relative fecundity, implying that northern pikeminnow populations were not limited by density.

Sport anglers pursue northern pikeminnow largely in Lower Granite Reservoir, mostly due to the bounty paid by the sport reward program (Freisen and Ward, 1997). Harvest in Lower Granite Reservoir was approximately 1,500 fish (although most were in the Snake River arm), and less than 260 fish in the other reservoirs (Table 3-7).

3.3.3.5 White Sturgeon

Limited information exists on the white sturgeon in the lower Snake River system. No known information exists on spawning activities of white sturgeon in the lower Snake River reservoirs. However, Parsley and Beckman (1994) quantified spawning habitat in three of the lower Columbia River reservoirs by using a geographic information system. They showed that spawning habitat was available downstream of each of the dams, although the quantity of available habitat was affected by flow variability. Rearing habitat for age 0 and juvenile white sturgeon was also quantified and found to be more available in the impounded river than in the unimpounded reach below Bonneville Dam.

Samples of numerous juvenile white sturgeon (less than 16 centimeters [6.3 inches]) suggest that juvenile rearing habitat is probably highly abundant in Lower Granite Reservoir (Bennett et al., 1993). Additionally, Bennett et al. (1994) concluded that the flowing water section of the Snake River above Lower Granite Reservoir may provide spawning habitat and ultimately could be a recruitment source for downstream reservoirs. Data collected in 1992 before and after the test drawdown indicated white sturgeon moved from Lower Granite Reservoir to the upstream portion of Little Goose Reservoir. However, Bennett et al. (1994) could not determine whether this movement was stimulated by the drawdown or occurred following the drawdown.

Rearing habitat for white sturgeon seems to be linked to water velocity. Apperson (1990) suggested that white sturgeon in the Kootenai River, Idaho, were found at water velocities between 0.05 and 0.56 meters/second (0.2 and 1.8 feet/second). Velocities in this range were found exclusively in the upper portion of Lower Granite Reservoir, the reach with the highest abundance of white sturgeon. Deep, slack water in Lower Granite Reservoir, and probably in other lower Snake River reservoirs, did not provide suitable habitat, and captures have been consistently low.

Lepla (1994) conducted the most comprehensive study on white sturgeon in the lower Snake River reservoirs on Lower Granite Reservoir, including the only known population estimate among the reservoirs. He estimated that 1,524 (95 percent CI–1,155 to 2,240) white sturgeon greater than 40 centimeters (15.7 inches) (fork length) inhabited Lower Granite Reservoir. White sturgeon density was estimated at 0.38 fish/hectare (0.15 fish/acre), or 12 to 45 sturgeon/rkm (19 to 73 sturgeon/rm). The density estimate was generally similar to that of Lukens (1985; 24 sturgeon/rkm

39 sturgeon/rkm) but lower than those of Coon et al. (1977) who reported 35 to 53 sturgeon/rkm (56 to 85 sturgeon/rm) between Lower Granite and Hells Canyon Dams.

Lepla (1994) sampled nearly 1,000 white sturgeon and examined habitat use. He found that 94 percent of the white sturgeon in Lower Granite Reservoir were less than 125 centimeters (49 inches) total length (TL) with the majority in the 0 to 8 age group. Lepla (1994) developed a stepwise discriminate model to explain white sturgeon distribution but could account for only 26 percent of the variation in distribution using habitat data. However, he found 56 percent of all fish sampled were from a 5.5-kilometer (3.4-mile) reach near Clarkston, Washington, (Port of Wilma to Red Wolf Crossing) in upper Lower Granite Reservoir (Figure 3-2). Catches in the mid- to lower reservoir were consistently low.

Coon (1975) also suggested the importance of moving water to white sturgeon, based on tracking fish with sonic tags. Implanted white sturgeon moved to the upstream portion of Lower Granite Reservoir during the impoundment process and resided in the same area near Clarkston, Washington, as the majority of fish sampled by Lepla (1994).

Crayfish relative abundance has been quantified in Lower Granite Reservoir and its distribution appears very similar to that of white sturgeon (Bennett et al., 1993; Lepla, 1994). Crayfish are reportedly an important food item of white sturgeon in the Snake River (Coon et al., 1977; Cochanuer, 1983). Bennett et al. (1993) could not ascertain whether higher crayfish abundance in up-reservoir areas was responsible for the upstream abundance of white sturgeon, or whether both species had similar habitat preferences.

The sport harvest of white sturgeon is largely restricted to Little Goose Reservoir (Normandeau Associates et al., 1998a). Nearly 600 were caught, but estimated harvest was 40 individuals.

3.3.3.6 Channel Catfish

Reasonably good information exists on the relative abundance of channel catfish in the lower Snake River reservoirs, although absolute abundance is unknown. Bennett et al. (1983) recorded the first known estimates of abundance from samples collected in 1979 and 1980. Their study indicated that channel catfish attained highest relative abundance in Ice Harbor Reservoir (5.8 percent), followed by Little Goose (2.8 percent) and Lower Monumental (2.5 percent) reservoirs. Abundance in Lower Granite Reservoir was considerably lower than in the other three reservoirs. The abundance of channel catfish in Little Goose Reservoir was significantly correlated with the abundance of several other species. The highest correlation of channel catfish abundance was with brown bullhead and bluegill, suggesting its abundance in backwater habitats is highest where these other species attain high abundance.

Bennett et al. (1983) reported seasonal differences in the relative abundance of channel catfish. In the spring, 71 percent of the channel catfish in Little Goose Reservoir were collected from the Lower Granite Dam tailwater, whereas in the summer and fall, channel catfish were more highly abundant in lower embayment and gulch habitats. In general, the smallest catfish were collected from embayment habitats whereas the largest individuals were captured in the tailwater of Lower Granite Dam. Channel catfish distribution was not greatly different among habitats in Lower Granite (n=8), Lower Monumental (n=227), and Ice Harbor (n=467) reservoirs from spring to fall, although seasonal differences may have obscured any habitat preferences.

Growth of channel catfish in Little Goose Reservoir was deemed comparatively rapid (Bennett et al., 1983). Growth was more rapid during the first 6 years of life than in subsequent years. Bennett et al. (1983) suggested that growth increments increased since 1969, possibly a result of higher vulnerability of salmonid smolts downstream of Lower Granite Dam. Growth increments of channel catfish were significantly smaller in Ice Harbor Reservoir than either Lower Monumental or Little Goose reservoirs. The growth increments reported were similar to those for channel catfish in the midwestern United States, which was surprising because of below optimum Snake River water temperatures. Kilambi et al. (1970) reported 32°C (89.6°F) as the optimum temperature for growth, whereas the highest water temperatures in the lower Snake River reservoirs are typically 5-10°C (9 to 18°F) lower. These temperatures were taken in slack water areas and are higher than average high temperatures in the main reservoirs.

Food of 452 channel catfish (92 to 649 mm [3.6 to 25.6 inches]) was also examined by Bennett et al. (1983). They found that fish, aquatic insects, crayfish, wheat, and cladocerans were the more important food items. Food items varied with sampling location. Seasonally, fish was the predominant food item in the spring. Predation on downstream migrating juvenile steelhead and chinook salmon was high in the spring, especially in samples taken from the Lower Granite tailwater. In the summer, crayfish, cladoceran zooplankton, and aquatic insects were important food items.

More recently, Bennett et al. (1988) examined food items of channel catfish in Lower Granite Reservoir. They found that fish constituted 42 percent by weight of the food items during spring 1987. Rainbow trout, presumably juvenile steelhead, comprised 38 percent of the weight of fish consumed and juvenile chinook salmon about 1 percent. Chironomidae comprised about 29 percent of the remaining items of the diet in spring and 60 and 85 percent, respectively, of the channel catfish diet in the summer and fall. Juvenile salmonids comprised about 1 percent of all food items in the fall.

The highest sport harvests of channel catfish in 1997 occurred in Little Goose (5,654 fish) and Ice Harbor (5,607 fish) reservoirs (Table 3-7). In contrast, the harvest in Lower Granite Reservoir was estimated at only 228 fish.

3.3.4 Other Fish

Several species of fish in the Snake River reservoirs occur in lower relative abundance than the key species. Some of these are native fish, while many others were introduced into the Snake River. The native fish are largely from two fish families: Cyprinidae and Cottidae. Of the cyprinids, chiselmouth and redside shiners are the most abundant. From limited sampling, chiselmouth seem to be equally abundant between Little Goose and Ice Harbor and between Lower Granite and Lower Monumental reservoirs, although differences in relative abundance may be more related to habitats sampled (Bennett et al., 1983). In Lower Granite Reservoir, Bennett and Shrier (1986) reported that chiselmouth were collected in highest abundance at the confluence of the Snake and Clearwater rivers and immediately downstream of the riverine portion of the Clearwater River. Data presented by Bennett et al. (1993) and Bennett et al. (1988) suggest that chiselmouth movements occur throughout the year. In the spring, abundance is higher at shallow water locations, whereas in the winter they are found in deeper waters. Time of spawning is similar to northern pikeminnow, based on the presence of hybrids (Smith, 1996).

Redside shiners are about equally abundant in the upper three reservoirs compared to their higher relative abundance in Ice Harbor Reservoir. Redside shiners have been sampled in highest abundance in the spring in the impounded portion of the Clearwater River arm (Bennett and Shrier, 1986) and in shallow water stations in Lower Granite Reservoir (Bennett et al., 1988). Few were collected in the summer through the fall. The common carp is an introduced species and most abundant in Little Goose Reservoir, probably because of the extensive backwater habitats. Peamouth and speckled dace, both native cyprinids, have consistently been collected in low abundance in the lower Snake River reservoirs.

Limited information exists on the species composition and relative abundance of various species of cottids in the lower Snake River reservoirs. Bennett et al. (1983) listed three species of cottids. Prickly sculpin, Piute sculpin and mottled sculpin were all identified, although all were treated as an assemblage throughout their work. No other known information has been collected on sculpins, especially their species composition and relative abundance in the lower Snake River reservoirs. Little life history information exists on these species in the lower Snake River reservoirs, although general life history information is available on each of these species from other systems (Simpson and Wallace, 1978; Blair et al., 1968).

The species complex of introduced ictalurids, other than channel catfish (see Section 3.3.3), has been consistently low (less than 1 percent of the total fish community) in relative abundance in the lower Snake River reservoirs (Bennett et al., 1983). Brown, black, and yellow bullheads have been found along with tadpole madtoms and a low number of flathead catfish. Brown bullheads have been the most abundant of the bullheads in Lower Granite Reservoir, although they comprise only 10 to 20 percent of the catch of channel catfish (Bennett et al., 1988, 1993). Tadpole madtom is a common species to the middle Snake River reservoirs above Hells Canyon (Dunsmoor, 1990). They consumed similar food items as juvenile smallmouth bass in Brownlee Reservoir, Snake River, Idaho, with the bulk of their energy coming from cyclopoid microcrustaceans and freshwater shrimp. Species comprising the Snake River ictalurid complex are generally late-spring or summer spawners in areas out of the current with adequate bottom cover (Bratovich, 1985).

The centrarchid and percid assemblage consists of all introduced fish in the lower Snake River. Centrarchid fish are largely found in backwater areas out of the current. A general characteristic of this habitat is finer substrate and the presence of aquatic vegetation. The exception to this generalization is smallmouth bass, which is common throughout the reservoirs. Pumpkinseed is the most abundant “sunfish” other than crappies and smallmouth bass.

Yellow perch are included in this complex because of their use of similar habitat as the centrarchid fish. Yellow perch are almost exclusively found in conjunction with aquatic macrophytes in the lower Snake River reservoirs (Bennett et al., 1983). They have consistently been found in relatively low abundance and only achieve higher abundance in backwater habitats that characteristically have finer substrates, low velocity, and aquatic macrophytes.

All of the centrarchid and percid fish are spring and summer spawners in shallower water on substrates that are protected from the current. Yellow perch in the lower Snake River reservoirs are the earliest spawners, and some of the centrarchids are the latest (Bratovich, 1985).

Sunfish (bluegill and pumpkinseed) and yellow perch were important components of the sport harvest only in Ice Harbor Reservoir. More than 10,000 yellow perch and more than 4,800 sunfish were harvested from Ice Harbor Reservoir in 1997 (Normandeau Associates et al., 1998a). These data suggest that as the lower Snake River reservoirs have aged, habitat for the centrarchid and percid fish, except smallmouth bass, has increased.

3.4 Spawning Temperature Summary

One of the key environmental variables that will serve as a limiting factor in the ability of the members of the resident fish community to successfully adapt to new riverine or impoundment conditions is water temperature. The seasonal Snake River hydrograph typically experiences peak flows in May and/or June from spring rains and snowmelt. Dry or wet springs or accelerated or delayed snow melt create highly variable inter-annual spring runoff, which in turn plays a major role in the overall timing of the water temperature regime and the summer thermal maxima experienced by lower Snake River fish. High temporal variability in water temperature may have a profound effect on the spawning success of lower Snake River resident fish.

The ranges of spawning temperatures and time frames for the resident fish described in Sections 3.3.3 and 3.3.4 are summarized in Table 3-9. Site-specific Snake River spawning temperatures are provided for 13 species, largely from the work of Bennett et al. (1983). White sturgeon spawning temperatures were those reported for the lower Columbia River by Parsley et al. (1993). Spawning temperatures for the remaining species were derived from several literature sources. Sculpins, white sturgeon, and bridgelip sucker are the earliest spawning native species. Yellow perch generally spawn earliest among the introduced fish, in very early spring at 7 to 8°C (44 to 46°F). However, most non-native Snake River fish such as bass, sunfish, crappie, and, particularly, catfish spawn much later, usually at least after water temperatures have attained 15 to 18°C (59 to 64°F).

Water temperatures were monitored in Lower Granite Reservoir by recording thermographs for several years (Bennett et al., 1997; Connor et al., 1998). Hourly forebay (rkm 178 [rm 111]) surface water temperatures were summarized for 3 recent years and shown for the spring through fall seasons in Figure 3-5. These data represent at least the lower two-thirds of the reservoir (Connor et al., 1998). For the 3 years depicted, 1994 represents a dry or low flow year, 1995 an "average" flow year, and 1997 a wet or high flow year. These data show typical seasonal water temperatures and trends experienced by lower Snake River resident fish. A major source of variability imposed on the spring-summer temperature regime experienced by resident fish in reproductive mode is the apparent cooling effect of augmentation flows released from upstream reservoirs (e.g., Dworshak Reservoir) to enhance juvenile salmonid smolt outmigration. These effects are clearly shown on the ascending limb of the temperature curves in Figure 3-5, and are particularly notable during 1994, the low flow year. Three episodes of rapidly declining water temperatures are evident in mid-May, mid-June, and nearly the entire month of July into August. Two similar episodes occurred in June 1995.

The release of upstream storage for flow augmentation, primarily to speed passage of salmonid smolts through reservoirs, can affect the spawning and growth of resident fish in several ways. The attainment of a suitable temperature to initiate spawning can be delayed substantially. If the delay were prolonged, as may have occurred in 1994, the effect on year-class production and/or growth due to persistent, lower-than-optimal temperatures can be severe (Bennett et al., 1991). Delayed spawning followed by a short growing season may yield young-of-the-year too small to survive over-wintering. Spawning also can be interrupted, potentially several times (e.g., 1994; Figure 3-5), by the steep temperature declines that can accompany release of augmentation flows, particularly during releases from Dworshak Reservoir. Such releases pose an additional stress on introduced resident fish that may already be exposed to sub-optimal thermal regimes in the Pacific Northwest (e.g., smallmouth bass-Bennett et al., 1991).

Table 3-9. Spawning Temperatures of Snake River Fish

	Spawning temperature and time frame		
Species*	**Temperature range (°C)**	**Month**	**Source**
Smallmouth bass	14-19.6	Mid-June to late July	1
White crappie	15.8-20.4	June-August	2
Black crappie	15.8-19.6	June-July	2
Largescale sucker	**12.2-15.8**	**May-June**	**1**
Bridgelip sucker	**10.2-12.2**	**April-May**	**1**
Northern pikeminnow	**14.0-20.4**	**mid-May to late June**	**1**
White sturgeon	**10.0-18.0**	**April-July**	**7**
Channel catfish	18.1-21.7	July-August	1
Redside shiner	**18.1-20.4**	**July-August**	**1**
Brown bullhead	20.4-21.7	June-August	1
Pumpkinseed	18.1-19.6	late June to early August	1
Bluegill	19.6-21.7	July-August	1
Yellow perch	12.2-13.6	April-May	1
Common carp	16.5-17.0	mid-June	1
Chiselmouth	**17.0**	**May-June**	**3**
Peamouth	**12.2**	**May-June**	**3**
Sculpins (3 spp.)	**7.8-17.2**	**April-June**	**4**
Flathead catfish	22.0-29.0	July-August	5
Sandroller	**14.0-16.0**	**May-June**	**8**
Yellow Bullhead	20.0	June-July	4
Black bullhead	21.0	June-July	3
Warmouth	21.0-25.0	late June-July	6
Largemouth bass	16.0-24.0	June-July	6
Tadpole madtom	22.0-26.0	late June-August	3

Sources:
1-Bennett et al., 1983
2-Bratovich, 1985
3-Scott and Crossman, 1979
4-Smith, 1985
5-Turner and Summerfelt, 1971
6-Carlander, 1977
7-Parsley et al., 1993
8-Gray and Dauble, 1979

*Data are for resident, in-river spawners. Tributary spawners are not included.
Native species are shown in bold type.
Lower Snake River spawning temperature data are shown for underlined fishes.

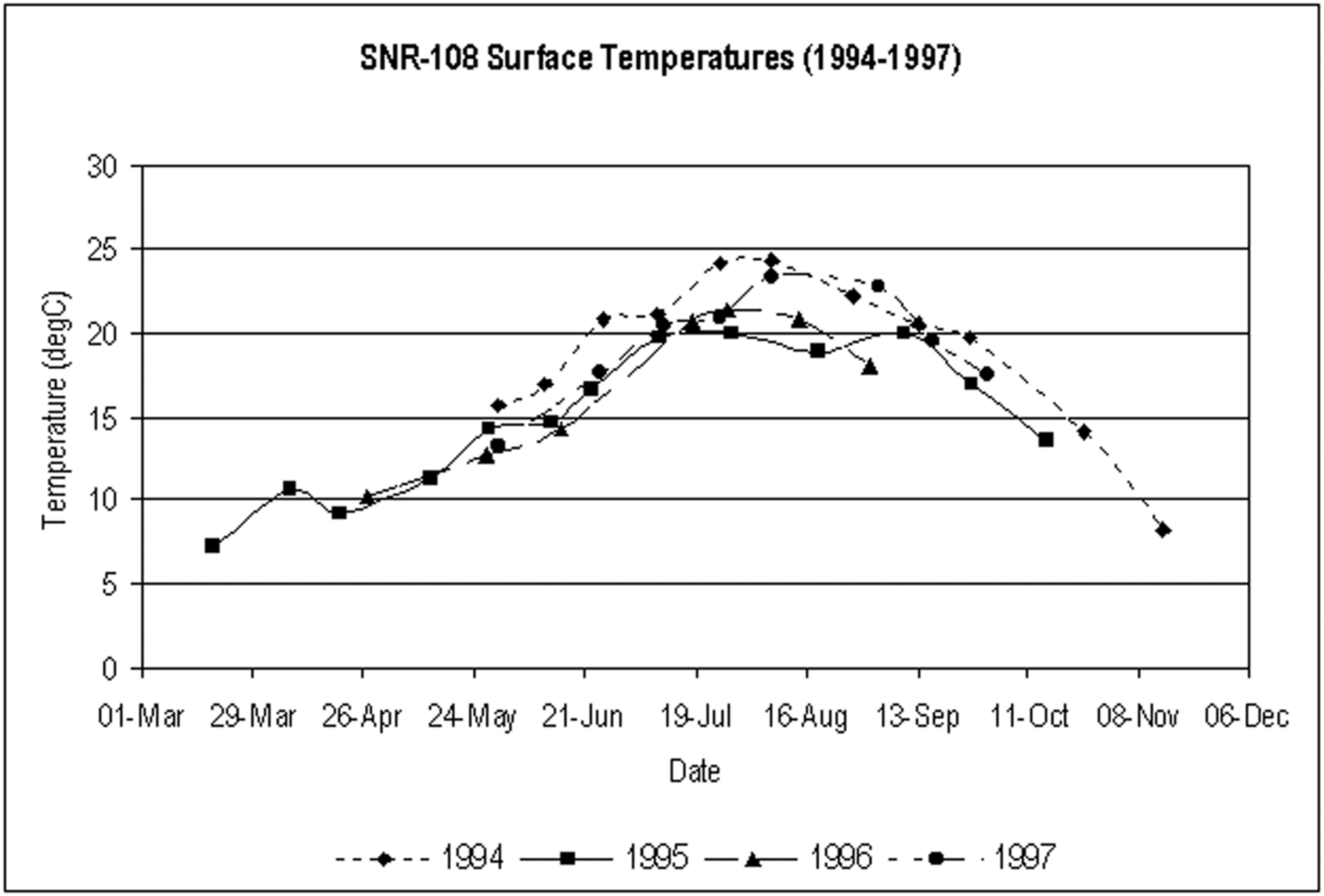


Figure 3-5. Surface Water Temperature Data Recorded at Station SNR-108 for the Years 1994-1997

The delay attaining certain critical spawning temperatures in some years can be substantial. For example, 18°C (64.4°F) is a critical temperature for initiation or continuation of spawning activities for many of the introduced sunfish and catfish (Table 3-9). However, the date when 18°C (64.4°F) is attained can vary as much as 50 days from late May (1992) to mid-July (1993; Bennett et al., 1998). In addition, the attainment of peak summer temperatures may vary by a comparable time period. For example, the highest summer water temperature reached in Lower Granite Reservoir in 1995 was 20.4°C (68.8°F) on July 23, compared to a peak of 22.2°C (72°F) on September 5 in 1997, a difference of 44 days (Figure 3-5).

The effects of accelerated, delayed, or depressed spawning temperatures may be dramatic, but very difficult to isolate. Successful early spawning of some species may create a year-class with greater than average first-year growth, a recruitment advantage that may remain with that year class throughout its life. Conversely, delayed spawning may limit the growth of first-year fish, possibly to the extent that over-winter survival is poor, and the year-class may be virtually absent from the population as advanced juveniles or adults. While the above implications were evaluated for Snake River smallmouth bass (Bennett et al., 1991), similar effects on other resident, introduced fish not studied in such detail are likely. Further, for some species with relatively high spawning temperature requirements such as catfish, late warming may preclude attainment of optimum temperatures, seriously impacting reproductive success in that year.

3.5 Gas Bubble Trauma

Gas bubble trauma (GBT), a result of high total dissolved gas (TDG), is an accumulated stress where mortality is either a result of acute or chronic exposure. It affects resident and anadromous fish in the lower Snake River as a result of spilling water through the dams. Water is spilled for juvenile salmonid passage or as a result of seasonal runoff from rain and snowmelt, but the amount and duration of spillage varies depending upon current and previous climatic conditions. Improved monitoring of TDG throughout the reservoir system in recent years and installation of flow deflectors on all 10 spillbays at Ice Harbor Dam from 1996 to 1998 have allowed use of more spill, but studies of GBT in resident Snake River fish are scarce.

Laboratory studies of speckled dace, black bullhead, crappie, northern pikeminnow, and largemouth bass have confirmed that resident fish are more tolerant of supersaturated water than salmonids (Blahm et al., 1976; Fickeisen et al., 1976; Nebeker et al., 1980; Weitkamp and Katz, 1980). Further, resident fish such as northern pikeminnow may seek deeper water to reduce their exposure to supersaturated water (Bentley, 1976). Sublethal GBT may also induce behavioral changes such as sounding in northern pikeminnow that could reduce predation on juvenile salmonids (Meekin and Turner, 1974; Bentley, 1976). Suppressed feeding on juvenile salmonids by northern pikeminnow at 115 percent TDG concentrations may have been the result of inhabiting deeper water to avoid high gas concentrations (Bentley, 1976).

Angler-caught smallmouth bass and northern pikeminnow from Lower Monumental Dam on the Snake River downstream to John Day Dam on the Columbia River were examined for evidence of exposure to supersaturated (greater than 115 percent) water (Montgomery and Becker, 1980). External exposure symptoms existed on 72 percent and 85 percent of the bass and pikeminnow examined, although these were wild, unrestricted fish that presumably could have sounded to avoid high gas concentrations. These external symptoms were not indicative of subsequent mortality or possible effects on reproductive success. In general, acute toxicities to resident fish are rare in supersaturated water less than 120 percent, although sublethal effects are unknown.

Bennett et al. (1994) examined 2,139 resident fish in upper Little Goose Reservoir following short-duration spills from Lower Granite Dam during the 1992 drawdown experiment and found no incidence of GBT. Cochnauer (1995) examined 3,848 resident fish for possible effects of flow augmentation spills from Dworshak Reservoir into the lower Clearwater River, including upper Lower Granite Reservoir, and found a 0.2 percent incidence of GBT. Dell (1975) examined 29,273 resident fish for GBT in the mid-Columbia River and found a 10.6 percent incidence. Most fish affected, however, had not been free-swimming for up to 20 hours before examination and likely reflected a gear-capture bias. Among the three studies, fish examined by Dell (1975) were the only ones exposed to sustained TDG concentrations exceeding 120 percent of saturation. This value (120 percent) is presently used as a cap for TDG in Snake River Dam tailwaters (NMFS, 1995). Further, all of the referenced studies concluded that the effects of ambient, elevated TDG concentrations were not detectable in the populations of resident reservoir fish evaluated.

3.6 Entrainment of Resident Fish

Passage of resident fish from one Snake River reservoir to the next impoundment downstream can occur via spills, or through turbines and bypass systems. Bennett et al. (1994) qualitatively examined entrainment by spillage during the 1992 drawdown experiment. They found limited evidence that marked resident fish, principally largescale sucker, moved downstream out of Lower Granite Reservoir as a result of spills for the drawdown experiment. Bennett et al. (1994) also found substantial movement of marked white sturgeon from Lower Granite Reservoir into Little Goose Reservoir, although there was little direct evidence that this movement was related to the drawdown experiment.

There are no quantified or analyzed data reporting entrainment of resident fish through turbines or bypass systems at Snake River Dams. Some proportion of resident fish approaching turbine intakes is directed through the bypass systems to juvenile salmonid facilities by submerged intake screens at Snake River Dams. The number and species of resident fish collected daily during juvenile facility separator operation during the smolt outmigration period (typically April 1 into November) are recorded and provide preliminary evidence of the species composition of fish entrained through the juvenile salmonid bypass systems and, potentially, project turbines. These data were provided by Corps project biologists and are summarized in Tables 3-10 to 3-12 for resident fish retained by and counted at the separators at Lower Granite, Little Goose, and Lower Monumental Dams. Additionally, a substantially higher number of resident fish, particularly smaller-sized individuals including young-of-year, pass through the separator bars and are directed to raceways. Although these fish are tallied, those data are somewhat less reliable and are not summarized or discussed herein.

Suckers, channel catfish, and carp were the most common resident fish tallied at juvenile facility separators at each dam (Tables 3-10 to 3-12). Gamefish other than channel catfish were typically less abundant, although young white crappie were common in some years (Rex Baxter, Corps of Engineers, personal communication). Peamouth predominated among other fish, and six walleye were also reported at fish separators at Little Goose and Lower Monumental Dams. However, despite unconfirmed reports of angler-caught walleye, no walleye have previously been collected by conventional sampling methods in the Snake River above Ice Harbor Dam in either 1979 to 1980 (Bennett et al., 1983) or 1991 (Zimmerman and Parker, 1995).

Table 3-10. Resident Fish Counted at the Juvenile Facility Separator at Lower Granite Dam, 1992 to 1998

	1992	1993	1994	1995	1996	1997	1998	Total
Sucker spp.	1,167	2,451	1,072	2,379	4,102	3,166	3,137	17,474
Carp	46	405	38	499	700	1,656	3,529	6,873
Channel Catfish	34	95	28	176	145	92	118	688
White sturgeon	54	64	72	112	157	106	36	601
Northern Squawfish	69	44	37	79	44	12	6	291
Crappie spp.	5	50	5	0	0	2	4	66
Smallmouth bass	17	18	4	8	13	2	2	64
Other species	18	19	12	7	31	45	4	136
Total	1,410	3,146	1,268	3,260	5,192	5,081	6,836	26,193

Note: Other species may include largemouth bass, yellow perch, mountain whitefish, Pacific lamprey chiselmouth, peamouth, bullhead spp., sockeye/kokanee, bull trout, coho, and sunfishes.

Source: Corps, 1998a.

Table 3-11. Resident Fish Counted at the Juvenile Facility Separator at Little Goose Dam, 1988 to 1997

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Total
Sucker spp.	2,860	2,095	3,699	3,688	1,867	2,408	967	1,389	776	1,074	20,823
Carp	62	57	138	75	26	184	26	132	158	429	1,287
Channel Catfish	348	226	407	669	843	1,919	464	4,297	2,025	820	12,018
White sturgeon	48	30	49	31	41	61	13	22	18	41	354
Northern Squawfish	562	273	1,109	535	291	183	149	135	46	31	3,314
Crappie spp.	484	84	147	240	741	524	182	295	647	288	3,632
Smallmouth bass	15	24	57	79	187	921	33	75	70	59	1,520
Other species	62	54	136	405	354	963	233	680	635	935	4,457
Total	4,441	2,843	5,742	5,722	4,350	7,163	2,067	7,025	4,375	3,677	47,405

Note: Other species may include largemouth bass, yellow perch, mountain whitefish, Pacific lamprey chiselmouth, peamouth, bullhead spp., sockeye/kokanee, bull trout, coho, sunfishes, and walleye.

Source: Corps, 1998b.

Table 3-12. Resident Fish Counted at the Juvenile Facility Separator at Lower Monumental Dam, 1993 to 1997

	1993	1994	1995	1996	1997	Total
Sucker spp.	1,591	1,204	871	556	607	4,829
Carp	142	48	181	283	274	928
Channel Catfish	869	466	2,261	2,223	1,361	5,757
White sturgeon	49	25	35	30	23	162
Northern Squawfish	117	133	141	63	42	496
Crappie spp.	127	16	134	167	103	658
Smallmouth bass	71	3	52	26	9	161
Other species	128	37	208	265	304	942
Total	3,094	1,932	3,883	3,613	2,723	13,933

Note: Other species may include largemouth bass, yellow perch, mountain whitefish, Pacific lamprey chiselmouth, peamouth, bullhead spp., sockeye/kokanee, bull trout, coho, sunfishes, and walleye.

Source: Corps of Engineers, 1998c.

Although these limited data suggest that entrainment, particularly of non-game fish, is occurring and could be substantial, there is no information relating resident fish entrainment to the status of reservoir fish populations. It is likely that intake screening associated with bypass systems built for juvenile salmonids prevents some turbine mortality of resident fish. However, the issue of resident fish entrainment and mortality remains largely unassessed.

3.7 Predation by Resident Fish on Juvenile Salmonids and American Shad

3.7.1 Juvenile Salmonids

Predation on rearing or migrating juvenile salmonids has received considerable attention because of several mechanisms related to impoundment construction (Gray and Rondorf, 1986). Each dam acts as a funnel, concentrating salmonids into the forebay. Below the dam, tailraces provide a steady supply of migrating fish, some of which are injured or disoriented. Predation is exacerbated during low flow years (Anglea, 1997). Further, impoundments have slowed smolt emigration and decreased turbidity, factors that increase the likelihood of predation. Similarly, the reservoirs have enhanced habitat for non-native predators such as crappie and yellow perch.

A number of studies have examined predation by resident fish on downstream migrating juvenile salmonids in the lower Snake River system. The first known study to assess predation by resident fish in the lower Snake River reservoirs was conducted by Bennett et al. (1983). Northern pikeminnow, smallmouth bass, and channel catfish all contained juvenile salmonids in their stomachs during spring 1979 and 1980. Their results suggested predation was occurring throughout Little Goose Reservoir, although the occurrence of salmonids in predator stomachs was considerably higher in the Lower Granite Dam tailwater than elsewhere in the reservoir. Chandler (1993) assessed predation by northern pikeminnow from 1987 through 1991 in Lower Granite Reservoir and found that daily ration was similar to that in John Day Reservoir, Columbia River (Vigg et al., 1991). Total juvenile salmonid losses were estimated, although an absolute estimate of northern pikeminnow abundance was not made. Ward et al. (1995) assessed the intensity of predation on juvenile salmonids in each of the lower Columbia River and Snake River reservoirs. Predation was highest in the Snake River tailwaters, followed by the forebays and mid-reservoir areas, and was considerably lower than in the Columbia River reservoirs.

More recently, emphasis has been placed on the predatory role of fish other than northern pikeminnow on salmonid survival, particularly in Lower Granite Reservoir. Curet (1994) evaluated the effects of predation on subyearling chinook salmon by smallmouth bass. He estimated that approximately 4 percent of the potential downstream run of subyearling chinook salmon was consumed during 1992. His results were equivocal, however, because 1992 was the year of the experimental drawdown in Lower Granite Reservoir, and that may have affected the abundance of crayfish, the most important dietary item of smallmouth bass. During 1994 and 1995, Anglea (1997) estimated that 80,000 and 60,000 juvenile salmonids, respectively, were consumed by smallmouth bass in Lower Granite Reservoir. His results indicated that approximately 7 percent of the potential downstream run of subyearling chinook salmon were consumed by smallmouth bass. Anglea’s (1997) results also strongly suggested that major annual differences in the magnitude of predation could be attributed to differences in flows. For example, flows were considerably higher in 1995, coincident with lower levels of predation. Naughton (1998) recently reported that smallmouth bass predation on juvenile salmonids was considerably lower during 1996 and 1997, two other high flow years in Lower Granite Reservoir. Predation by smallmouth bass in 1996 and 1997 was highest in the tailwater of Lower Granite Dam, followed by the reservoir forebay and Snake and Clearwater River arms.

Stomachs of other introduced, resident fish such as white and black crappie and yellow perch have been found to contain juvenile salmonids (David H. Bennett, University of Idaho, unpublished data). Juvenile salmonids composed over 20 percent of dietary items by weight of both crappie and yellow perch during some years between 1994 and 1997.

These studies indicated that resident fish can be significant predators on downstream migrating juvenile salmonids. Smallmouth bass are the most significant salmonid predators in the lower Snake River reservoirs because of their high abundance. Relatively little is known about channel catfish abundance and predation, although juvenile salmonid predation by catfish was reported by earlier studies (Bennett et al., 1983; Bennett et al., 1988). These species currently represent the major sources of predation by resident fish because populations of northern pikeminnow have been greatly reduced, at least in Lower Granite Reservoir, by the sport reward program and scientific sampling (Naughton, 1998).

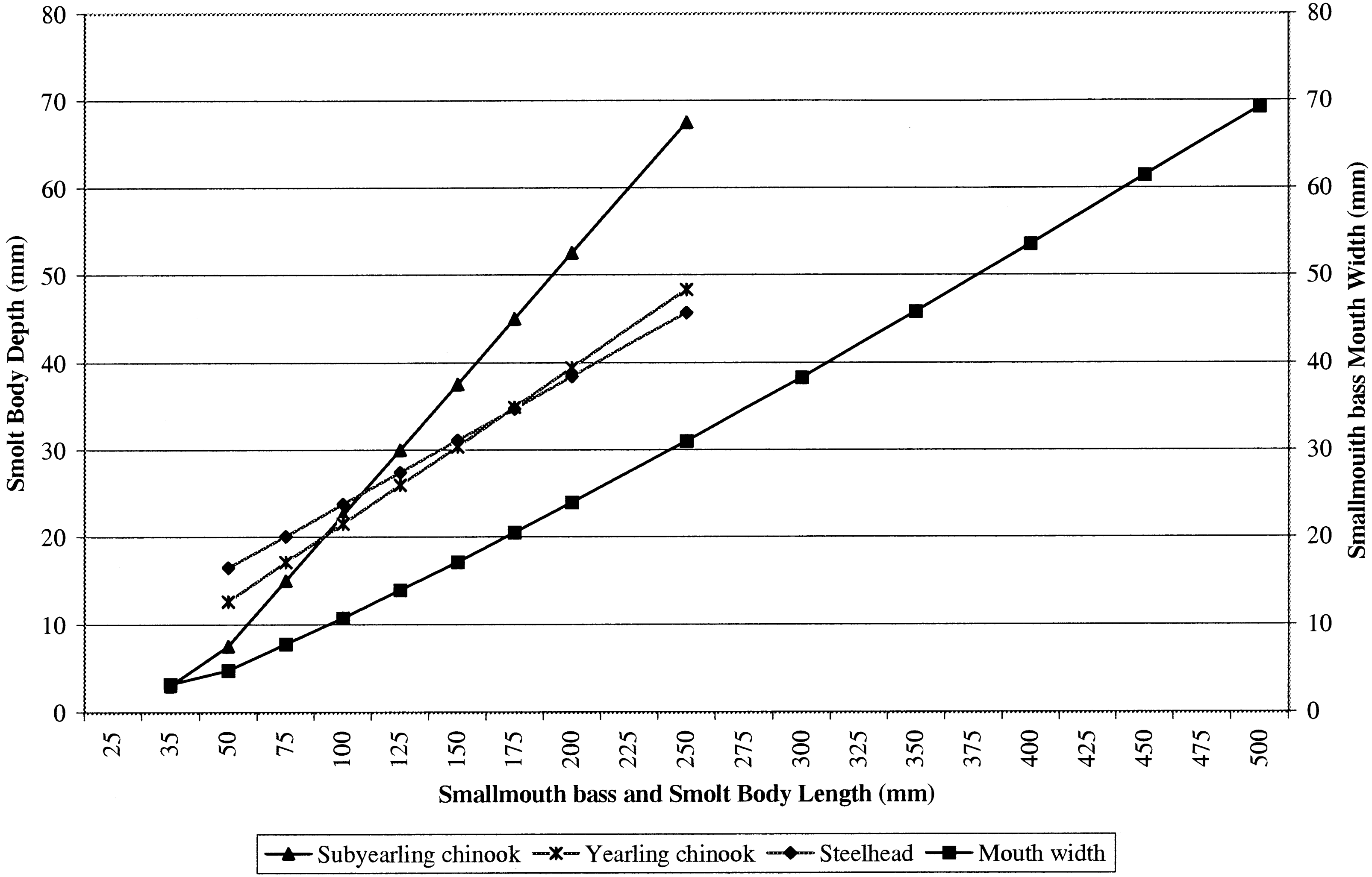
Numerous factors have the potential to affect the magnitude of salmonid predation in the lower Snake River. Variation in flow among years appears to be related to the intensity of predation, which seems highest during low flow years. Water clarity, water temperature, and predator and prey sizes are all important when attempting to assess predation. Under conditions of low water clarity, visual predators such as smallmouth bass, northern squawfish, and crappie require close proximity to see their prey (Vinyard and O’Brien, 1976). Because fish are ectothermic vertebrates, their metabolic activities are highly dependent upon water temperature; numerous fish such as smallmouth bass typically do not actively search for food at temperatures lower than 10°C (50°F) (Coble, 1975). Feeding activity of channel catfish, less of a sight predator, is similarly low at low water temperatures; however, northern pikeminnow feeding activity is less affected by low water temperatures. Application of these principles to assess salmonid prey consumption suggests that far fewer prey are consumed early in the downstream migration of yearling chinook salmon and juvenile steelhead because it coincides with lower water temperatures and higher turbidities. Downstream migration of these salmonid fish generally coincides with peak flow events; higher flows suspend more sediment particles and are fed by snow melt, creating less than favorable conditions for sight-feeding ectothermic predators. Conversely, as flows and turbidities decrease in the late spring, water temperatures increase, enhancing the potential for higher predation. For this reason, predation on subyearling chinook salmon that migrate later than yearling chinook and steelhead has been shown in both the lower Snake River reservoirs (Curet, 1994; Anglea, 1997) and John Day Reservoir on the lower Columbia River (Poe et al., 1991).

Estimating the magnitude of predation by the principal resident fish predators (northern pikeminnow, channel catfish, and smallmouth bass) on various stocks of juvenile salmonids under current reservoir conditions is difficult. Both theoretical and empirical approaches provide insight into salmonid predation. Limited empirical information exists on prey sizes consumed by various fish predators in the Columbia River Basin. The most complete information originates from the John Day Reservoir (Columbia River) predator study. Poe et al. (1991) reported on differences in dietary composition of northern pikeminnow, smallmouth bass, channel catfish, and walleye. They reported that salmonid consumption increased with channel catfish and northern pikeminnow length, although the increase was slight with smallmouth bass and decreased with walleye. Minimum sizes (fork length [FL]) of predators containing juvenile salmonids were 175 millimeters (6.9 inches)—northern pikeminnow, 225 millimeters (8.8 inches)—walleye, 75 millimeters (3.0 inches)—smallmouth bass, and 325 millimeters (12.8 inches)—channel catfish. Also, predator size was strongly correlated with prey size. Poe et al. (1991) found that the maximum salmonid size in northern pikeminnow increased linearly (salmonid FL = (0.716) (northern pikeminnow FL)—84.435; r^2=0.96). For example, the maximum-size salmonid consumed by a northern pikeminnow 275 millimeters (10.8 inches) long was 112 millimeters (4.4 inches), compared to a 350-millimeter (13.8-inch) northern pikeminnow that consumed a 166-millimeter (6.5-inch) salmonid and a 500-millimeter (19.7-inch) northern pikeminnow that consumed a 274-millimeter (10.8-inch) salmonid. In Lower Granite Reservoir on the lower Snake River, Chandler (1993) reported a slightly steeper slope of prey length to predator length, suggesting that northern pikeminnow consumed larger salmonids per unit length than those in John Day Reservoir, although the relationship was more weakly correlated.

Theoretical analyses of prey consumption can also be used to examine the potential for salmonid predation in the lower Snake River. Several studies have examined prey size as a function of predator size (Timmons et al., 1980; Timmons and Pawaputanon, 1980; Winemiller and Taylor, 1987; Dunsmoor, 1990). Early studies by Lawrence (1958) showed that largemouth bass in aquaria will swallow forage fish whose maximum body depth is equivalent to bass mouth width. More recently, Timmons and Pawaputanon (1980) developed a mathematical model to estimate the size of prey that largemouth bass could consume. Their studies suggest that largemouth bass will consume shad (threadfin and gizzard) approximately one-half their length.

Based on this principle, Dunsmoor (1990) developed a model for prey size consumption as a function of smallmouth bass mouth width (ln MW = -2.97 + 1.16 [ln total length (TL)]) and body depth of the prey fish. A relationship between length and body depth of salmonids in the Snake River Basin indicated that smallmouth bass could consume salmonids that were about 50 percent of their length (Table 3-13). These data strongly support other data reported by Anglea (1997) that age-1 smallmouth bass about 70 millimeters (2.8 inches) (TL) consumed age-0 fall chinook salmon. Because of their greater depth, however, a longer smallmouth bass would be required to consume a fall chinook salmon at a given length (75 to 100 millimeters (3.0 to 3.9 inches) than either a yearling chinook salmon or steelhead (Table 3-13; Figure 3-6). For example, smallmouth bass at 300 millimeters (11.8 inches)TL can consume a 153-millimeter (6.0-inch) FL fall chinook salmon juvenile, compared to a 194-millimeter (7.6-inch) FL spring/summer chinook salmon and a 200-millimeter (7.9-inch) FL steelhead (Figure 3-6). These models demonstrate the potential for individuals from various salmonid stocks to be consumed throughout the Snake River Basin by smallmouth bass. However, consideration of mouth size is of limited value for northern pikeminnow and channel catfish because of a lack of known mouth-size data. Larger northern pikeminnow and larger channel catfish in the lower Snake River reservoirs probably can consume all sizes of subyearling and yearling chinook salmon and wild steelhead juveniles, as well as most sizes of hatchery-reared steelhead.

These data enable examination of what segment of the various stocks would be consumed during their migration downstream and can provide some idea of the magnitude of predation. Anglea (1997) reported that stomachs of smallmouth bass as small as 70 millimeters (2.8 inches) contained salmonids, although no relationship was found between predator length and prey length. However, larger smallmouth bass consumed a higher proportion of salmonids and, as indicated from their



Source: David H. Bennett, unpublished data

Figure 3-6. Potential for Salmonid Smolt Consumption by Smallmouth Bass as Indexed by Smallmouth Bass Mouth Width and Smolt Body Depth and Length

Table 3-13. Relationships Between Body Length (Smallmouth Bass TL and Salmonid FL), Mouth Width (mm) of Smallmouth Bass, and Body Depth (mm) of Salmonid Smolts in the Snake River Basin

Smallmouth Bass and Salmonid Body Length (mm)	Smallmouth bass Mouth Width (mm)	Chinook Body Depth Subyearling	Chinook Body Depth Yearling	Juvenile Steelhead Body Depth
35	3.2	3.0	-	
50	4.8	7.5	12.6	16.5
75	7.8	15.0	17.1	20.1
100	10.7	22.5	21.5	23.8
125	13.9	30.0	26.0	27.4
150	17.1	37.5	30.4	31.1
175	20.5	45.0	34.9	34.7
200	24.0	52.5	39.4	38.4
250	31.0	67.5	48.3	45.7
300	38.3			
350	45.8			
400	53.5			
450	61.4			
500	69.3			

Source: Data from Ken Tiffan, U. S. Geological Survey, Cook, Washington (unpublished data)

mouth size, have the potential to consume most sizes of subyearling and yearling chinook salmon and smaller steelhead juveniles. Anglea (1997) showed that the number of larger smallmouth bass (greater than 300 millimeters [11.8 inches]) was less than 1 percent of the bass population. Further, he and others (Curet, 1994; Naughton, 1998) have consistently reported that approximately 95 percent of the smallmouth bass population (greater than 74 millimeters [2.9 inches]) in Lower Granite Reservoir is less than 250 millimeters (9.8 inches). Assuming similar growth rates of smallmouth bass throughout the Snake River (Bennett et al., 1983), we conclude that, generally, fall chinook greater than 128 millimeters (5.0 inches) FL, yearling chinook salmon greater than 153 millimeters (6.0 inches) FL, and juvenile steelhead greater than 150 millimeters (5.9 inches) FL would escape predation by more than 95 percent of the smallmouth bass in the lower Snake River system. These interpretations have been consistently supported in findings by Curet (1994), Anglea (1997), and Naughton (1998) and suggest that subyearling chinook salmon are consistently preyed upon more heavily than either yearling chinook salmon or juvenile steelhead. Even though most smallmouth bass are relatively small (less than 250 millimeters [9.8 inches]), smallmouth bass consumption can range from a few thousand to over 100,000 (Anglea, 1997) juvenile salmonids per season per reservoir. Most of these are believed to be subyearling chinook salmon and, probably, considerably less juvenile wild steelhead and yearling chinook.

Among other species, the current magnitude of predation on all juvenile salmonids by the northern pikeminnow is believed to be lower than perhaps a decade ago. Current population abundance of northern pikeminnow is reduced because of widespread removals by both scientific and sport reward programs. Crappie and yellow perch are relatively minor predators on juvenile salmonids in the lower Snake River system. Their small body size restricts consumption to mainly subyearling chinook and smaller yearling chinook and wild steelhead.

In summary, although the northern pikeminnow has the potential to consume nearly all sizes of juvenile salmonids in the lower Snake River, their currently low numbers reduce their predation potential. Crappie and yellow perch are limited by their smaller body size and, therefore, consume primarily small subyearling chinook and wild steelhead. Smallmouth bass consume largely subyearlings and wild steelhead because of the relatively low abundance of larger sized bass. The small proportion of larger smallmouth bass (greater than 250 mm [9.8 inches]) has the potential to consume limited numbers of yearling chinook salmon, but the severity of this predation is probably low, because they migrate earlier at lower water temperatures through the lower Snake River Reservoirs.

3.7.2 American Shad

Although American shad are an anadromous fish in the Snake River, their abundance may indirectly affect resident predatory fish. To our knowledge, little American shad life history information exists in the Columbia River basin other than estimates of abundance from passage counts at dams. American shad in the Snake River are most abundant in the lower reservoirs, while few adults are observed upstream of Lower Granite Dam (Bennett et al., 1988). Some biologists have hypothesized that American shad may assist in maintaining fish predator populations at artificially high levels. Research is needed to determine if this hypothesis has merit.

Where juvenile American shad are most abundant, such as in lower Columbia River reservoirs, they may constitute a protein source for predators that enables them to maintain higher population levels than could occur without shad. However, their role as prey is insignificant in Lower Granite Reservoir for smallmouth bass (Curet, 1994; Anglea, 1997; Naughton, 1998) and northern pikeminnow (Chandler, 1993). Further, it is unlikely that juvenile shad currently constitute a major prey item in predator diets in the lowermost Snake River reservoirs, based on recent passage estimates of 5,000 to 14,000 adults at Ice Harbor Dam during 1996 to 1998 (Corps data).

3.8 Habitat-Use Guilds of Snake River Resident Fish

The descriptions of fish and assemblages in lower Snake River reservoirs represent the 23- to 37-year-evolution of complex reservoir fish communities comprised of native and introduced species. Eighteen native species have been supplemented with at least 15 introduced species (BPA, 1995). Some of these species are inherently more successful in lotic habitats, while others are more typical of lacustrine (lake-like) water bodies. Fish in the lower Snake River reservoirs are distributed according to the habitat conditions that occur in the reservoirs; some prefer habitat conditions in the tailwaters, while others prefer habitat conditions in the mid-reservoir or forebays.

Such high species richness makes impact analysis difficult when using a habitat-based approach. In order to predict the future community structure of such a complex assemblage under any adopted alternative, we developed a simple habitat guild system. The guild approach may simplify analysis by grouping species that exploit stream resources in a similar manner (Leonard and Orth, 1988). The selection of guilds is based on our expectation of riverine habitats that will develop following implementation of the chosen alternative (Austen et al., 1994; Lobb and Orth, 1986). Each species present in the lower Snake River was assigned to one or more of the following habitat guilds (Table 3-14). Habitat generalists such as smallmouth bass and native suckers were assigned to more than one guild.

Riffle/rapids guild—The riffle/rapids guild comprises fish that prefer higher velocities in areas of steep or moderate gradient. Substrates are generally large (cobble/boulder) due to the lack of deposition of finer materials.

Upper pool guild—This guild is analogous to run habitat guilds developed for smaller streams. Upper pool habitats would be mostly shallow, with a moderate and variable velocity component.

Such "head of pool" areas represent transitional habitats between swift areas of rapids and the deeper, slower main portions of the pools. Substrates will be variable and dependent on velocities, but are comprised of generally smaller particles than those in rapids such as cobble and gravel, with only minimal deposition of fines (limited embeddedness).

Mid/lower pool guild-shallow—Fish in this guild should prefer slower current velocities and comprise those generally inhabiting shallower areas, such as pool margins. Substrates in mid/lower pool areas will be variable, but should range among the smaller-size particles such as the finer gravels and sands.

Mid/lower pool guild-deep—This guild also will prefer slower current velocities, but will comprise fish that prefer the deeper portions of pools. Generally, finer substrates such as fine gravel and sand should characterize the deeper portions of pools.

Slough/backwater guild—This guild prefers off-channel areas with little or no current and variable bottom substrates, typically with a high fines component. Sloughs and backwaters may be shallow, or may provide a full range of depths for fish to exploit. Deposition of fines will encourage macrophyte growth and add to habitat complexity.

There is a tendency among the habitat use guilds portrayed in Table 3-14 for native fish to occur in the riverine habitats that are shallower with higher current velocities. In contrast, most of the introduced species were assigned to the embayment/backwater guild that will be expected to utilize areas of slower current off the main river channel. The primary exception is smallmouth bass, a highly adaptable, introduced species that is typically considered a habitat generalist (Leonard and Orth, 1988). As a generalist, it was assigned to several guilds. Another generalist that was assigned to multiple guilds was largescale sucker.

We expect these five general habitat types to characterize a restored lower Snake River (Table 3-14). Four represent main river channel habitats and will be characterized by depth or velocity criteria representative of free-flowing river habitat conditions. Pools at variable depth will likely be a dominant habitat type. The habitat guilds reflect pools partitioned into faster, shallow portions representing transitional areas from rapids to pools and slower portions of variable depth. As a result, we further partitioned the slower portions of pools into shallow and deep areas. While substrates will be variable, current velocities typically dictate riverine substrate conditions. Thus, we expect the coarser substrates such as boulders and large cobble to occur in rapids and riffles, while sand and finer materials will settle out and accumulate in the pools, typically at depth or along the pool margins. The fifth habitat type is expected to be backwaters or sloughs, which are off-channel areas with little or no current velocity, gravel, or finer substrates, with the potential for submerged aquatic vegetation growth. Embayment or slough habitats will likely be the most important in terms of the ability of most introduced resident fish to maintain remnant populations if the lower Snake River is restored to an unimpounded condition.

Table 3-14. Expected Habitat-Use Guilds of Snake River Fish Following Dam Removal

Riffle/rapids	Head of pool/run	Mid/lower pool-shallow	Mid/lower pool-deep	Slough/backwater
largescale sucker (ad)	**bridgelip sucker**	**bridgelip sucker**	**white sturgeon (juv & ad)**	bluegill
sculpins	**largescale sucker**	**largescale sucker**	flathead catfish	pumpkinseed
	sculpins	**mountain whitefish**	channel catfish (juv & ad)	bullheads
	rainbow trout	**redside shiner**	**northern pikeminnow (adult)**	warmouth
	brown trout	**peamouth**	smallmouth bass (adult)	white crappie
	speckled dace	**northern pikeminnow (juv)**	**sculpins**	black crappie
	smallmouth bass (ad)	smallmouth bass (juv & ad)	**sandroller**	common carp
	chiselmouth			largemouth bass
	northern pikeminnow (ad)			yellow perch
				tadpole madtom
				smallmouth bass (juv)
				northern pikeminnow (juv)

Notes: Key (Section 3.3.3) species are underlined; native species are bold. Ad=adult; Juv=juvenile.

4. Alternatives Analysis

This section describes each of the alternatives analyzed and the projected impacts to resident fish. Each alternative discussion is focused on the operational and structural modifications proposed that are most likely to impact lower Snake River resident fish. Although there are demonstrated differences among individual reservoirs in the characteristic assemblages of resident fish, as discussed in Section 3.0, our predictions as to the effects of any alternative action on resident fish are made as if affecting a single resident fish population within the entire impounded reach. Potential impacts are evaluated for both short-term or transition-period construction effects, and long-term operational effects on resident fish. Short-term effects are those expected to occur in the first year following drawdown. Long-term effects are those that would occur in subsequent years and may take several years to become apparent. For each alternative, fish habitat-use guilds and the key resident species are discussed. For the drawdown alternative, the key species (see Section 3.3.3) are discussed within the framework provided by the habitat-use guilds outlined in Section 3.8. This analysis will focus on the expected community structure and abundance of populations that will remain, and how key biological processes such as feeding, growth, and reproduction will be affected. For the drawdown alternative, the analysis will also address the amount, types, and attributes of riverine habitat expected to develop.

Reviewers of this appendix are cautioned that there is uncertainty inherent in projecting the effects of any action or combination of actions on biological systems. Because of the dramatic changes in the quality and quantity of resident fish habitats that will occur with the drawdown alternative, the highest uncertainty resides with predictions of changes in fish abundance, growth, feeding, reproduction, and other biological parameters associated with the dam removal alternative.

4.1 Description of Alternatives

The various structural and operational modifications proposed for the Snake River Project within each alternative selected for analysis by PATH are summarized for comparison in Table 4-1. The eight alternatives under consideration are grouped into three major pathways: existing condition pathway (including the existing condition alternative), major system improvements pathway, and the natural river drawdown pathway. For the existing condition pathway, the system would continue to be operated as at present, with ongoing research and planned improvements to various structures and transportation facilities and components. For the major hydro system improvements pathway, the operation of the system would continue, with an emphasis on surface bypass and collection systems. The adaptive management alternative (Alternative A-2c) within the major system improvements pathway implies that current operations would continue, but that promising new technologies that might improve juvenile salmonid survival can be adopted following successful evaluation studies. The natural river drawdown pathway means that all four dams would be removed (breached) and the river returned to a free-flowing state.

However, not all the measures embedded in each alternative are expected to affect resident fish. The emphasis in the descriptions in the following sections is placed on those structural or operational measures (italicized in Table 4-1) proposed for an alternative with the greatest likelihood of affecting resident fish. Similarly, we have focused our discussion of expected impacts in subsequent sections on the impacts of those measures most likely to have an effect on lower Snake River resident fish populations. Proposed structural and operational changes to the Snake River Project that appear most

Table 4-1. Lower Snake River Juvenile Salmon Migration Feasibility Study Alternatives Matrix, Page 1 of 2

	Pathway Alternatives							
	Existing System		Major System Improvements					Drawdown
	Existing Condition	Maximize Transport	w/Maximized Transport	w/Minimized Transport	w/Adaptive Management	w/In-river Migration and Additional 1.0 Million Acre-Foot Flow Augmentation	w/In-river Migration and Zero Flow Augmentation	Natural River Drawdown
	A-1	A-2	A-2a	A-2b	A-2c	A-6a	A-6b	A-3
STRUCTURAL CONFIGURATION								
Navigation								
Current configuration	●	●	●	●	●	●	●	
No navigation								●
Hydropower								
Current configuration	●	●	●	●	●	●	●	
No hydropower								●
Planned Improvements								
LGR Juvenile Fish Facility	●	●	●	●	●	●	●	
Fish separator	●	●	●	●	●	●	●	
Cylindrical dewatering screens	●	●	●	●	●	●	●	
New trash shear booms	●	●	●	●	●	●	●	
Modify ESBS	●	●	●	●	●	●	●	
Major Dam Feature Replacement/Rehabilitation								
Turbines and generators	●	●	●	●	●	●	●	
ESBS and VBS	●	●	●	●	●	●	●	
Spillway gates	●	●	●	●	●	●	●	
Navigation gates	●	●	●	●	●	●	●	
Timber bumbers	●	●	●	●	●	●	●	
Valves	●	●	●	●	●	●	●	
Fish ladder pumps	●	●	●	●	●	●	●	
Facility roadways	●	●	●	●	●	●	●	
Major Fish Passage Improvements								
Surface Bypass Collector			●	●	●	●	●	
Behavioral guidance curtain			●	●	●	●	●	
Raise spillway basin			●	●	●	●	●	

Table 4-1. Lower Snake River Juvenile Salmon Migration Feasibility Study Alternatives Matrix, Page 2 of 2

	Pathway Alternatives							
	Existing System		Major System Improvements					Drawdown
	Existing Condition	Maximize Transport	w/Maximized Transport	w/Minimized Transport	w/Adaptive Management	w/In-river Migration and Additional 1.0 Million Acre-Foot Flow Augmentation	w/In-river Migration and Zero Flow Augmentation	Natural River Drawdown
	A-1	A-2	A-2a	A-2b	A-2c	A-6a	A-6b	A-3
Earthen Portion of Dams								
Remain intact	●	●	●	●	●	●	●	
Breached								●
OPERATIONAL REQUIREMENTS								
Flow Augmentation								
1995/98 biological opinion (427 KAF)	●	●	●	●	●	●		●
Upper Snake augmentation								
Additional 1.0 MAF						●		
Zero augmentation							●	
Spill								
1995/98 biological opinion	●	●	●	●	●	●	●	
Maximize volunteer spill						●	●	
No volunteer spill		●	●					
Transport								
1995/98 biological opinion	●			●				
Maximize transportation/limited in-river migration		●	●					
No transportation/maximize in-river migration						●	●	
LSRFWCP Requirements								
Current operation	●	●	●	●	●	●	●	
Amended operation								●
Recreation Requirements								
Current operation	●	●	●	●	●	●	●	
Amended operation								●

likely to affect resident fish are related to TDG, spill operations, various flow augmentation options, and natural river drawdown. Each is described in detail below as to the current status of the measure and the changes expected to occur among the respective alternatives.

4.1.1 Total Dissolved Gas Improvements

4.1.1.1 Spillway Flow Deflectors

Spillway flow deflectors (flip lips) were installed at lower Snake River Dams to minimize the problem posed to migrating salmonid smolts by high dissolved gas concentrations in spilled waters. The Spillway flow deflectors reduce TDG in tailraces by redirecting plunging spill flows downstream and along the surface of the stilling basin. This reduces the entrainment of gases by reducing the depth and causing more turbulence.

All eight spill bays at Lower Granite Dam were fitted with flip lips during construction. Subsequently, six of eight spillbays received flip lips at Little Goose and Lower Monumental Dams. Most recently, spill deflectors were installed at eight of ten spillbays at Ice Harbor Dam during 1997 and 1998. Additional construction at Ice Harbor Dam during the winter of 1998 to 1999 will add flip lips to the two outside spillbays. The spill deflectors at the lower three dams were needed because of recent, increased emphasis on spillage to increase smolt survival through the reservoirs. The outside spillbays (one at each end of the spillway) at Lower Monumental and Little Goose Dams remain unmodified due to adult anadromous fish passage concerns. Compared to available information for salmonids, the effects of TDG on Snake River resident fish (see Section 3.5) are poorly documented.

4.1.1.2 Additional TDG Abatement Improvements

Ambient TDG in forebays and tailraces is now closely monitored throughout the FCRPS at automated stations. Increased monitoring and control of TDG are desired to permit increased use of spill for smolt passage. Studies are underway to evaluate whether Spillway flow deflectors can be installed at Snake River Dams where they are now absent (i.e., at outside spillbays). Reconfiguring existing flip lips at the older installations to a more effective design is also being considered. Additional measures under consideration to reduce TDG include raising the floor elevation of stilling basins and installing alternate methods of passing water. Increasing the elevation of stilling basin floors would reduce stilling basin depth and potentially reduce the entrainment of atmospheric gas.

4.1.2 Spill Requirements

Spilling water through lower Snake River Dam spillways is designed to reduce salmonid smolt passage through turbines by bypassing fish through the spillway, a presumably safer route. However, unregulated spill increases TDG in the tailwaters and main portions of the reservoirs and potentially affects the resident fish utilizing these habitats. Because of concerns for high TDG in unregulated spill, among other issues, spill is currently regulated to a target percentage of spring (all dams) or summer (Ice Harbor only) instantaneous flow and managed so as not to exceed a target TDG cap concentration determined at various in-river monitoring sites. The gas cap in reservoir forebays is now set at 115 percent of saturation and is equal to 120 percent of saturation in tailraces. Washington State Department of Ecology personnel administer these cap values for the lower Snake River. However, the effects of these various gas concentrations on resident fish are poorly understood.

Under certain conditions, spill rates equal to project-specific flow targets may yield TDG concentrations below cap targets. To further increase migration speed of smolts, the project managers may be asked to release more spill than required; this is termed “voluntary spill.”

Relative to the variable use of spill among the alternatives, reduction in the amount of spill will mean potentially more resident fish passing through dam turbines or bypass systems and fewer using the spillways. Conversely, increased spill may reduce the numbers of fish passing through turbines and bypass systems. No quantification of turbine-entrained or spilled resident fish exists. Samples of resident fish from juvenile salmonid facility separators at the dams are identified and recorded during the juvenile salmonid outmigration period (see Section 3.6). These data have only recently been collated, but have not been analyzed.

4.1.3 Flow Augmentation

Flow augmentation has been implemented to speed passage of salmonid smolts through the lower Snake River reservoirs or at hatchery release locations. Flow augmentation is provided during the salmonid smolt outmigration period of April through August. Flow augmentation can provide a significant increase in spring flows in below-average water years and improve summer flows and moderate summer water temperatures in most water years. Experiments have also been conducted to examine the use of flow augmentation to moderate high, late-summer water temperatures that potentially could affect adult salmonid runs entering the Snake River (Karr et al., 1992).

Since at least the early 1980s, a water budget of 1.64 million acre-feet (MAF) in the Snake River Basin was managed to simulate and shape the spring runoff through the reservoirs. The principal use of flow augmentation prior to 1991 was to increase reservoir current velocities during salmonid smolt outmigration, and the flows were timed to coincide with spring hatchery releases. Specific seasonal flow targets were developed, and summer flow augmentation began in 1991 in response to listing of Snake River chinook salmon (Connor et al., 1998). Summer augmentation flows can originate from upper Snake River storage released through the Hells Canyon complex, or from Dworshak Reservoir on the North Fork Clearwater River. Initial summer augmentation flows were provided primarily to speed smolt passage, but flows provided from Dworshak Reservoir were more readily available and were also capable of cooling high summer water temperatures by utilizing selective-depth withdrawal structures. Augmentation flows from the Hells Canyon complex lack cooling ability. As a result, flow augmentation from Dworshak Reservoir has been used more often in recent, low flow years (e.g., 1994) to speed salmonid smolt passage and moderate lower Snake River reservoir water temperatures. As a result of continued emphasis on increasing outmigration speed, the releases are provided as relatively low, consistent volumes as opposed to higher volumes of shorter duration, such as a pulse.

Release of additional upstream storage in the amount of 427 thousand acre-feet (KAF) has been part of the operational requirements for the Snake River projects since issuance of the 1995 Biological Opinion by NMFS (NMFS, 1995). Delivery of the 427 KAF comes from the Hells Canyon complex on the mid-Snake River and from Dworshak Reservoir and is released to meet specific, seasonal flow targets at Lower Granite Dam. Although upper Snake River reservoir drafts are limited to specified minimum elevations to protect fish and wildlife in the storage reservoirs (BPA, 1995), little attention has been focused on the effects of augmentation flows on resident fish of the lower Snake River reservoirs.

4.1.3.1 Options for Flow Augmentation

Three options for flow augmentation are under consideration for the lower Snake River (Table 4-1). For most alternatives, provision of the 427 KAF from the Hells Canyon complex and Dworshak Reservoir, as called for in the 1995 and supplementary 1998 Biological Opinions, would continue (NMFS, 1995; 1998). Increased flow augmentation (Alternative A-6a) referenced in NMFS Biological Opinions refers to an additional 1.0 MAF to be studied by the Bureau of Reclamation (BOR) from upper Snake River basin storage (exclusive of Dworshak Reservoir) to further shape lower Snake River flows. The 1.0 MAF could be delivered during the April through August period of salmonid smolt outmigration, in addition to the 427-KAF requirement. Zero flow augmentation (Alternative A-6b) would mean use of only the 1.64 MAF established for the Snake River Basin in the original Water Budget developed by the Northwest Power Planning Council (NPPC).

4.1.4 Natural River Drawdown

All four lower Snake River Dams would be breached by removing the earthen embankment portion of the dam. Potential dam removal scenarios include removal of all four dams in one year, removal of two dams per year in successive years, or one dam removal for four successive years. We assume the dams would be removed from lowermost to uppermost for any of the scenarios. However, the specific order of dam removal has not been established. We believe the greatest magnitude of potential short-term impacts to the entire lower Snake River corridor, but for the briefest period of time, would result from the all-in-one-year scenario. Other scenarios would impact the corridor for as long as removal of the four dams takes, but the magnitude of effects in any one year may not be as great. The expected long-term impacts to the lower Snake River likely would not change appreciably regardless of which time scenario were selected. However, any potentially deleterious effects to resident fish of the lower Columbia River reservoirs may be exacerbated if several years are required to remove all four lower Snake River Dams.

Current scenarios for dam removal utilize reconfigured turbines and turbine passageways as low level outlets to facilitate lowering reservoir water levels. Earthen embankment excavation and removal is planned to coincide with reservoir drawdown, which is planned for the August to December time period. The goal is to produce controlled flow patterns to minimize erosion and water quality impacts. Channelization levees around remaining concrete portions of each dam would then be constructed and completed by March. Thus, the entire physical removal process that lowers river levels to pre-impoundment conditions would be completed during the 8-month period from August to March. What remains unclear is the number of years required to remove the four dams and restore the entire 140-mile (225-km) section to free-flowing condition. At present, the most likely scenario is to remove the four dams during two successive years, i.e., two dams per year.

Breaching the dams would eliminate the four reservoirs and return 140 miles (225 km) of the lower Snake River to a free-flowing condition. Although free-flowing in character, upstream regulation for flood control and power production would continue. The present 427-KAF flow augmentation provided from upper Snake River storage and from Dworshak Reservoir would also continue for low flow augmentation and cooling. As a result, the lower Snake River would not be subject to the completely stochastic nature of an unregulated hydrologic regime. Following an expected transition period of less than five years, during which most of the accumulated silt would be transported downstream, a relatively stable river channel would reestablish.

One anthropogenic feature likely to remain after dam removal is large quantities of riprap. Although the drawdown will restore the lower Snake River corridor to a flowing water system, current engineering plans suggest a substantial portion of the channel will be covered with riprap to protect roads, railroads, and bridges. Thus, the full riparian zone will not be restored to pre-dam conditions. The magnitude of the effects of riprap will depend upon channel length coverage, as well as the extent of riprap down the bank. For example, a river bank segment fully armored down to typical summer water levels will prevent establishment of most riparian vegetation in that segment. Present plans suggest a higher proportion of shoreline will be covered with riprap in the Lower Granite and Little Goose segments than in the two downstream reservoirs. Also, mainly north shoreline reaches will be riprapped in the upper two segments, compared to primarily south shoreline sections in the Lower Monumental and Ice Harbor segments. Bioengineering opportunities could be expected where practicable and cost-effective, but were not included in the initial engineering.

4.1.4.1 Expected Riverine Habitats in a Restored Lower Snake River

An historical data set representing depth, substrate, and current velocity measurements taken in 1934 at transects along the lower Snake River was digitized and converted to layers within a GIS format. These geomorphic data were then input to one-dimensional (depth or substrate) and two-dimensional (velocity and depth or substrate) models to predict habitat conditions in a free-flowing Snake River following dam removal at a representative moderate summer flow near Lower Granite Dam. For the one-dimensional model, this was 21,000 cfs, and it was 24,000 cfs for the two-dimensional model. While depth and velocity data reflected actual 1934 field measurements, substrate data inputs were interpreted from anecdotal information noted on the original field maps. From these data, we were able to calculate the following habitat descriptors from Ice Harbor Dam to the Snake River-Clearwater River confluence in Lewiston/Clarkston. These descriptors permit qualitative predictions of riverine habitat conditions that will affect resident fish abundance, distribution, and species assemblages following dam removal.

- River gradient in 1.6 kilometer (1-mile) increments
- Distribution of depths (meters) (ft) and river velocities (meters/second) (ft/s)
- Distribution of dominant and subdominant substrate types
- Predicted total surface area of the restored river reach
- Predicted surface areas of the habitat types as described and used to develop habitat-use guilds in Section 3.8.

There is substantial uncertainty regarding whether post-drawdown habitat conditions will develop as predicted. Inputs to the predictive models were based on 1934 data that reflected a largely unregulated river system, different climatic conditions, different basin agricultural practices, etc. In addition, the time frame required to attain such a steady state, as portrayed by the 1934 data, is unknown. Thus, these predictions should be viewed with caution.

The predictive data reflect habitat conditions expected for moderate summer river flows. However, annual spring runoff will create temporary habitat conditions of increased depth and water velocity in the main river channel, as well as temporary flooding of off-channel sloughs and backwaters. These backwaters may represent velocity shelters for some resident fish, and possibly attract potential spawning fish, especially in those sloughs where sufficient warming occurs. Recruitment of young from these areas ultimately may depend upon connectivity with the main channel as seasonal flows subside.

4.1.4.2 Expected Lower Snake River Gradient

The relatively gradual descent of the lower Snake River from Lewiston/Clarkston to the Tri-Cities is shown in Figure 4-1. Elevation changes and mean gradients for the entire restored reach and individual reach segments are shown in Table 4-2. The modeled data suggest there will be no steep rapids and relatively few long pools in the restored lower Snake River. The average gradient throughout the 208-km (129.3-mile) reach from Ice Harbor Dam to the Snake-Clearwater River confluence is estimated at 0.53m/km (2.81 feet/mile), or 0.053 percent, and little variability in gradient is expected among the four river segments corresponding to the existing reservoirs.

The model data predict there will be two 1.6-km (1-mile) reaches where stream gradient exceeds 1.89 m/km (10 feet/mile). The steepest section is expected between Silcott Island and Clarkston, Washington (rms 136 to 137), where the predicted gradient will be 1.97 m/km (10.41 feet/mile). The gradient in the reach below Little Goose Dam near Starbuck, Washington, (near Texas Rapids, approximately RM 66.5) is predicted to be 1.90 m/km (10.03 feet/mile). Additionally, there will be three reaches where river gradient would exceed 3.05 m/3.2 km (10 feet/2 miles). These reaches occur in the Ice Harbor area near Fishhook Park (rms 16 to 18), upstream of the Lyons Ferry area (rms 59 to 61 between the Palouse and Tucannon river mouths), and below Nisqually John Landing (rms 125 to 127) in the Lower Granite reach.

Long, flatwater reaches (pools) will be equally scarce. Three such areas are predicted to occur near Fishhook Park between RMs 14 to 26 in the Ice Harbor reach; one of these is at least 3.2 km (2 miles) long. Other pools about 1.6 km (1 mile) long will occur at intervals throughout the entire riverine portion, except from RMs 26 to 66, where no long pools are predicted to occur.

4.1.4.3 Expected Riverine Habitats—Velocities, Depths, and Substrates

The total amount of riverine habitat available to resident fish will be substantially less than that in the reservoirs. Total riverine habitat following drawdown is estimated to be 5,327 hectares (13,162 acres), about 38.8 percent of the total surface area in the reservoirs (Table 4-3). Variation in the predicted amounts of aquatic riverine habitat among restored reaches ranged from 48 percent of Lower Monumental Reservoir surface area to 31 percent of Lower Granite Reservoir surface area.

A Corps' contractor has prepared predictive depth, velocity, and substrate maps in GIS format based on the 1934 geomorphology data for the reach affected by the drawdown. The entire reach has been subdivided into segments roughly comparable to the lengths of the current reservoirs. These maps form the basis for the following descriptions. Access to the habitat maps will be available through a link on the Corps’ Walla Walla District home page (http://www.nww.usace.army.mil).

At moderate summertime flows of 24,000 cubic feet per second (cfs) (as measured at Lower Granite), modeled river velocities in approximately 90 percent of the restored riverine reach will exceed 2.0 feet/second at all depths, with little variation in the amount of current greater than 0.6 meters/second (2.0 feet/second) among reaches (Table 4-3). Modeled data further suggest that about 30 percent of the restored river will be relatively swift, comprised of currents greater than 1.5 meters/second (5.0 feet/second) (Figure 4-2). In contrast, shallow (less than 3.0 meters [10 feet deep]) habitat with moderate velocities of 0.15 to 0.6 meters/second (0.5 to 2.0 feet/second) will

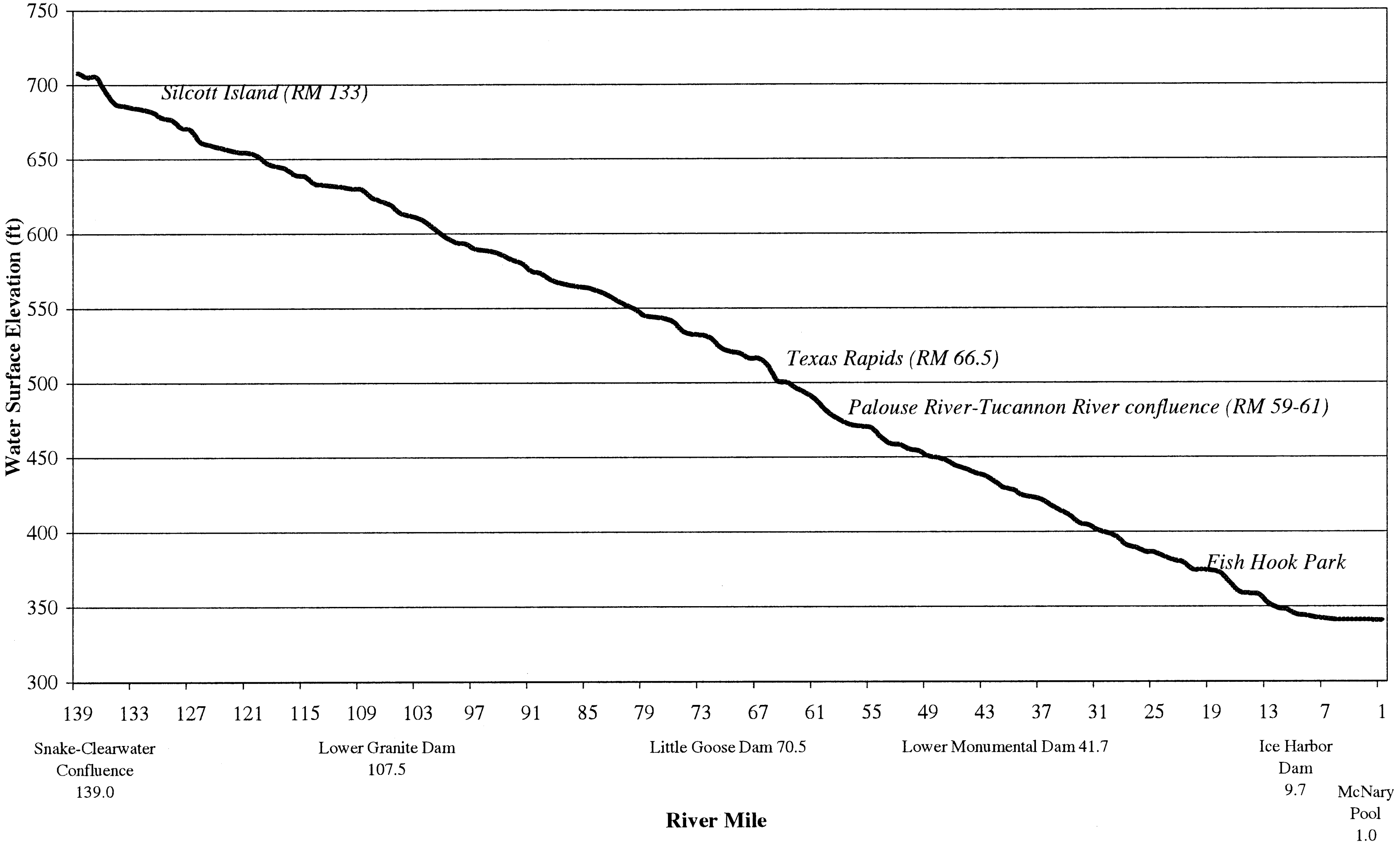


Figure 4-1. Stream Profile of Lower Snake River by River Mile, Upper McNary Pool Arm to Snake-Clearwater River Confluence

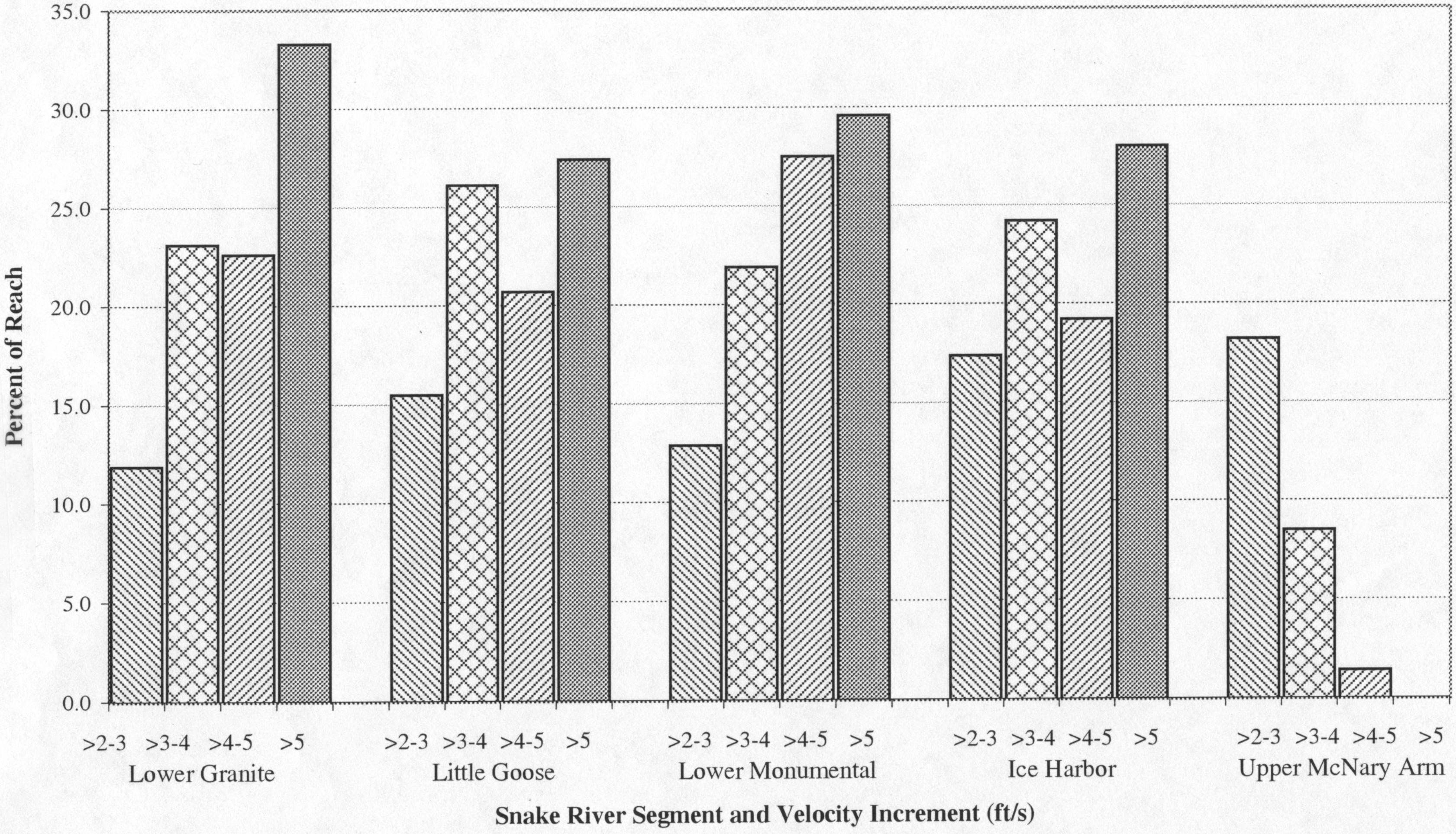


Figure 4-2. Proportional Distribution of Predicted River Velocities in a Restored Lower Snake River Determined by a Two-Dimensional Model

Table 4-2. Summary Statistics from Longitudinal Snake River Profile Based on Modeled Water Surface Elevations

Snake River Reach	Reach Length (mi)	Elevation Change (ft)	Gradient (ft/mi)	Gradient (%)
IHR Dam to Snake-Clearwater R. confluence	129.3	363.90	2.81	0.053
IHR Dam to LMO Dam	32.0	88.03	2.75	0.052
LMO Dam to LGO Dam	28.8	90.10	3.13	0.059
LGO Dam to LGR Dam	37.0	100.84	2.72	0.052
LGR Dam to Snake-Clearwater R. confluence	31.5	84.93	2.70	0.051

IHR=Ice Harbor; LMO=Lower Monumental; LGO=Little Goose; LGR=Lower Granite

Table 4-3. Summary of Amount of Expected Habitat Types in a Restored Lower Snake River After Dam Removal

	Surface Area (acres)		Riverine Habitat Types*	Individual Habitat Surface Area	
Snake River Segment	**Reservoir**	**Riverine**		**Acres**	**%**
Upper McNary Arm	1,989	1,989	A	559	28.1
			B	216	10.5
			C	966	48.6
			D	91	4.6
			E	157	7.9
			F	0	0.0
			G	28	1.4
Ice Harbor	8,375	3,475	A	3,087	88.8
			B	260	7.5
			C	54	1.5
			D	70	2.0
			E	4	0.1
			F	0	0.0
			G	20	0.6
Lower Monumental	6,590	3,191	A	2,931	91.9
			B	200	6.3
			C	21	0.6
			D	40	1.2
			E	1	0.0
			F	0	0.0
			G	8	0.2
Little Goose	10,025	3,754	A	3,367	89.7
			B	283	7.6
			C	33	0.9
			D	68	1.8
			E	2	0.1
			F	0	0.0
			G	13	0.4
Lower Granite	8,900	2,742**	A	2,494	91.0
			B	157	5.7
			C	42	1.5
			D	46	1.7
			E	3	0.1
			F	0	0.0
			G	11	0.4
Total Reach	33,890	13,162	A	11,879	90.3
			B	900	6.8
			C	150	1.1
			D	224	1.7
			E	10	0.1
			F	0	0.0
			G	52	0.4

*Key to riverine habitat types

A=velocity > 2.0 ft/s; all depths.
B=velocity = 0.5-2.0 ft/s; depths < 10 ft.
C=velocity = 0.5-2.0 ft/s; depths > 10 ft.
D=velocity < 0.5 ft/s; depths < 10 ft.
E=velocity <0.5 ft/s; depths 10-35 ft.
F=velocity <0.5 ft/s; depths > 35 ft.
G=velocity <0.1 ft/s; all depths to 35 ft.

**Area estimate does not include section from Lewiston to Asotin.

Note: Upper McNary Pool arm shown for comparison.

comprise less than 7 percent of riverine surface area. The predicted amounts of deep, slow, or standing water habitat for resident fish would be severely restricted to 2.1 percent or less of the surface area of a restored lower Snake River.

The projected quantity of free-flowing habitat with velocities higher than 0.6 meters/second (2.0 feet/second) contrasts with the preponderance of habitat that will remain in the upper McNary Pool section of the lower Snake River. More than 59 percent of this uppermost portion of McNary Pool will have moderate river velocities between 0.15-0.6 meters/second (0.5-2.0 feet/second) (Table 4-3). Slow water (less than 0.15 meters/second [0.5 feet/second]) will comprise greater than 11 percent of the McNary section, while faster currents of primarily 0.6 to 0.9 meters/second (2 to 3 feet/second) will be limited to about 28 percent of this relatively short reach (Table 4-3; Figure 4-3).

Based chiefly on the expectation of relatively high river velocities throughout the restored reach, traditional concepts of riverine habitat sequences (fast riffles transitioning into slow pools) may not accurately represent a restored lower Snake River. A common feature suggested by model outputs throughout the restored reach is a consistent, moderate to high velocity component. The lack of major gradient changes also means less distinct transitions between habitats on a longitudinal axis. As a result, much of the variability in habitats will occur across the channel. In fact, the modeled data suggest that the only reduced-velocity areas exist in narrow bands along the channel edges or in areas where islands or, less frequently, backwaters create habitat complexity.

The modeled steady-state flow utilized to produce the depth and substrate maps was 21,000 cfs at Lower Granite Dam, representing moderate summer flows. At the modeled flows, most of the restored river will be less than 4.3 meters (14 feet) deep, with deeper mid-channel areas occasionally more than 7.6 meters (25 feet) deep. Three areas were predicted to be 15.2 meters (50 feet) deep or more. These included two locations in the Ice Harbor segment, one just above the present dam site and the other above Fishhook Park. The other very deep reach will be located just upstream of the Palouse River confluence in the Lower Monumental segment.

Substrates are predicted to be variable throughout the restored reach, and model outputs suggest that substrate heterogeneity will be higher in the section downstream of Little Goose Dam. The reach upstream of Little Goose Dam to Lewiston/Clarkston will be predominantly a mix of gravel (dominant particle) and sand (sub-dominant particle).

Interspersed throughout are relatively short sections of bedrock-cobble or gravel-cobble. The shorter sections of coarser substrate suggest areas supporting higher current velocities. The two segments from Little Goose Dam downstream to Ice Harbor Dam should provide a greater variety of habitats. The predominant substrate in the Little Goose-Lower Monumental segment is cobble-gravel, interspersed with bedrock-cobble and gravel-sand substrates in the upper and lower portions of this segment, respectively. The upper two-thirds of the segment from Lower Monumental to Ice Harbor is mostly gravel-sand, whereas the lower one-third is an equal mix of cobble-gravel or gravel-cobble. Embeddedness of these substrates will remain a factor affecting river productivity for some time, however.

Although there was no attempt in this analysis to link areas with specific substrates to areas with a specific velocity or depth, typically the swiftest stream reaches support the coarsest substrates. Also, areas with coarser substrates appeared to agree with those areas having a steeper gradient (see Figure 4-1). Further, although limited, the amount of detail in the substrate data was sufficient

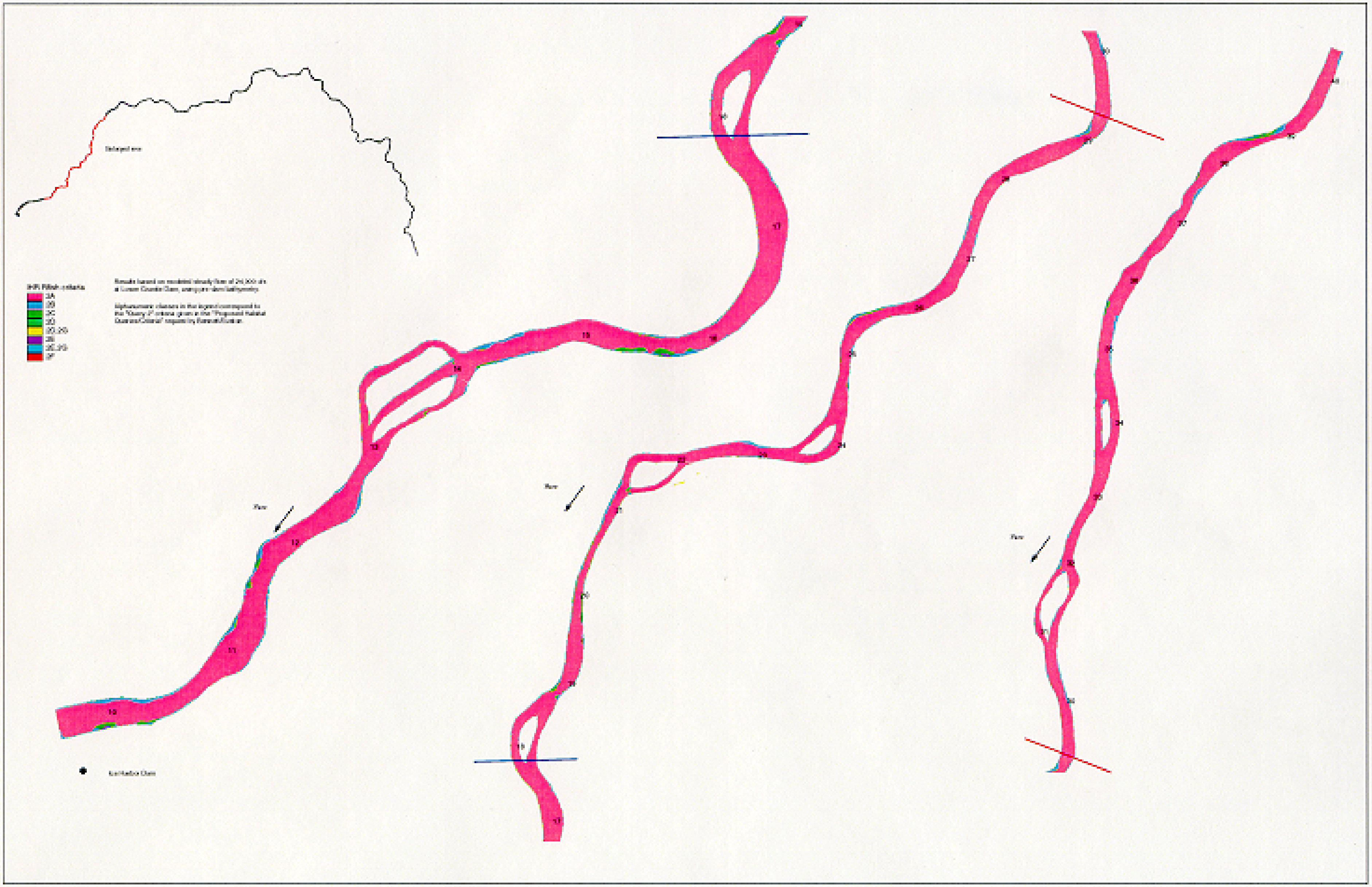


Figure 4-3. Example of GIS Output Available on Corps' Walla Walla Home Page

to suggest that most of the resident fish should not be limited by lack of suitable substrate. In general, the finer substrates would be expected to occur in areas with the least current, such as pool margins and backwater areas. Located throughout the restored reach will be occasional complex-habitat sites represented by islands, braided channels, or backwaters/sloughs. Approximately seven complex habitat areas are expected in the upper half of the reach, primarily islands creating split or braided channels. Model outputs suggest island complexes at RM 72, 75 to 76, 89, 97 to 97.5, 100 to 101, and 102. In the lower half of the restored reach, complex habitat areas appear substantially more abundant in the segment from Lower Monumental Dam to Ice Harbor Dam than elsewhere. As many as seven island, braided channel, or backwater complexes will occur in this segment. Approximate locations of these areas will be at RM 13 to 14, 18, 21 to 22, 24, 31 to 32, and 34.

The above descriptions qualitatively depict the expected substrate composition of the restored lower Snake River. However, the embedded substrates that now characterize most of the impounded areas after nearly 40 years of a depositional environment may require several years of high (greater than 200,000 cfs) flows to cleanse the gravels. Such high flows may rarely be available from Snake River Basin storage. A geomorphology study that addresses the flows needed to remove the interstitial fine sediments and promote normal, riverine substrate character and movement was performed by Battelle's Pacific Northwest Laboratory and is discussed in Technical Appendix H, Fluvial Morphology.

Additional requirements that may be necessary to restore essential habitat attributes are addressed in the Coordination Act Report (CAR) prepared by the U. S. Fish and Wildlife Service. The CAR is attached to the EIS as Appendix M.

4.2 Predicted Impacts

4.2.1 Alternative A-1: Existing Condition

4.2.1.1 Synopsis of Relevant Actions

This alternative would implement the planned structural reconfigurations and maintain the operational requirements as shown in Table 4-1. Recent structural changes include the addition of spillway flow deflectors at Ice Harbor Dam in 1997 and 1998. Those actions embedded in current operations that most affect resident fish are the provisions for flow augmentation and spill. Under current procedures, 427 KAF is to be available from upper Snake River basin storage, including Dworshak Reservoir, to augment low spring or summer flows during April through August. Spillage is to be provided up to TDG cap levels of 120 percent and 115 percent in tailraces and forebays, respectively.

4.2.1.2 Short-term/Transition Period Effects

There would be no specific short-term effects of this alternative that would have detectable effects on resident fish. A potential reduction in TDG levels in the Ice Harbor Dam tailrace and upper McNary Pool (Lake Wallula) due to recent installation of flip lips is possible, but detecting any effects on resident fish is unlikely.

4.2.1.3 Long-term Effects

Resident fish communities would not change under this alternative. Proposed system configurations and dam feature replacements/rehabilitations would have little effect on the resident fish community. Improvements to dam structures such as modifications to ESBS systems may reduce the amount of turbine entrainment of fish by directing more fish through bypass systems, but there are no baseline data from which to measure an impact. Similarly, turbine replacement or rehabilitation may reduce the mortality of resident fish due to turbine passage, but the effects would likely not be detectable in the reservoir populations. Although Corps data from samples taken at juvenile salmonid smolt by-pass systems suggest that resident fish entrainment can be significant at each of the lower Snake River Dams, overall changes in fish community structure and abundance are not anticipated. Extended length screens and flip lips may increase survival of entrained fish, although the populations of resident fish appear to be at saturation; therefore, any changes in survival would not result in overall changes in community structure.

Continued flow augmentation and, to a lesser degree, spill have the highest potential for long-term effects on resident fish among the proposed operational requirements shown in Table 4-1. Flow augmentation of 427 KAF could alter the fish community structure at Lower Granite Reservoir, depending upon timing, but probably not at other lower Snake River reservoirs. Karr et al. (1992) showed that low temperature water released from Dworshak Reservoir could be used to lower the water temperature of each of the four lower Snake River reservoirs, although water temperatures in Lower Granite Reservoir were the most dramatically affected. The potential for alteration in the fish community exists with several of the centrarchid species (sunfish), as these fish generally require warmer water for spawning. Centrarchid fish require specific water temperatures to initiate spawning activity. Delayed spawning can result in shorter growing seasons and ultimately, smaller body size entering their first winter. Several studies have identified size-related winter mortality; smaller fish have higher mortality than larger fish. For example, if age-0 smallmouth bass do not attain a minimum size of 50 mm (2.0 inches), they do not survive their first winter. Therefore, high volume inflows that lower water temperatures in the lower Snake River reservoirs have the potential to reduce annual survival by delaying spawning and possibly retarding growth. However, Bennett et al. (1994) reported that low temperature inflows from Dworshak Reservoir in 1991 and 1992 did not affect year-class strength, growth, and survival of smallmouth bass and speculated that water temperatures were not sufficiently affected to reduce growth and ultimately survival.

Current operational strategy encourages spill up to limits imposed by subsequent TDG concentrations. However, the best spill strategy for many resident fish would be no spill. In general, lower flow years in the lower Snake River coincide with the highest water temperatures, highest zooplankton abundance, and highest water clarity. All of the resulting conditions are generally beneficial to the resident fish community. Chipps et al. (1997) speculated that during low flow years, centrarchid fish appeared to produce strong year-classes, while the abundance of native cyprinid fish declined. We anticipate that the introduced fish component of the resident fish community would be enhanced under the lowest flow scenarios, while the native fish component would be disadvantaged. Conversely, native resident fish, more so than introduced resident fish, are more tolerant of a maximize-spill strategy.

4.2.1.4 Cumulative Effects

Under the existing condition alternative, the reservoirs would continue to age. Reservoir aging, especially in a sand-laden river like the Snake, involves continued deposition of fines, leading to shallower habitats with improved conditions for aquatic macrophytes. Thus, reservoir habitat conditions for those fish most dependent upon lacustrine conditions, particularly crappie, largemouth bass, and yellow perch, may improve with time.

The existing condition alternative also means continued provision of 427 KAF flow augmentation with attendant cooling effects. Thus, those years with low flows that might be expected to produce abundant year-classes of many of the introduced resident fish would continue to be subject to the greatest interruption of reservoir warming. Although detection of any measurable effects on fish population composition or growth due to cooling by augmentation flows has not occurred to date, over the long term, such effects might eventually be detectable in Lower Granite Reservoir.

Planned structural improvements and operational changes (other than continued flow augmentation), as identified in Table 4-1 for the existing condition alternative, are unlikely to result in any detectable, long-term changes to resident fish populations.

4.2.2 Alternative A-2: Existing Condition/Maximize Transport of Juvenile Salmon

4.2.2.1 Synopsis of Relevant Actions

The system configuration and planned improvements for Alternative A-2 (Table 4-1) would be identical to Alternative A-1, as discussed above. However, to maximize transport under current operations, voluntary spill (see Section 4.1.2) would be eliminated, thus passing a higher proportion of water and, potentially, more fish through the turbines or bypass systems.

4.2.2.2 Short-term/Transition Period Effects

Fewer spills may reduce TDG levels in reservoirs and tailraces, potentially reducing any effects of elevated gas levels on resident fish. Although more fish may be entrained through turbines, there would be no short-term effects detectable on resident fish populations.

4.2.2.3 Long-term Effects

Few aspects of Alternative A-2 have the potential to significantly affect resident fish. Flip lips at Ice Harbor Dam and reduction in TDG supersaturation (as discussed above) can potentially improve survival of resident fish either entrained through Ice Harbor Dam, or those rearing in all dam tailwaters. Reduction in gas supersaturation can ultimately increase survival, although the resident fish community structure probably would not be altered. Similarly, more fish entrained through turbines as a result of fewer spills may decrease survival of those fish most susceptible to entrainment (e.g., mostly juveniles of suckers, channel catfish, carp, peamouth, and white crappie), although not to the extent that long-term community structure is altered. Enhanced conditions for juvenile salmonid migration through Lower Granite Reservoir (i.e., higher flows and velocities with cooler temperatures due to augmentation) would have the effect, as identified under Alternative A-1, of influencing the timing of resident fish spawning, growth, and year-class strength. Other changes in the configuration of dam structures, as shown in Table 4-1, would have little effect on the resident fish community.

4.2.2.4 Cumulative Effects

The cumulative effects of Alternative A-2 (maximum smolt transport) will be similar to those of Alternative A-1. The chief difference among potential actions relative to the existing condition alternative, as applicable to resident fish, is curtailment of voluntary spill at the dams, which may reduce TDG levels in those years. However, detection of any chronic effects of high TDG levels in the resident fish populations of lower Snake River reservoirs has so far been elusive.

4.2.3 Alternative A-2a: Major System Improvements/Maximized Transport of Juvenile Salmon

4.2.3.1 Synopsis of Relevant Actions

Alternative A-2a is designed to maximize juvenile salmonid transport and increase fish survival through major system improvements to structures. The major structural improvement currently envisioned (and currently undergoing testing) is installation of surface bypass collectors at dam intakes to attract, collect, and bypass surface-oriented salmonids to downstream areas. Below the dams, collected fish may be loaded for barge transport or passed to the tailwater for in-river migration. For this alternative, smolts will be loaded for transport. Among other potential structural improvements, only raising the elevation of spillway basins would have the potential to affect resident fish. Elevating the floor of stilling basins should reduce TDG levels in tailwaters. Voluntary spill would not be requested under this alternative to achieve maximum barge transport.

4.2.3.2 Short-term/Transition Period Effects

The initial effect of this alternative on resident fish would be to reduce TDG levels in tailwaters by reducing the depth of plunging spill flows, potentially increasing the survival of fish rearing in tailwaters. It is unlikely any other effects would be noticed in the short term.

4.2.3.3 Long-term Effects

Structural configuration additions under Alternative A-2a are anticipated to have little overall effect on the resident fish community or composition. Current configurations have little effect on the resident fish community, and proposed improvements and replacements such as surface bypass collectors would have minimal effects on the populations of resident fish in the lower Snake River reservoirs. Continuation of operational requirements such as flow augmentation would have the predicted effects described for Alternative A-1, the existing condition alternative. Curtailment of voluntary spills combined with shallower stilling basins may further reduce TDG levels in tailwaters, although the effects of lower gas levels would not be likely to alter resident fish communities.

4.2.3.4 Cumulative Effects

Efforts to maximize transport of juvenile salmonids through structural improvements and reduced emphasis on spill would not be likely to result in any measurable, long-term effects on resident fish populations in the reservoirs. Shallower stilling basins designed to reduce TDG levels could reduce habitat suitability for fish such as white sturgeon that tend to occur in deeper portions of dam tailwaters.

4.2.4 Alternative A-2b: Major System Improvements/Minimized Transport of Juvenile Salmon

4.2.4.1 Synopsis of Relevant Actions

Actions within Alternative A-2b with more potential to affect resident fish include raising the spillway basin floor elevation, providing 427 KAF flow augmentation during April through August from the upper Snake River basin, and spilling as much water as possible within the limits of tailrace and forebay gas cap levels. However, volunteer spill would not be requested. Surface bypass collection is the principal improvement currently under consideration (see Alternative A-2a).

4.2.4.2 Short-term/Transition Period Effects

Raising the stilling basin floors may reduce TDG levels in tailraces and offset the potential short-term effects (i.e., higher TDG levels) of maximizing spill.

4.2.4.3 Long-term Effects

Under Alternative A-2b, spill would be maximized up to the gas caps to enhance passage of juvenile salmonid smolts through the reservoirs and minimize smolt transport. We do not anticipate any long-term adverse effects to the resident fish community outside of the potential for increased gas supersaturation and increased flow and velocities and cooler water temperatures through the reservoirs. As indicated for Alternative A-2, TDG abatement measures (stilling basin floor modifications and modified/additional flip lips) may enhance survival of resident fish in tailwaters of the lower Snake River Dams, although the long-term structure of the resident fish community would not change. Flow augmentation into the reservoirs would have the greatest potential for adverse effects. As indicated under Alternative A-1, the timing of increased augmentation flows has the potential to alter the fish community. We would anticipate that higher flows would enhance the native fish component (i.e., suckers and cyprinids) of the resident fish community and decrease the abundance of introduced species, largely centrarchid fish such as bass, crappie, and sunfish.

4.2.4.4 Cumulative Effects

The cumulative effects of structural and operational changes with a reduced emphasis on transport should be essentially similar to those expected for Alternative A-2a. Any of the proposed actions would not likely result in detectable effects on resident fish populations.

4.2.5 Alternative A-2c: Major System Improvements/Adaptive Management

4.2.5.1 Synopsis of Relevant Actions

Adaptive management would include actions in addition to the major fish passage structural improvements, optimized spill, and 427 KAF flow augmentation identified among operational requirements in Table 4-1. The results of ongoing research to improve salmonid smolt passage survival may yield promising new technologies as yet unidentified. These may be incorporated within the structure currently identified as providing the best dam-in-place matrix of actions to enhance juvenile salmonid survival.

4.2.5.2 Short-term/Transition Period Effects

Short-term effects will be limited to those discussed earlier for Alternatives A-2a and A-2b.

4.2.5.3 Long-term Effects

The dam configuration and operational changes included under an adaptive management alternative, as shown in Table 4-1, would have only limited potential to result in minor changes to the resident fish community. We believe that the dam configuration and operational changes would have the potential to shift the resident fish community to favor more native than introduced fish, but that changes in community structure would be relatively minor in scope. Any structural modifications of the dams or spillways that leave the dams in place would afford the least potential to alter the resident fish community structure, whereas operational changes, primarily those related to flow augmentation, would have the greatest potential effect. The effects of flow augmentation as proposed for Alternative A-2c are discussed above (see Alternative A-1). Although future salmonid management options that may be developed are unclear, most actions designed or implemented to enhance juvenile salmonid survival typically are potentially detrimental to the resident fish community, especially the introduced component.

Potential fisheries management options that could affect resident fish include modifications to the sport reward program that targets large, predatory northern pikeminnow, or changes to sport fishing regulations that might affect smallmouth bass or channel catfish harvest. Continuation of the bounties for northern pikeminnow will continue to depress population levels. If the program is discontinued, pikeminnow populations will likely rebound. Other significant predators are currently managed under non-restrictive regulations (no size limits or closed season) that, to the extent allowed by sport fishing effort, reduce the abundance of larger smallmouth bass and channel catfish.

4.2.5.4 Cumulative Effects

Structural or operational changes adopted in the future for use under an adaptive management plan that would result in enhancements to anadromous fish would most likely not enhance resident fish populations. However, detection of any deleterious effects on resident fish would also be unlikely. Future actions that would alter delivery of augmentation flows would have the most potential to adversely affect resident fish populations but there is little likelihood that such effects could be separated from the variability resulting from basin-wide factors such as weather and/or precipitation and runoff. Further, any changes to resident fish populations must also be separated from those accruing from normal reservoir aging processes.

4.2.6 Alternative A-6a: Major System Improvements/In-river Migration and Additional 1.0 MAF Flow Augmentation

4.2.6.1 Synopsis of Relevant Actions

Alternative A-6a would incorporate major structural improvements for fish passage and TDG abatement (Table 4-1). Operational changes are related to maximized or optimized spill, with additional involuntary spill correlated to the amount of increased flow augmentation. Alternative A-6a calls for 1.0 MAF of water for flow augmentation in addition to the 427 KAF provided since 1995. Under full implementation, the amount of water available from the upper Snake River basin for shaping lower Snake River flows during outmigration would more than triple.

4.2.6.2 Short-term/Transition Period Effects

The short-term effects of these actions would be increased flows and velocities through the reservoirs, higher spill volumes, and potentially higher TDG throughout the lower Snake River. However, since the 1.0 MAF would be released from the Hells Canyon complex with little or no cooling potential, one net effect may be to dilute the cooling effects of Dworshak Reservoir flow releases. The short-term effects to resident fish, if any, would likely be very dependent on seasonal timing of augmentation releases.

4.2.6.3 Long-term Effects

Major system improvements providing for maximum in-river migration with enhanced flow augmentation would have the highest potential to alter the resident fish community of all the alternatives, except drawdown. The potential alterations in the resident fish community would result from enhanced flow augmentation. At present, flow augmentation of 427 KAF could alter the resident fish community structure at Lower Granite Reservoir, depending upon in-season timing of the flows, but probably not at other lower Snake River reservoirs. Karr et al. (1992) showed that low temperature water released from Dworshak Reservoir could be used to lower the water temperature of each of the four lower Snake River reservoirs, although water temperatures in Lower Granite Reservoir would be the most dramatically affected. Data in Connor et al. (1998; Figure 3) subsequently showed that releases from Dworshak Reservoir could alter the temperature regime experienced by resident fish in Lower Granite Reservoir, particularly during the critical spawning periods for introduced species. Further, the effects of temperature reductions during spawning periods are potentially the greatest and are most likely to occur during low flow years. Low flow years produce thermal and flow conditions that tend to favor production of most introduced resident fish, such as bass, crappie, and sunfish (Chipps et al., 1997).

Tripling the volume of flows passed through the reservoirs during the spawning period could further the negative impacts on introduced resident fish, while potentially enhancing spawning conditions for native, resident fish. The negative impacts to the introduced resident fish component would result from higher in-reservoir velocities and cooler, or more moderate, water temperatures, conditions that tend to favor native resident species. In contrast, the dilution of Dworshak Reservoir releases by increased augmentation flows from the upper Snake River basin through the Hells Canyon complex may moderate the theoretical, detrimental cooling effects produced by Dworshak augmentation releases.

4.2.6.4 Cumulative Effects

Additional flows up to 1.0 MAF provided during juvenile salmonid outmigration as needed from April through August would result in more frequent spills and somewhat higher main-channel velocities in the reservoirs and could alter the composition of resident fish to favor those with more lotic habitat preferences. In general, these would include primarily native resident fish such as suckers, white sturgeon, redside shiner, and chiselmouth. More water passed through the reservoirs may also shrink available lacustrine (off-channel) habitats, potentially affecting populations of sunfish, crappie, yellow perch, and largemouth bass that are dependent on these habitats. At the same time, these larger inflows are planned to originate from the upper Snake River Basin and lack cooling ability. Thus, they could moderate any cooler inflows supplied from Dworshak storage. Ultimately, enhancement of lotic habitat characteristics by increased flow volumes may offset the reservoir aging process, prolong the current population structure, and benefit the existing native fish component.

4.2.7 Alternative A-6b: Major System Improvements/In-river Migration and Zero Flow Augmentation

4.2.7.1 Synopsis of Relevant Actions

The proposed actions in Alternative A-6b expected to affect resident fish are identical to those of Alternative A-6a except for flow augmentation (Table 4-1). Alternative A-6b would provide for zero flow augmentation. That is, only regulated runoff volumes that mimic natural runoff patterns from the upper Snake River basin would be passed through the lower Snake River reservoirs. Provision of 427 KAF from the Hells Canyon complex and Dworshak Reservoir would cease.

4.2.7.2 Short-term/Transition Period Effects

Reservoir water temperatures would be allowed to warm naturally, and artificially induced cooling due to flow augmentation would cease. The specific short-term effects would depend on the water year experienced following implementation. A low water year would tend to favor the production of introduced fish, while a high water year would tend to favor the native fish complement, as discussed by Chipps et al. (1997).

4.2.7.3 Long-term Effects

Major system improvements providing for maximum in-river migration without flow augmentation would have a very low, long-term potential to alter the resident fish community. Zero flow augmentation would result in “natural” warming of the reservoirs that would ultimately depend on air temperatures and runoff volume. Lower flow years would favor the centrarchid fish component (bass, crappie, and sunfish), whereas higher flow years would provide more suitable habitat conditions for suckers and the cyprinid component of the resident fish community. Connor et al. (1998) reported that flow and water temperature are highly correlated. Water temperature seems to be the principal limiting factor affecting spawning and growth of resident fish within the lower Snake River reservoirs. Operational conditions that provide for lower flows in the lower Snake River reservoirs would, therefore, have the highest potential to enhance habitat conditions for introduced resident fish. Lower flows that result in higher spring water temperatures would allow earlier spawning of most of the resident fish that are spring spawners. Early spawned fish would experience a longer growing season, resulting in larger body size and lower over-wintering mortality. Lower flows and higher water temperatures would also result in higher production of zooplankton that is the principal food source for many of the resident fish during their early life history (Scott and Crossman, 1973).

4.2.7.4 Cumulative Effects

Elimination of flow augmentation would allow reservoir aging to occur at a pace prescribed by basin geomorphology and at the same time would potentially favor introduced resident fish over native species. Low flow years that result in early warming would enable earlier spawning, a longer growth period, and enhanced fitness of fish entering the over-winter period. While annual variations in growth would continue due to annual variation in runoff and thermal units that control warming, the benefits of enhanced growth opportunities for introduced resident fish may become evident over the long term. Such opportunities are now truncated by flow augmentation. The cumulative effects of other structural and operational changes would be negligible compared to those resulting from elimination of flow augmentation.

4.2.8 Alternative A-3: Natural River Drawdown

4.2.8.1 Synopsis of Relevant Actions

Actions proposed to achieve permanent natural river drawdown would be the most drastic in terms of potential changes in the abundance and composition of the current resident fish assemblage. All four dams would be removed, and the Snake River ultimately would revert to a free-flowing system with flows regulated by upstream projects. Additionally, Alternative A-3 would provide for continued 427 KAF flow augmentation during the April through August salmonid smolt outmigration season. There would be substantial efforts to speed up the natural revegetation of river banks once accumulated silt deposits erode away and pass downstream. However, to protect existing infrastructure such as bridges, roads, and railroads, about 16 percent of the river shorelines would be covered with riprap.

4.2.8.2 Short-term/Transition Period Effects

The initial impact to resident fish would be a relatively rapid decline in water levels that would strand substantial numbers of fish and crayfish, an important food source to resident fish predators such as smallmouth bass, northern pikeminnow, channel catfish, and white sturgeon. Backwaters, embayments, and off-channel mitigation ponds would drain progressively as reservoir levels decline. As backwaters and other shallow areas were cut off, stranded fish in small, shallow impoundments would be subject to water stagnation, increased predation by other fish, birds, and land-based predators, and eventual desiccation (Schuck, 1992). A temporary drawdown of Lower Granite Reservoir in March, 1992 stranded more than an estimated 15,000 fish, primarily juveniles comprised mostly of brown bullhead and crappie. In terms of impacts to resident fish populations, largemouth bass were believed to be the most seriously impacted due to apparent susceptibility of adults to stranding in the limited, off-channel spawning habitats available in Lower Granite Reservoir (Schuck, 1992). The lacustrine habitat favored by many introduced, resident species such as largemouth bass, crappie, sunfish, and yellow perch is found in higher abundance in the older downstream reservoirs. Therefore, the immediate impacts on backwater/embayment guild members would be greater in those reservoirs with extensive embayment complexes such as Deadman Bay (Little Goose Reservoir), Lyons Ferry/Palouse River mouth (Lower Monumental Reservoir), and Dalton Lake (Ice Harbor Reservoir).

Current plans envision the drawdown beginning in August and extending through March (see Section 4.1.4). Young-of-year fish produced in off-channel sites such as mitigation ponds and flooded gulches cut off by railroad berms (Kenney et al., 1989) that retain some connection to the reservoirs (e.g., culverts), as well as any juveniles and adults residing in these ponds, could be subject to the effects of drawdown reported by Schuck (1992). In addition, the angling opportunities provided by fish in the backwaters and mitigation ponds would be lost. However, angling activities focused at stocked rainbow trout and crappie typically peak in spring (Normandeau Associates et al., 1998a); thus, effects on angling in these popular areas would not be felt until after the drawdown in a particular area was complete.

As reservoir water levels decline, short-term effects concomitant with stranding would be an increase in channel current velocities, especially during the spring and early summer high-volume runoff period, and subsequent erosion and transportation downstream of accumulated sediment deposits from the reservoirs. High sediment loads from eroding deposits would greatly increase turbidity of the lower Snake River and downstream to at least the McNary Pool (Lake Wallula) on the lower Columbia River. A direct impact of high suspended solids could lead to mortality due to gill clogging. However, we expect instances of such direct mortality to be localized and infrequent. The literature indicates that resident fish can generally survive high concentrations of suspended solids for extended periods of exposure. Wallen (1951), in his evaluation of turbidity tolerances of 16 warm water fish, observed limited behavioral changes occurred until concentrations neared

20,000 milligrams/liter (parts per million [ppm]), and acute lethal effects occurred only when concentrations exceeded between 175,000 to 225,000 milligrams/liter (ppm). Acute lethal effects occurred in little more than 1 hour at suspended solid concentrations of 200,000 milligrams/ liter (ppm). Direct mortality as a result of prolonged exposure to extremely high concentrations of suspended solids generally occurs as a result of gills becoming coated with sediment, rather than from abrasion. Under this condition, aeration of blood is prevented, and fish often die from a combination of anoxemia and carbon dioxide retention (see review by Cordone and Kelly, 1961).

The high suspended solids would potentially create indirect sublethal impacts such as decreased food production and fish feeding efficiency, which would negatively impact growth and other processes. These indirect impacts would be more likely than direct mortality and would affect fish in both the lower Snake River and McNary Pool. Sublethal effects on feeding, growth, and reproduction occurred in warmwater fish exposed to suspended solid concentrations of 62.5 to 144.5 milligrams/liter (ppm) for 30 days (Buck, 1956, cited in Newcombe and Jensen, 1996). Since biological response of fish is related to exposure duration and suspended solid concentration, relatively moderate suspended solid concentrations for extended time periods may produce sublethal effects (Newcombe and Jensen, 1996). Thus, expected high turbidities may affect growth and year-class strength of all resident fish.

The higher channel velocity would impact principally those resident species dependent upon lacustrine habitats by further restricting the availability of spawning sites. These species mainly include introduced embayment habitat-use guild members such as yellow perch and centrarchids such as smallmouth and largemouth bass, crappie, and sunfish.

As a result, a critical factor in determining potential short-term effects on resident fish is the seasonal timing of dam removal. Most resident fish are spring and early summer spawners. Dam removal as planned during late summer, fall, winter, and very early spring would likely result in a lower overall impact due to water level declines and high turbidity since spawning, growth and feeding by resident fish are minimal during most of this period, and many of these fish are believed to overwinter in deep water.

Declining water levels would also result in the loss of large numbers of crayfish that inhabit off-channel sites (Schuck, 1992), possibly affecting feeding in late summer by smallmouth bass, channel catfish, and other resident fish that consume crayfish. The effects of reduced reservoir volumes on feeding may offset the loss of large numbers of crayfish as forage, however. The drawdown would place predators and prey in closer proximity, potentially enhancing feeding conditions on remaining prey items in the short term. Ultimately, the degree of turbidity experienced might determine whether predators could capitalize on their closer proximity to food resources.

As natural flows subside during the initial post-removal year, the lower Snake River would return to an elevation within the old river channel. Most of the accumulated silt would be transported downstream, and increased flow would expose larger substrates, resulting in improved water clarity. However, heavy rains or thunderstorms might still wash quantities of silt from exposed, unvegetated riverbanks into the river channel, creating additional high turbidity periods that could interrupt fish spawning and reduce general river productivity. High turbidity resulting from runoff of accumulated silt deposits might be a factor for several years until riverbanks stabilize. The frequency of turbid periods might ultimately depend upon the annual variability of spring and summer runoff volume experienced in the Snake River basin. High spring runoff in the initial year after dam removal would transport more silt downstream than low spring runoff, resulting in less silt available for transport in subsequent years.

4.2.8.3 Long-term General Effects

Substantial changes in habitat characteristics would occur with removal of the four Lower Snake River Dams. With impoundment, the resident fish community structure is largely composed of herbivorous fish (e.g., suckers and chiselmouth) and omnivores (e.g., carp, peamouth, redside shiners, etc.) that generally feed on benthos. Under a natural river scenario, the food production of a flowing water ecosystem would be based primarily on attached organisms and drift would become a major source of nutriment for the ecosystem. The fish community would eventually revert to one more historically representative of the fish originally found in the system, such as native cyprinids (e.g., chiselmouth, redside shiners, etc.; see Li et al., 1987), with a much smaller component of selected introduced fish. In general, abundance of ictalurid fish (e.g., channel catfish and bullheads) probably would exhibit little change, whereas the relative abundance of certain centrarchid fish would drastically change. For example, suitable habitat for black and white crappie would shrink drastically and be limited to isolated, off-channel sites such as backwaters. Pumpkinseed and bluegill would be two other centrarchid fish that would decline in abundance because of the functional elimination of standing waters. The yellow perch, a percid, would substantially decrease in abundance and would be limited to backwaters that developed aquatic macrophytes.

Most of the 451+ kilometers (280+ miles) of shoreline would eventually revert to the pre-impoundment riparian character. Current estimates of future riprap coverage following dam breaching (about 72 kilometers [45 miles]) represent a reduction in bank armoring from the present 156 kilometers (97 miles) (see Appendix D.). Improved riparian habitat would result in increased organic and nutrient input to the system from grasses and leaf litter, potentially increasing system productivity. Ultimately, added riparian vegetation would increase shading of nearshore waters and potentially expand the amount of woody debris available for fish cover.

We know of no quantitative data on the resident fish community in the lower Snake River system prior to impoundment, and there is an overall paucity of data available on large, unaltered, lower elevation rivers as models for community structure. The conceptual community composition for high-order northwest streams such as the lower Snake River was developed by Li et al. (1987). However, the relative abundance of fish was generalized to the northwest region and could not be used to predict expected abundance of fish in a restored lower Snake River. As a result, we used the fish community structure of the flowing water section of the lower Snake River from Asotin, Washington, to the Oregon–Washington state line as a model to assess what changes in the resident fish community would occur if dam removal were implemented. Current knowledge of the lower Snake River system and the 48-km (30-mile) section of the flowing Snake River suggests that these adjacent areas are more comparable than either the Hanford Reach of the Columbia River or reaches further upstream in the Snake River (Glenn Mendel and Art Viola, Washington Department of Fisheries and Wildlife, and Larry Barrett, Idaho Department of Fish and Game, personal communication). We project that the fish community in the lower Snake River following dam removal would be similar to that in the 48-km (30-mile) free-flowing section.

We used preliminary fish community data determined by field sampling in the unimpounded portion of the Snake River upstream of Asotin, Washington (R. D. Nelle, University of Idaho, unpublished data), to project the probable community structure for a normative lower Snake River. We projected standing crops for members of the fish community for the natural river alternative from estimates of absolute abundance for smallmouth bass, fish community indices of relative abundance, and trophic position upstream of Asotin. Minor adjustments in community structure were made relative to projected habitat differences between the normative river section and the current upstream riverine section. When mean lengths of fish were not available from the unimpounded section, we used mean lengths from lower Snake River reservoir studies (Bennett et al., 1983, 1988, 1993). Weights were computed from weight–length equations from Little Goose Reservoir (Bennett et al., 1983) and Carlander (1978).

The fish community of Lower Granite Reservoir is compared to the projected fish community in the unimpounded Snake River above Asotin in Table 4-4. The drawdown will result in a large loss of aquatic surface area. When projecting community biomass estimates after drawdown it is, therefore, possible for standing crop, expressed as kilograms/hectare or pounds/acre, to increase, but biomass on a linear basis, kilograms/kilometer (kg/km) or pounds/mile, to decrease. The term "standing crop" refers to biomass per unit of surface area, whereas linear biomass refers to biomass per unit of stream length.

Projected standing crop of the fish community in the normative river would be higher than under the current reservoir conditions. Standing crop in the reservoirs was estimated at 50.9 kilograms/hectare (45.4 pounds/acre) from data collected by Bennett et al. (1983, 1986, 1990; Table 4-4), whereas estimated standing crop in the flowing water section would be about 85 kilograms/hectare (75.9 pounds/acre). Our analyses suggested that the resident fish community would be dominated by herbivores and omnivores such as suckers, chiselmouth, and common carp that would account for about 61 percent of the biomass. Suckers would be very abundant, whereas common carp would be represented by fewer, but very large, individuals. White sturgeon would also be a dominant member of the fish community because of their large body size. In contrast, standing crops of most centrarchid fish such as crappie, largemouth bass, bluegill, and pumpkinseed would be reduced because of their need for standing water habitat (i.e., backwaters) for spawning. Salmonids represented in the standing crop estimates are considered seasonal residents, as water temperatures would create unsuitable habitat conditions during the warmer summer months.

Estimates of predator community linear biomass indicate a probable net decrease under riverine conditions, although northern pikeminnow and smallmouth bass standing crops (kilogram/hectare) are anticipated to increase and be similar between species (Table 4-4). Estimates of smallmouth bass from the riverine section suggested that smallmouth bass standing crops would be about 7 kilograms/hectare (6.2 pounds/acre) in the normative river, compared to about 1 kilogram/hectare (0.9 pounds/acre) under current reservoir conditions. Among catfish, channel catfish biomass should not change appreciably, but biomass of bullheads, less tolerant of lotic conditions, should decline.

As a result, cumulative predator community biomass on a linear scale (kilograms/kilometer) should decrease for smallmouth bass, northern pikeminnow, and channel catfish.

In summary, we believe that the post-drawdown fish community in the lower Snake River would eventually be similar to that shown in Table 4-4. Factors that would affect the long-term fish community abundance and composition are similar to those that would ultimately influence running water systems. These factors would include events on a large spatial scale such as floods, droughts, and land-use practices. Substantial changes in community structure would occur with removal of the four lower Snake River Dams due to an altered mosaic of mesohabitat features. Community composition following drawdown would be substantially altered to favor fish that are generalists (e.g., smallmouth bass, northern pikeminnow, and suckers) or riverine specialists, whereas specialists that require standing waters would encounter a less favorable environment.

Table 4-4. Comparison of Estimated Biomass for Native and Introduced Resident Fish in the Free-flowing Snake River above Asotin and in Lower Granite Reservoir

	Free-flowing Snake River		Lower Granite Reservoir	
Species	**Kg/ha**	**Kg/km**	**Kg/ha**	**Kg/km**
Sucker spp.	42.0	596.4	28.5	1,634.7
Northern pikeminnow	8.0	113.6	3.5	200.7
Common carp	4.0	56.8	1.8	101.5
Smallmouth bass	7.0	99.4	1.0	58.5
Chiselmouth	6.0	85.2	5.0	286.8
White sturgeon	5.0	71.0	0.4	21.8
Peamouth	2.0	28.4	3.0	172.1
Mountain whitefish[a]	3.0	42.6	0.1	6.3
Catfish/bullheads	1.5	21.3	2.8	161.7
Rainbow trout[a]	2.0	28.4	NA	NA
Redside shiner	1.0	14.2	NA	NA
Crappie spp.	0.1	1.4	0.3	18.9
Bull trout[a]	0.1	1.4	NA	NA
Other centrarchids[b]	0.5	7.1	1.3	74.6
Yellow Perch	NA	NA	2.9	163.5
Other cyprinids; sculpins	2.5	35.5	0.3	17.2
Totals	84.7	1,202.7	50.9	2,918.3

Note: Projected based on raw data provided by R. D. Nelle, University of Idaho

a. Seasonal residents

b. Pumpkinseed, bluegill, and warmouth

Riverine specialists such as the native cyprinids speckled dace, chiselmouth, redside shiner, and sculpins would probably exhibit significant increases in abundance under the drawdown alternative. Dams have significantly altered the habitat of riverine specialists, and removal of the dams would recreate more favorable habitat conditions. However, elevated water temperatures during the summer would probably preclude permanent residence of native salmonids such as bull trout and mountain whitefish. These salmonids might inhabit the restored river section only from late fall through early summer when water temperatures would be within their suitable ranges.

The white sturgeon is another riverine specialist that should benefit from dam removal. White sturgeon typically rear in the more lotic areas of Lower Granite Reservoir (e.g., Clarkston, Washington, vicinity; Lepla, 1994) and tend to occur more in the tailwaters of other Snake River reservoirs. Dam removal would enhance their ability to move long in-river distances, eliminate isolation of potential spawning-size individuals, and might create additional spawning habitat.

White sturgeon require fast-moving water for spawning. For example, most observations of newly spawned white sturgeon eggs in the lower Columbia River were near 2.0 meters/second (6.5 feet/second: Parsley et al., 1993). Modeled river velocity data for the restored lower Snake River suggests about 30 percent of the reach may provide velocities greater than 1.5 meters/second (5.0 feet/second) (Figure 4-2).

Flow augmentation could have further effects on the fish community beyond that of changing from a lacustrine system to a lotic system. One of the unknowns is the timing of flow augmentation from the April through August smolt outmigration period, particularly releases that occur from Dworshak Reservoir. Flow augmentation during spring out-migration of salmonids would probably have minimal effects on the fish community. Under an early spring (April to May) flow augmentation scenario, the influence of temperature changes would be minimized, and we believe that the community structure and relative abundance of resident fish that would develop following drawdown would reflect the fish community as depicted for the 48-kilometer (30-mile) reach in Table 4-4. However, deviation from the natural timing of peak flows (i.e., emphasis on late spring or summer flow augmentation from Dworshak Reservoir) could have significant effects on the timing of various life cycle events of the resident fish, principally spawning. The major feature of summer flow augmentation that could result in substantial fish community composition changes would be rapid, repeated declines in water temperature. Although temperature declines during spawning are relatively common occurrences in natural streams (during spates, etc.), the relatively long duration of augmentation events relative to spates means a longer interruption in ascending, early summer water temperatures that stimulate spawning and impact food production and growth. Therefore, flow augmentation scheduling that would maintain lower water temperatures in the late spring and summer could result in community structure changes beyond those solely from the drawdown.

Following drawdown, the cooling effects of flow augmentation provided largely from Dworshak Reservoir in late spring or summer might magnify impacts to resident fish. The huge volumes of the lower Snake River reservoirs serve to moderate Dworshak effects; it takes longer to cool a large body of water, and the amount of cooling achieved is lower. We expect that the smaller volume of the restored lower Snake River would react more quickly and severely to Dworshak releases if the flow augmentation volumes provided remained the same.

4.2.8.4 Expected Habitats and Fish Habitat Preferences

Habitat preferences of smallmouth bass, including the importance of stream gradient or velocity, have been widely assessed in the literature. Carlander (1975) reported that smallmouth bass require lotic systems with moderate current. Paragamian (1987) reported that stream gradients of 0.07 to 4.7 meters/kilometer (4 to 25 feet/mile) (0.08 to 0.47 percent gradient) were preferred by smallmouth bass. Edwards et al. (1983) indicated that gradients of 0.08 to 0.46 percent were the optimum, while those steeper or lesser were less suitable for smallmouth bass. Rankin (1986) reported preferred velocities for smallmouth bass less than 0.15 meters/second (0.5 feet/second) but rarely higher than 0.20 meters/second (0.67 feet/second).

Studies with northern pikeminnow have largely focused on their habitation of areas surrounding dams in the Columbia River Basin using radio telemetry. Faler et al. (1988) reported that northern pikeminnow avoided areas with velocities in excess of 1.0 meter/second (3.3 feet/second) and were rarely found in areas where water velocities exceeded 0.75 meter/second (2.5 feet/second). Other investigators have reported similar findings for northern pikeminnow in response to water velocity.

Gradients in the lower Snake River after drawdown would average lower than those considered optimum for smallmouth bass, although estimated mean predicted velocities would exceed those considered optimum. The overall gradient is predicted to average 0.053 percent, lower than the 0.08 to 0.46 percent optimum range recommended by Edwards et al. (1983) and Paragamian (1987). Average river velocities were estimated to exceed 0.6 meters/second (2.0 feet/second) for over 90 percent of the area from the confluence of the Snake and Clearwater rivers downstream to Ice Harbor Dam. However, closer examination of the gradient progression suggests that substantial gradient changes occur in several specific locations, e.g., Texas Rapids near Starbuck, Washington, between Chief Timothy Park and Clarkston, Washington. Gradients in these locations are nearly 0.4 percent and ostensibly weight the average gradient estimation for the proposed drawdown section. Velocity model predictions indicate average river velocities would likely exceed those considered to be preferred by smallmouth bass and northern pikeminnow, although suitable habitat for these species would exist along river margins, other areas outside of the main current, and behind cover. For example, any large boulders throughout this section would provide suitable habitat on the downstream side, similar to those being used by smallmouth bass and northern pikeminnow in the free-flowing reach upstream of Asotin, Washington (R. D. Nelle, University of Idaho, personal observation). As a result of use of cover objects, predicted river gradient and relatively high river velocities would not be likely to overly restrict habitat use by these two fish.

Similar suitability data are not as widely available to project the effects of pronounced habitat changes (i.e., substantially increased velocities) on the likely distribution of channel catfish. Unpublished data from unchannelized portions of the Missouri River in Nebraska suggest that adult channel catfish prefer velocities less than 0.3 meters/second (1.0 feet/second) (Kallemyn and Novotny, U. S. Fish and Wildlife File No. R0024). Juvenile channel catfish seem more plastic, preferring habitats with water velocities less than 0.46 to 0.61 meters/second (1.5 to 2.0 feet/second) (Hilgert, 1981). Based on modeled velocities, about 90 percent of restored riverine habitat is predicted to exceed 0.6 meters/second (2.0 feet/second). Channel catfish would be restricted to main channel borders, other off-channel sites, and areas of low velocity such as those associated with cover objects. In particular, woody structure that creates cover and scour habitats has been found to be a particularly important habitat component to channel catfish in streams (Paragamian, 1990). However, we do not anticipate extensive permanent accumulations of woody debris throughout the restored reach. In addition, because channel catfish generally are considered bottom fish, water velocities immediately above the substrate may also be suitable.

White sturgeon distribution in a restored lower Snake River may be inferred from data reported in Haynes et al. (1978) and Parsley et al. (1993). Juveniles were collected in the lower Columbia River below Bonneville Dam mostly from deep water (15 to 20 meters [50 to 65 feet]) within the thalweg, at near-substrate velocities centered at about 0.6 meter/second (about 2 feet/second). Adults should also be found principally in deeper water. However, movement of white sturgeon throughout a free-flowing lower Snake River should be common. White sturgeon exhibited upstream and downstream seasonal movements in summer and early fall that averaged 40.2 kilometers (25 miles) in the Hanford Reach of the mid-Columbia River (Haynes et al., 1978). Adults will also move to fast-water spawning areas in spring, where mean column velocities may be up to 1.8 to 2.4 meters/second (6 to 8 feet/second) (Parsley et al., 1993). In the lower Snake River, the steeper gradient areas as found near Texas Rapids (Lower Monumental reach), above Chief Timothy Park (Lower Granite reach), and near Fishhook Park (Ice Harbor reach) may support such velocities and would probably serve as significant spawning areas. Habitat under a drawdown alternative would be more suitable than under the current lacustrine conditions.

In summary, the relatively low velocity preferences of smallmouth bass, northern pikeminnow, and channel catfish suggest that all three species would seek areas expected to be of limited availability. These areas would include pool edges and complex-type habitats (backwaters, sloughs, and island complexes). In addition, areas of instream cover offering a velocity shelter, such as large boulders and woody debris would be important to these three species. In contrast, white sturgeon would be expected to generally prefer main channel areas, although specific areas would vary according to season and life stage.

4.2.8.5 Long-term Impacts to Key Species

Smallmouth Bass

Data recently collected from the free-flowing Snake River upstream of Lower Granite Reservoir indicated that smallmouth bass standing crop would probably increase after drawdown. Smallmouth bass standing crop in the flowing water reach of the Snake River from Asotin to the Washington–Oregon state line was higher (R.D. Nelle, University of Idaho, unpublished data) than that found in Lower Granite Reservoir (Anglea, 1997), suggesting that the smallmouth bass population would likely increase above that currently in the reservoirs. Standing crop estimates were also approximately five times higher in this flowing water section than in Lower Granite Reservoir. Therefore, we believe the abundance of smallmouth bass would increase as a result of drawdown. Our projections are supported by higher smallmouth bass abundance in Lower Granite Reservoir than the other three downstream reservoirs (Zimmerman and Parker, 1995; Normandeau Associates et al., 1998a). Lower Granite Reservoir is the most lotic in character among lower Snake River reservoirs.

One of the major obstacles to predicting future abundance of smallmouth bass is the influence exerted by low water temperatures due to flow augmentation from Dworshak Reservoir. Properly timed releases (for juvenile salmonids) from Dworshak Reservoir could result in reduced thermal units that would reduce growth rates, retard the normal timing of reproduction, and result in higher than “normal” mortality in younger age classes (Coble, 1975). Present volumes of flow augmentation would exert greater cooling influence due to the reduced water volume of a restored lower Snake River.

White and Black Crappie

The abundance of white and black crappie, although not high in the lower Snake River reservoirs, would certainly decrease because of habitat loss under the drawdown alternative. Crappie are found in highest abundance in lower Snake River reservoirs in backwaters (Bennett et al., 1983). Preliminary morphometry information suggests that much of the restored lower Snake River would be low gradient, yet would support moderate or higher current velocities. Thus, crappie habitat would be greatly reduced and largely restricted to a limited number of backwaters. Crappie spawn in the spring when main channel velocities are typically highest. Water velocity would be sufficiently low, and planktonic food production would be higher in remaining backwaters, but the expected severe reduction in the amount of favorable habitat would substantially decrease the crappie community.

Largescale and Bridgelip Sucker

The absolute abundance of suckers in the lower Snake River reservoirs is unknown, although localized abundance in Deadman Bay was quantified in 1979 and 1980 (Bennett et al., 1983). Recent studies by University of Idaho personnel indicate that sucker standing crop in the flowing waters upstream of Lower Granite Reservoir probably exceeds that in the lower Snake River reservoirs (R.D. Nelle, University of Idaho, unpublished data). Suckers are habitat generalists and probably food-limited under current reservoir conditions. Their principal food items, diatoms and algae (Bennett et al., 1983), would probably increase under natural river flow. Therefore, available data indicate that standing crop of the sucker community made up by bridgelip and largescale suckers would probably increase if the drawdown alternative were selected.

Northern Pikeminnow

Although no study has been conducted that compares the population structure and abundance of northern pikeminnow in lacustrine ecosystems with that in lotic ecosystems, limited data suggest that the current northern pikeminnow standing crop may be higher in the flowing portions of the Snake River than in the reservoirs. Catch per effort data in the flowing portion of the Snake River upstream of Lower Granite Reservoir are generally comparable to those for smallmouth bass (R. D. Nelle, University of Idaho, unpublished data). Northern pikeminnow spawning should benefit from more flowing water habitat (BPA, 1995). Sport reward anglers specifically targeted northern pikeminnow in the free-flowing Snake River upstream of Asotin during 1997 (Normandeau Associates et al., 1998a, b). These very limited data indicate that northern pikeminnow standing crop probably would also be higher in a restored Snake River. Whether northern pikeminnow would continue as the focus of the sport reward program would also determine their ultimate abundance after drawdown.

White Sturgeon

Conversion of the lower Snake River reservoirs to a lotic environment would enhance the white sturgeon population. Increased population abundance through increased recruitment would occur with drawdown. Recruitment is not limited in Lower Granite Reservoir (Lepla, 1994), probably because of recruitment from upstream areas of the free-flowing mid-Snake River (i.e., Hells Canyon), but most likely is in the other reservoirs. Beamesderfer et al. (1995) showed that white sturgeon in lower Columbia River reservoirs were isolated by dams, and the populations in each of the reservoirs reflected the presence or absence of suitable spawning habitat. Also, Lepla (1994) showed that the abundance of white sturgeon in Lower Granite Reservoir downstream of the influence of the Snake and Clearwater rivers was very low. Most (56 percent) sturgeon collected were sampled from a relatively small area in upper Lower Granite Reservoir near the Port of Wilma and Red Wolf Crossing. White sturgeon would also benefit from enhanced abundance of crayfish, one of the most important food items of white sturgeon. Lepla (1994) and Anglea (1997) found crayfish abundance was also highest in uppermost Lower Granite Reservoir. Habitat suitability is likely related to the higher crayfish abundance in the upper section of Lower Granite Reservoir. The signal crayfish, *Pacifastacus leniusculuss*, the species of crayfish found in the Snake River, is a non-burrowing, cover-seeking form. Under riverine conditions, fine sediments would be removed from the substrate, and larger sized substrate would remain. This would provide expanded habitat for the crayfish.

Channel Catfish

Projections of channel catfish abundance are difficult because of the paucity of comparative data between flowing waters of the Snake River and the lower Snake River reservoirs. A number of indications however, suggest that their abundance may remain similar or increase slightly relative to current reservoir abundance (although the bullhead community would decrease). Channel catfish are one of the prominent species currently caught in the flowing section of the mid-Snake River, upstream of Lower Granite Reservoir (Normandeau Associates, unpublished data). Their relative abundance was highest in the spring in the tailwater in Little Goose Reservoir (Bennett et al., 1983). Physical habitat conditions would not be appreciably different between the restored lower Snake River, the dam tailwaters, and the free-flowing Snake River upstream of Lower Granite Reservoir. Feeding conditions might also improve. Channel catfish feed heavily on crayfish that, as indicated for smallmouth bass, would likely increase in abundance in the long term following drawdown. Therefore, channel catfish standing crop would not change appreciably and could possibly increase after drawdown. As a caution, however, a restored lower Snake River would be subject to cooling augmentation flows from Dworshak Reservoir that do not affect the mid-Snake River. Optimum temperatures for most channel catfish life history processes are higher than for many other resident species, including smallmouth bass. As a result, cooling augmentation flows might affect channel catfish more severely than smallmouth bass.

4.2.8.6 Anticipated Predation on Juvenile Salmonids After Drawdown

Several factors must be considered when projecting predation on juvenile salmonids following removal of the lower Snake River Dams. As indicated earlier, the biomass of northern pikeminnow and smallmouth bass, the two most significant predators of juvenile salmonids in lower Snake River reservoirs, would be expected to decrease after drawdown. However, comparisons of standing crop in the flowing water section upstream of Lower Granite Reservoir with that in Lower Granite Reservoir suggest that the standing crop (density) of smallmouth bass would probably be higher for the drawdown alternative. Similarly, the standing crop of northern pikeminnow would probably increase. As a result, the standing crops of significant predators would probably be higher after drawdown.

Factors that limit the predator populations are not known. The empirical data from fish collections in the flowing water section upstream of Asotin, Washington (R. D. Nelle, University of Idaho, unpublished data) and model predictions of future river productivity (see "Lower Snake River Water Quality and Post-Drawdown Temperature and Biological Productivity Modeling Study" by Normandeau Associates, Inc. et al., 1999, Appendix C, Water Quality, Exhibit A) have indicated that herbivorous and benthivorous fish that tolerate lotic conditions would likely increase in abundance following dam removal. Those fish, such as most centrarchids, that require low velocities to complete their life history would likely decrease in abundance. Although walleye have never been sampled by scientific methods in the lower Snake River reservoirs, their potential for remains relatively high under reservoir conditions. However, suitable habitat under a drawdown scenario would be very low, and, without an upstream source of recruitment, their numbers are anticipated never to increase. Both smallmouth bass and northern pikeminnow are predatory fish that are typically associated with slower (less than 0.9 meters/second [3 feet/second]) water velocities. Both are considered habitat generalists and, therefore, have prospered under lacustrine and lotic conditions. However, the majority of restored riverine habitat has projected water velocities in excess of approximately 0.9 meters/second (3 feet/second), substantially higher than the preferred velocity for both northern pikeminnow and smallmouth bass. The factors that will limit both of these species will likely be suitable rearing habitat for pre-adult life history stages.

The future abundance and distribution of non-salmonid prey, including American shad, will likely affect predatory pressure on salmonid juveniles and possibly population abundance of resident predators. Some potential non-salmonid prey fish may be segregated from predators under current reservoir conditions. For example, young suckers were common in fisheries sampling, but uncommon as food items of smallmouth bass in Lower Granite Reservoir (Bennett et al., 1988). Similarly, redside shiners were an abundant pelagic species in the Lower Granite tailwater, but are unimportant as smallmouth bass prey. Restoration of the lower Snake River would eliminate most deep water (greater than 15.2 meters [50 feet]) and reduce the total amount of habitat, potentially reducing the segregation of young suckers and other possible prey species from predators such as smallmouth bass and northern pikeminnow. Whether the increased exposure of young suckers (and other young fish) to predation in generally shallower habitats would reduce predation pressure on juvenile salmonids is unknown, but is not likely. Food habits of smallmouth bass in the unimpounded section upstream of Asotin, before Lower Granite Dam, suggest low consumption of native non-salmonid fish (Keating, 1970). Nelle (1999) also reported about 55 percent of the smallmouth bass consumption consisted of “other fish” (non-salmonids), although he did not specify the proportion of native versus non-native fish.

Several factors related to water quality also have to be considered in assessments of predation after drawdown. Both northern pikeminnow and smallmouth bass are sight feeders. Reservoirs create conditions highly favorable for reduced turbidities; lower water velocities and retention of waters permit sand, silts, and clays to settle and to reduce turbidity. If the reservoirs were removed, turbidity would increase substantially throughout the lower Snake River in spring during the bulk of the juvenile steelhead and yearling chinook salmon emigration. Under flowing water conditions, velocities would be higher, and the finer particles would remain suspended, resulting in higher turbidities. Higher velocities coupled with turbidity would decrease the ability of smallmouth bass and northern pikeminnow to see the juvenile salmonids, reducing feeding efficiency and, thus, overall predation. Although we also anticipate that free-flowing waters could warm faster under a natural river alternative, leading to an increase in metabolic activity and, potentially, predation, the higher turbidities would probably reduce this potential.

In contrast, predation may increase on subyearling chinook salmon as a result of drawdown. Subyearling chinook salmon rear in the lower Snake River in summer when flows and turbidities have generally subsided (Connor et al., 1998). This behavior would probably increase their susceptibility to predation. Reduced summer flows would increase the potential for a predatory encounter by increasing the proximity of predator and prey. The metabolic needs of predators are also higher due to higher summer water temperatures.

Other introduced resident fish would probably have less predatory influence after drawdown. Decreases in suitable habitat for introduced fish such as crappie and yellow perch would probably decrease their predation potential, although it is currently minimal. Population abundance of these fish would be substantially reduced; therefore, fewer individuals of these predators would be available. Predation by channel catfish would probably remain constant, although higher spring turbidities may decrease their ability to prey on juvenile steelhead and yearling chinook salmon. In contrast, higher water temperatures in summer would increase their metabolic activity and result in higher predation on subyearling chinook salmon throughout the latter period of downstream juvenile migration.

4.2.8.7 Cumulative Effects

Removal of the four lower Snake River Dams would reverse effects of nearly 40 years of impoundment and create a swift, lotic system that would support a markedly altered community of resident fish. Large populations of some introduced fish such as crappie and sunfish would be replaced by mostly native species. Other introduced fish such as smallmouth bass and channel catfish could continue to flourish, although perhaps not to the degree suggested by standing crop estimates (Table 4-4) in the free-flowing river above Asotin. The reason for this cautious outlook is continued flow augmentation releases planned from Dworshak Reservoir. The cooling effects of these releases would likely create a lotic system with a lower potential for summer warming than in the unimpounded Snake River above Asotin. However, populations of those fish that would benefit from prolonged, cooler water temperatures should be enhanced. These include early native spawners such as bridgelip sucker, white sturgeon, and sculpins.

The cooler water temperatures due to Dworshak releases also might affect productivity and the length of the growing season in the normative river compared to the potential productivity and growing season of the river without artificial cooling flows. Reduced productivity could result in slower growth of remaining native species. A shorter growing season could lead to higher over-winter mortality due to smaller young-of-year fish entering their first winter.

5. Comparison of Alternatives

In summary, Alternatives A-1, A-2, A-2a, A-2b, A-2c, and A-6b are dam-in-place alternatives that are expected to result in little or no detectable, long-term changes to resident fish populations. Although the dams would also remain, Alternative A-6a, in contrast, has the potential to alter resident fish communities due to effects of an additional 1.0 MAF of flow augmentation from April to August. Higher flows through the reservoirs would enhance water velocities and potentially benefit native resident fish at the expense of introduced resident fish.

Alternative A-3 would remove the four dams on the lower Snake River and would induce the most dramatic changes to resident fish populations. Fish community structure would be altered to favor riverine generalists (e.g., suckers and smallmouth bass) and riverine specialists (e.g., white sturgeon and speckled dace). In particular, the native fish component would be enhanced because of the expansion of suitable habitats, whereas most of the introduced fish component would shrink due to severe habitat loss. Two significant predators on juvenile salmonids (northern pikeminnow and smallmouth bass) should also increase in abundance. Under Alternative A-3, the thermal regime of a restored lower Snake River would continue to be affected by flow augmentation. Interruptions of spring and summer warming by augmentation releases would negatively affect native and, especially, introduced resident fish.

6. Literature Cited

Anglea, S. R. 1997. Abundance, food habits and salmonid fish consumption of smallmouth bass and distribution of crayfish in Lower Granite Reservoir, Idaho-Washington. Master’s thesis, University of Idaho, Moscow.

Apperson, K. A. 1990. Kootenai River white sturgeon investigations and experimental culture. Annual progress report to Bonneville Power Administration (Project No. 88-65). Portland, Oregon.

Austen, D. J., P. B. Bayley, and B. W. Menzel. 1994. Importance of the guild concept to fisheries research and management. Fisheries 19(6): 12-20.

Beamesderfer, R. C. and B. E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Beamesderfer, R. C. P. Rien, A. Thomas, A. A. Nigro. 1995. Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. Transactions of the American Fisheries Society 124:857-872.

Bennett, D. H. 1976. Effects of pumped storage project operations on the spawning success of centrarchid fish in Leesville Lake, Virginia. Doctoral dissertation. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Bennett, D. H., P. M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of the warmwater fishery and the potential of improving warmwater fish habitat in the lower Snake reservoirs. Completion Report No. DACW68-79-C-0057. U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., J. A. Chandler, and L. K. Dunsmoor. 1991. Smallmouth bass in the Pacific Northwest: benefit or liability. First International Smallmouth Bass Symposium:126-135.

Bennett, D. H., T. J. Dresser, T. S. Curet, K. B. Lepla, and M. A. Madsen. 1993. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program Year-3 (1990). U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., T. J. Dresser, Jr., and M. A. Madsen. 1994. Evaluation of the 1992 drawdown in Lower Granite and Little Goose reservoirs. Completion Report. U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., T. J. Dresser, Jr., and M. A. Madsen. 1994. Effects of reservoir operations at minimum pool and regulated inflows of low temperature water on resident fish in Lower Granite Reservoir, Idaho-Washington. Completion Report (Draft). U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., T.J. Dresser, Jr., and M. A. Madsen. 1994. Evaluation of the effects of the 1992 test drawdown on the fish communities in Lower Granite and Little Goose reservoirs, Washington. Appendix P. prepared for Corps of Engineers, Walla Walla District, by University of Idaho, Department of Fish and Wildlife Resources.

Bennett, D. H., and T. J. Dresser Jr., and M. A. Madsen. 1998. Habitat use, abundance, timing, and factors related to the abundance of subyearling chinook salmon rearing along the shorelines of Lower Snake River reservoirs. Completion Report. Projects 14-16-0009-1559, 14-16-0009-1579, 98210-3-4037. US Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., L. K. Dunsmoor, and J. A. Chandler. 1988. Fish and benthic community abundance at proposed in-water disposal sites, Lower Granite Reservoir. Completion Report. U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., L. K. Dunsmoor, and J. A. Chandler. 1990. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 1 (1988). Completion Report. U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., M. H. Karr, and M. A. Madsen. 1994. Thermal and velocity characteristics in the Lower Snake River reservoir, Washington, as a result of regulated upstream water releases. Completion Report (Draft). U. S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., M. A. Madsen, S. M. Anglea, T. Cichosz, T. J. Dresser Jr., M. Davis, and S. R. Chipps. 1997. Fish interactions in Lower Granite Reservoir, Idaho-Washington. Projects 14-45-0009-1579 w/o 21 and 14-16-0009-1579 w/o 32 Completion Report (Draft). US Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H. and G. P. Naughton. 1998. Predator abundance and salmonid prey consumption in Lower Granite Reservoir and tailrace. Draft Completion Report. US Army Corps of Engineers, Walla Walla, Washington.

Bennett, D. H., and F. C. Shrier. 1986. Effects of sediment dredging and in-water disposal on fish in Lower Granite Reservoir, Idaho-Washington. Completion Report. U. S. Army Corps of Engineers, Walla Walla, Washington.

Bentley, W. W., E. M. Dawley, and T. W. Newcomb. 1976. Some effects of excess dissolved gas on squawfish, Ptychocheilus oregonensis (Richardson). In: Fickeisen and Schneider 1976, pages 41-46.

Blahm, T. H., R. J. McConnell, and G. R. Snyder. 1976. Gas supersaturation research, National Marine Fisheries Service Prescott Facility. In: Fickeisen and Schneider 1976, Pages 11-19.

Blair, W. F., and four co-authors. 1968. Vertebrates of the United States, 2nd ed. McGraw-Hill Book Company, New York, New York. 616 pp.

Bonneville Power Administration, U. S. Army Corps of Engineers, and U. S. Department of the Interior. 1995. Columbia River System Operation Review, Final Environmental Impact Statement. Appendix K, Resident Fish. DOE-EIS-0170.

Bratovich, P. M. 1985. Reproduction and early life histories of selected resident fish in Lower Snake River reservoirs. Master's thesis. University of Idaho, Moscow.

Buck, D.H. 1956. Effects of turbidity on fish and fishing. Transactions of the North American Wildlife Conference 21: 249-261.

Carl, G. C., W. A. Clemens, and C. C. Lindsey. 1959. The freshwater fish of British Columbia. British Columbia Province Museum Handbook No. 5.

Carlander, K. D. 1977. Handbook of freshwater fishery biology, Volume 2. The Iowa State University Press, Ames Iowa. 431 pp.

Casey, O. E. 1962. The life history of the northern squawfish in Cascade Reservoir. Master's thesis. University of Idaho, Moscow.

Chandler, J. A. 1993. Consumption rates and estimated total loss of juvenile salmonids by northern squawfish in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Chipps, S. R., D. H. Bennett, and T. J. Dresser, Jr. 1997. Patterns of fish abundance associated with a dredge disposal island: implications for fish habitat enhancement in a large reservoir. North American Journal of Fisheries Management 17: 378-386.

Cichozs, T. A. 1996. Factors limiting the abundance of northern squawfish in Lower Granite Reservoir. Master's thesis. University of Idaho, Moscow.

Coble, D. W. 1975. Smallmouth bass. Pages 21-33. in Black Bass Biology and Management. H. Clepper (ed.). Sport Fishing Institute, Washington, D.C.

Cochnauer, T. G. 1983. Abundance, distribution, growth and management of white sturgeon (Acipenser transmontanus) in the middle Snake River, Idaho. Ph.D. dissertation, University of Idaho, Moscow.

Cochnauer, T. 1995. Gas bubble trauma monitoring in the Clearwater River drainage, Idaho, 1995. Report to Bonneville Power Administration and National Marine Fisheries Service, Portland, OR. Idaho Department of Fish and Game, Lewiston, Idaho.

Connor, W. P., H.L. Burge, and D. H. Bennett. 1998. Detection of PIT-tagged subyearling chinook salmon at a Snake River Dam: implications for summer flow augmentation. North American Journal of Fisheries Management 18:530-536.

Coon, J. C. 1975. Movement, distribution, abundance and growth of white sturgeon in the mid-Snake River. Master's thesis, University of Idaho, Moscow.

Coon, J. C., R. R. Ringe, and T. C. Bjornn. 1977. Abundance, growth, distribution, and movements of white sturgeon in the mid-Snake River. Forest, Wildlife and Range Experiment Station, Contribution No.97, University of Idaho, Moscow.

Cordone, A.J., and D.W. Kelly. 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish and Game 47:189-228.

Corps (U.S. Army Corps of Engineers). 1998a. Personal communication from Pete Verhey to Terry Euston, Normandean Associates. Raw data files sent electronically July 23, 1998.

Corps. 1998b. Personal communication from Rex Baxter, Corps, to Terry Euston, Normandean Associates. Information regarding smolt collection, transportation, and bypass at Little Goose Dam excerpted from Annual Reports for 1995, 1996, and 1997 furnished in hard copy July 23, 1998.

Corps. 1998c. Personal communication from Bill Spurgeon, Corps, Lower Monumental Dam, to Terry Euston, Normandean Associates. Raw data files sent electronically during July 1998.

Corps. 1970. Influence of temperature and photoperiod on growth, food consumption, and food conversion efficiency of channel catfish. Proceedings of the 24th Annual Conference of the Southeastern Association of Game and Fish Commissioners: 519-531.

Coutant, C.1975. Response of bass to natural and artificial temperature regimes. Pages 272-285. In: Black Bass Biology and Management. H. Clepper (ed.). Sport Fishing Institute, Washington, D.C.

Curet, T. S. 1994. Habitat use, food habits and the influence of predation on subyearling chinook salmon in Lower Granite and Little Goose reservoirs, Washington. Master's thesis. University of Idaho, Moscow.

Dauble D. D. 1980. Life history of the bridgelip sucker in the central Columbia River. Transactions of the American Fisheries Society 109:92-98.

Dauble, D. D., and D. R. Geist. 1992. Impacts of Snake River drawdown experiment on fisheries resources in Little Goose and Lower Granite reservoirs, 1992. Appendix Q. Corps of Engineers Contract No. DE-AC06-76RLO 1830. Pacific Northwest Laboratory, Richland, Washington.

Dauble, D. D., R. L. Johnson, R. P. Mueller, W. H. Mavros, and C. S. Abernethy. 1996. Surveys of fall chinook salmon spawning areas downstream of Lower Snake River hydroelectric projects, 1995-1996 Season. Annual Report. Pacific Northwest Laboratory, Richland, Washington.

Dell, M. B., M. W. Erho, and B. D. Leman. 1975. Occurrence of gas bubble disease symptoms on fish in the Mid-Columbia River reservoirs. Unpublished report prepared for Public Utility Districts of Grant, Douglas, and Chelan counties, Washington.

Dresser, T. J. 1996. Nocturnal fish-habitat associations in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Dunsmoor, L. K. 1990. Relative prey importance and availability in relation to smallmouth bass growth in Brownlee Reservoir, Idaho, with notes on dietary indices. Masters thesis. University of Idaho, Moscow.

Dupont, J. M. 1994. Fish habitat associations and effects of drawdown on fish in Pend Oreille River, Idaho. Master’s thesis. University of Idaho, Moscow.

Edwards, E. A., G. Gebhart, and O. E. Maughn. 1983. Habitat suitability information: Smallmouth bass. US Department of Interior, Fish and Wildlife Service. FWS/OBS-82/10.36.

Faler, M. P., L. M. Miller, K. I. Welke. 1988. Effects of variation in flow on distributions of northern squawfish in the Columbia River below McNary Dam. North American Journal of Fisheries Management 8 (1):30-35.

Fickeisen, D. H., J. C. Montgomery, and R. W. Hanf, Jr. 1976. Effect of temperature on tolerance to dissolved gas supersaturation of black bullhead, *Ictalurus melas*. In: Fickeisen and Schneider 1976, Pages 72-74.

Fickeisen, D. H. and J. Schneider, editors. 1976. Gas bubble disease. CONF-741033, Technical Information Center, Energy Research and Development Administration, Oak Ridge, Tennessee, USA.

Friesen, T. A. and D. L. Ward. 1997. Management of northern squawfish and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. Paper No. 1, pages 5-27, In: Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.

Gray, G. A. and D. W. Rondorf. 1986. Predation on juvenile salmonids in Columbia Basin reservoirs. Pages 178-185 in Reservoir fisheries management: strategies for the 80s. American Fisheries Society, Bethesda, Maryland.

Gray, R. H. and D. D. Double. 1979. Biology of the sandroller in the central Columbia River. Transactions of the American Fisheries Society 108:646-649.

Hardy, J. D., Jr. 1978. Development of fish on the mid-Atlantic bight: At atlas of eggs, larval, and juvenile stages. Volume III. Aphredoderidae through Tachycentridae. U.S. Fish and Wildlife Service, Number FWS/OBS-78-12.

Haynes, J.M., R.H. Gray, and J.C. Montgomery. 1978. Seasonal movements of white sturgeon (Acipenser transmontanus) in the mid-Columbia River. Transactions of the American Fisheries Society 107:275-280.

Henderson, C. and R. F. Foster. 1957. Studies of smallmouth black bass (Micropterus dolomieui) in the Columbia River near Richland, Washington. Transactions of the American Fisheries Society 83:112-127.

Hilgert, P. 1981. Evaluation of instream flow methodologies for fisheries in Nebraska. Nebraska Technical Series No. 10, Nebraska Game and Parks Commission. Lincoln, Nebraska. 50pp.

Hjort, R. C., and nine co-authors. 1981. Habitat requirements for resident fish in the reservoirs of the lower Columbia River. Report by Oregon State University to the Walla Walla District, U.S. Army Corps of Engineers, Contract No. DACW57-79-C-0067.

Jeppson, P. W. and W. S. Platts. 1959. Ecology and control of the Columbia squawfish in northern Idaho lakes. Transactions of the American Fisheries Society 88:197-202.

Karr, M. K., B. Tanovan, R. Turner, and D. H. Bennett. 1992. Water temperature control project, Snake River Interim report: Model studies and 1991 operations. Columbia River Inter-Tribal Fish Commission, U.S. Army Corps of Engineers, and University of Idaho, Moscow.

Keating, T. F., Jr. 1970. Growth rates and food habits of smallmouth bass in the Snake, Clearwater, and Salmon rivers, Idaho 1965-67. Master's thesis, University of Idaho, Moscow.

Kenney, D., T. Wik, and J. Dedloff. 1989. Snake River embayment survey, river miles 59 to 90, 1988-1989. U.S Army Corps of Engineers, Walla Walla District. 45 pp.

Knox, W. J. 1982. Angler use, catch and attitudes on Lower Snake River reservoirs, with emphasis on Little Goose Reservoir. Master's thesis. University of Idaho, Moscow.

Knutsen, C. J. and D. L. Ward. 1997. Biological characteristics of northern squawfish in the lower Columbia and Snake rivers before and after sustained exploitation. Paper No. 3, pages 51-68, In: Ward. D. L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.

Lawrence, J. M. 1957. Estimated sizes of various forage fish largemouth bass can swallow. Proceedings of the 11th Annual Conference Southeastern Association of Fish and Wildlife Agencies: 220-225.

Leonard, P. M., and D. J. Orth. 1988. Use of habitat guilds to determine instream flow requirements. North American Journal of Fisheries Management 8: 399-409.

Lepla, K. B. 1994. White sturgeon abundance and associated habitat in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.

Li, H. W., C. B. Schreck, C. E. Bond, and E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. Pages 193-202 in W.J. Matthews and D.C Heins, editors. Community and evolutionary ecology of North American stream fish. University of Oklahoma Press, Norman, Oklahoma.

Lobb III, M. D., and D. J. Orth. 1991. Habitat use by an assemblage of fish in a large warmwater stream. Transactions of the American Fisheries Society 120: 65-78.

Lukens, J. R. 1984. Hells Canyon white sturgeon investigations. Idaho Department of Fish and Game, River and Stream Investigations, Job Performance Report, Project No. F-73-R-B. Idaho Department of Fish and Game, Boise.

MacPhee, C. 1960. Postlarval development and diet of the largescale sucker, *Catostomus macrocheilus*, in Idaho. Copeia 1960:119-125.

Meekin, T. K., and B. K. Turner. 1974. Tolerance of salmonid eggs, juveniles, and squawfish to supersaturated nitrogen. Washington Department of Fisheries Technical Report 12:78-126.

Montgomery, J. C. and C. D. Becker. 1980. Gas bubble disease in smallmouth bass and northern squawfish from the Snake and Columbia rivers. Transactions of the American Fisheries Society 109:734-736.

National Marine Fisheries Service (NMFS). 1995. Endangered Species Act-Section 7: biological opinion. Reinitiation of consultation on 1994-1998 operation of the FCRPS and juvenile transportation program in 1995 and future years. NMFS, Portland, Oregon.

National Marine Fisheries Service (NMFS). 1998. Endangered Species Act-Section 7: Supplementary Biological Opinion. NMFS, Portland, Oregon.

Naughton, G. 1998. Predator abundance and salmonid prey consumption in the tailrace and forebay of Lower Granite Dam and the upper arms of Lower Granite Reservoir. Master's thesis. University of Idaho, Moscow.

Nebeker, A. V., A. K. Hauck, F. D. Baker, and S. L. Weitz. 1980. Comparative responses of speckled dace and cutthroat trout to air-supersaturated water. Transactions of the American Fisheries Society 109:760-764.

Nelle, R. D. 1999. Smallmouth bass predation on juvenile fall chinook salmon in the Hells Canyon Reach of the Snake River, Idaho. Draft Master's thesis. University of Idaho, Moscow.

Nelson, J. S. and five co-authors. 1998. Recommended changes in common fish names: pikeminnow to replace squawfish (*Ptychocheilus* spp). Fisheries 23(9):37.

Nelson, W. R., R. E. Siefert, and D. V. Swedberg. 1967. Studies of the early life history of reservoir fish. Pages 375-385 In: Fishery Resources Symposium. American Fisheries Society. Washington, D.C.

Newcombe, C.P. and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16:693-727.

Normandeau Associates, Inc., University of Idaho, and Agricultural Enterprises, Inc. 1998a. Sport Fishery Use and Value on Lower Snake River Reservoirs. Phase I report: Part 1 of 2. Reservoir sport fishery during 1997. Contract No. DACW68-96-D-0003. US Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Normandeau Associates, Inc., University of Idaho, and Agricultural Enterprises, Inc. 1998b. Sport Fishery Use and Value on the Free-flowing Snake River above Lewiston, Idaho. Phase II report: Part 1 of 2. Free-flowing river sport fishery during 1997-1998. Contract No. DACW68-96-D-0003. US Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Normandeau Associates, Inc., and U.S. Army Corps of Engineers, in association with Foster Wheeler Environmental Corp., Washington State University, University of Idaho, and FTN Associates. 1999. Lower Snake River Water Quality and Post-drawdown and Biological Productivity Modeling Study. Pre-decisional Draft Document. Contract No. DAC 2W68-96-D-0003. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

Paragamian, V.L. 1987. Production of smallmouth bass in the Maquoketa River, Iowa. Journal of Freshwater Ecology 4(1): 141-148.

Paragamian, V.L. 1990. Characteristics of channel catfish populations in streams and rivers of Iowa with varying habitats. Journal of the Iowa Academy of Science 97(2):37-45.

Paragamian, V. L. 1991. Stream sedimentation and abundance of smallmouth bass. Pages 55-60 in D.C. Jackson, editor. The First International Smallmouth bass Symposium. American Fisheries Society, Bethesda, Maryland.

Parker, R. M., M. P. Zimmerman, and D. L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124: 335-346.

Parsley, M. J., L. G. Beckman, and G. T. McCabe, Jr. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society 122:217-227.

Parsley, M. J, and L. G. Beckman. 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management 14:812-827.

Patten, B. G. and D. T. Rodman. 1969. Reproductive behavior of the northern squawfish, *Ptychocheilus oregonensis*. Transactions of the American Fisheries Society 98:108-111.

Pflieger, W. L. 1975. Reproduction and survival of the smallmouth bass in Courtois Creek. Pages 231-239. In: Black Bass Biology and Management. H. Clepper (ed.). Sport Fishing Institute, Washington, D.C.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fish on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420.

Rankin, E. T. 1986. Habitat selection by smallmouth bass in response to physical characteristics in a natural stream. Transactions of the American Fisheries Society 115(2): 322-334.

Reynolds, J. B. 1965. Life history of smallmouth bass, Micropterus dolomieui Lacepede, in the Des Moines River, Boone County, Iowa. Iowa State Journal of Science 39:417-436.

Schuck, M. L. 1992. Observations of the effects of reservoir drawdown on the fishery resource behind Little Goose and Lower Granite Dams, March 1992. Washington Department of Wildlife, Dayton, Washington. 12 pp. + appendices.

Scott, W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. Ottawa. 966 pp.

Siefert, R. E. 1968. Reproductive behavior, incubation, and mortality of eggs, and post larval food selection in the white crappie. Transactions of the American Fisheries Society 97:252-259.

Simpson, J. and R. Wallace. 1978. Fish of Idaho. University of Idaho Press. Moscow.

Smith, C. L. 1985. The inland fish of New York State. The New York State Department of Environmental Conservation, Albany. 522 pp.

Smith, S. S. 1996. Analysis of hybridization between northern squawfish and chiselmouth in Lower Granite Reservoir, Washington. Masters Thesis. University of Idaho, Moscow.

Stewart, K. W. 1966. A study of hybridization between two species of cyprinid fish, *Acrocheilus alutaceus* and *Ptychocheilus oregonensis*. Doctoral dissertation. University of British Columbia, Vancouver.

Timmons, T. J. and Pawaputanon. 1981.Relative size relationship in prey selection by largemouth bass in West Point Lake, Alabama-Georgia. Proceedings of the 34th Annual Conference Southeastern Association of Fish and Wildlife Agencies: 248-252.

Timmons, T. J, W. L. Shelton, and W. D. Davies. 1980. Differential growth of largemouth bass in West Point Reservoir, Alabama-Georgia. Transactions of the American Fisheries Society 109:176-186.

Trautman, M. B. 1981. The fish of Ohio. Ohio State University Press, Columbus.

Turner, G. E. and H. R. McCrimmon. 1970. Reproduction and growth of smallmouth bass, *Micropterus dolomieui*, in a pre-cambrian lake. Journal of the Fisheries Research Board of Canada 27:395-400.

Turner, P. R. and R.C. Summerfelt. 1971. Reproductive biology of the flathead catfish *(Pylodictus olivaris)* in a turbid Oklahoma reservoir. Pages 107-120 In: G. E. Hall, editor. Reservoir fisheries and limnology. Special Publication No. 8, American Fisheries Society. Washington, D.C.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Vinyard, G. L. and R. K. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill *(Lepomis macrochirus)*. Journal of the Fisheries Research Board of Canada 33(12):2845-2849.

Ward, D. L., J .H. Peterson, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Transactions of the American Fisheries Society 124:3211-334.

Ward, D. L. and M. P. Zimmerman. 1997. Response of smallmouth bass to sustained removals of northern squawfish in the lower Columbia and Snake rivers. Paper No. 4, pages 69-89, In: Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.

Wallen, H.B. 1951. The direct effect of turbidity on fish. Oklahoma Agriculture and Mechanical College, Arts and Sciences Studies, Biological Series 2, Bulletin 48:1-27.

Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

Werner, R. G. 1967. Intralacustrine movements of bluegill fry in Crane Lake, Indiana. Transactions of the American Fisheries Society 96:416-420.

Winemiller, K. O., and D. H. Taylor. 1987. Predatory behavior and competition among laboratory-housed largemouth and smallmouth bass. American Midland Naturalist 117:148-166.

Zimmerman, M. P. and R. M. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the lower Columbia and Snake rivers. Northwest Science 69(1): 19-28.

Zimmerman, M. P. and D. L. Ward. 1997. Index of predation on juvenile salmonids by northern squawfish in the lower Columbia River basin from 1994-96. Paper No. 2, pages 28-50, In: Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.

7. Glossary

Acre-foot: The volume of water that will cover one acre to a depth of one foot.

Acre-meter: The volume of water that will cover one acre to a depth of one meter.

Anadromous fish: Fish, such as salmon or steelhead, that hatch in freshwater, migrate to and mature in the ocean, and return to fresh water as adults to spawn.

Anthropogenic: man-made; caused by man.

Assemblage (of fishes): a group of fishes, or a fish community.

Augmenting: Increasing; in this application, increasing river flows above levels that would occur under historical conditions prior to the Endangered Species Act (especially in late summer) by releasing water from storage reservoirs.

Benthic production: Pertaining to the production of aquatic organisms, such as insects and crustaceans, from the bottom of a lake or river.

Benthos: Organisms living on the bottom of a lake, river, or ocean.

Biomass: The amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat; in an aquatic environment, the total weight of fish of the same species, or organisms that serve as fish food.

Centrarchidae: Sunfish family of fish consisting of bass, crappie and sunfish (not native to the Columbia Basin).

cfs: cubic feet per second; a measure of water flow rate (discharge) in rivers.

Condition factor: the degree of well being, or relative robustness, of fish.

Confluence: the location where two streams flow together to form one.

Congener: fishes belonging to the same genus.

Cyprinidae: Minnow family of fish consisting of carp, peamouth, redside shiners, and northern pikeminnow, etc.

Density: The number of individuals of the same species per unit area, such as 12 bass/hectare, 1 steelhead/m^2.

Discharge: Volume of water flowing in a given stream at a given time, usually expressed in cubic feet per second or cubic meters per second.

Drawdown: The distance that water surface of a reservoir is lowered from a given elevation as water is released from the reservoir. In the current EIS application, drawdown generally refers to elevation changes to below minimum operating pool.

Ectothermic: An animal whose body temperature remains close to the temperature of its environment.

Embeddedness: degree that gravel and larger substrate particles (boulders, cobble) are surrounded or covered by fine sediment.

Entrainment: The movement of an organism downstream out of a reservoir due to discharges from dam operations.

Epilimnion: The uppermost, warmest portion of the water column of a reservoir, in which mixing can occur as a result of wind action and convection currents.

Eurytherm: an ectothermic animal able to maintain itself over a wide range of temperatures.

Fecundity: the number of eggs (typically) produced by an animal.

Fishery (sport and commercial): Of or pertaining to the catching and processing of fish; sport fishery refers to the practice of catching and processing fish for sport; commercial fishery refers to the catching and processing of fish for commercial sale.

Fish ladders: A series of ascending pools constructed to enable fish to bypass dams or other barriers.

Fish passage facilities: Features of a dam that facilitate fish movement around, through, or over the dam. Generally an upstream fish ladder or a downstream bypass channel.

Flip lips (also known as spill flow deflectors): Structural modifications made to spillways of some Columbia-Snake River projects to deflect flows and reduce the deep plunging flows that create high-dissolved gas levels.

Flow: The volume of water passing a given point per unit of time; also called discharge.

Forebay: The portion of a reservoir immediately upstream of the dam.

fps: feet per second, or ft/s; a measure of water velocity

Fry: An early life stage of fish, following absorption of the yolk sac, at which they have begun to feed

Full pool: The maximum level of a reservoir under its established normal operating range.

Gas supersaturation: Concentrations of dissolved gas in water that are above the saturation (100 percent capacity) level of the water, due to forcing air into solution (by heavy spill from a dam, for example). Excess dissolved gas can harm aquatic organisms (gas bubble trauma).

Growth increment: the amount of growth (length or weight) attained per unit of time (typically in one year).

Guild: a group of species that exploit the same class of environmental resources (e.g. habitat) in a similar way.

Habitat alterations: Changes in the areas where an organism lives, which determine the number and types of organisms in a body of water; can be natural or human-caused.

Habitat generalist: an organism able to live in a wide variety of habitats (e.g. slow and fast current velocities, shallow or deep water).

Herbivore: an animal that relies chiefly or solely on vegetation for its food.

Hydroelectric: The production of electric power through use of the gravitational force of falling water.

Hydrograph: the water flow past a specific point over time, typically one year.

Hypolimnion: A lower, coolest water stratum in a stratified lake.

Ichthyofauna: fishes in a water body.

Introduced (fish): Fish not native to a particular habitat; stocked for any number of purposes including to create a new fishery or to balance the growth of competing species.

Juvenile: An early life-stage (e.g., of a fish).

Lacustrine: pertaining to lakes; living in a lake.

Levee: An embankment constructed to prevent a river from overflowing. A levee pond is a pond behind the protective levee.

Littoral: Along the shoreline of a river, lake, or reservoir.

m^3/s: cubic meters per second; a measure of water flow rate (discharge) in rivers.

Macrohabitat: a large habitat unit sharing generally similar streamflow characteristics.

Macrophytes (aquatic): A rooted aquatic plant large enough to be visible to the unaided eye.

Mainstem: The principal portion of a river in a river basin, as opposed to the tributary streams and smaller rivers that feed into it.

Mesohabitat: a subset of macrohabitat; relatively distinct habitat units within a macrohabitat type.

Mesotherm: an organism with an intermediate temperature tolerance range.

Metabolic demand: the sum total of physiological processes of an organism (feeding, respiration, digestion, reproduction, etc.).

Mid-Columbia: The section of the Columbia River from Chief Joseph Dam to its confluence with the Snake River.

Minimum Operating Pool (**MOP**): The minimum elevation of the established normal operating range of a reservoir. Generally refers to operation of a run-of-river project.

Native species: Species that originated naturally in the geographic area under consideration.

Omnivore: an animal that consumes plants and animals.

Pelagic: Open water of a lake or reservoir; away from shore.

Percidae: fish family consisting of perch and walleye (not native to the Columbia Basin).

Phytoplankton: Microscopic plants that are suspended in a water body.

Piscivore (piscivorous): an animal that eats fish.

Plankton: Single-celled (or otherwise very small) plants and animals suspended in a body of water that swim weakly and thereby drift with the currents.

Pool: Reservoir; a body of water impounded by a dam.

Predation: The relationship among animals in which one captures and feeds on another.

Project outflow: The volume of water per unit of time discharged from a project.

Recruitment: The production of fish from one life-stage to another, e.g., recruitment from egg to fry. Also, the transition of young fish to a size at which they are available to be captured by fishing gear.

Reservoir elevation: The surface level of the water stored behind a dam; stated in reference to National Geodetic Vertical Datum.

Reservoir storage: The volume of water in a reservoir at a given time.

Resident fish: Fish that complete their life cycles in fresh water.

Riparian zone: the shoreline of a lake or river; the vegetated banks.

Riprap: Rocks or boulders used to protect a stream or reservoir shoreline.

River continuum: a theoretical framework that describes the longitudinal distribution of fishes and other organisms within a river basin.

Salmonidae: Fish family consisting of salmon, trout, steelhead, whitefish and char. (Most species found in the Columbia Basin are native.)

Sedimentation: The deposition or accumulation of mineral or organic matter at the bottom of a water body.

Shaping: The scheduling and operation of generating resources to meet changing load levels. Load shaping on a hydro system usually involves the adjustment of storage releases so that generation and load are continuously in balance.

Spate: A rapid temporary rise in streamflow caused by heavy rains or rapid snowmelt; freshet.

Spawning: The release of eggs by the female of a fish, and the fertilization of those eggs by a male.

Species composition: The make-up of different types of fish species in a defined habitat; the diversity of species.

Spill: Water passed over or through a spillway or through regulating outlets without going through turbines to produce electricity. Spill can be forced when there is no storage capacity and flows exceed turbine capacity, or planned; for example, when water is spilled to enhance juvenile fish survival.

Spillway: Overflow structure at a dam.

Sport Reward Program: a removal fishery that features cash bounties as incentives to sport anglers to increase exploitation of northern pikeminnow (northern squawfish), a predator of juvenile salmonids.

Stocking (fish): To release to a body of water a species or variety of fish that may or may not be native to that body of water.

Storage reservoirs: Reservoirs that provide space for retaining water from springtime snowmelts. Retained water is used as necessary for multiple uses: power production, flood control, water supply, fish benefits, irrigation, and navigation.

Streamflow: The volume of water that passes a given point in a stream, usually expressed in cubic feet per second (cfs).

Substrate: mineral or organic material forming the bottom of a water body, typically discussed in terms of particle size.

Tailrace: The canal or channel that carries water away from a dam.

Thalweg: path of a stream that follows the deepest part of the channel.

Thermal stratification: The development of different, isolated portions of the water column, each at a different temperature, due to low mixing and differing water densities.

Turbine: Machinery that converts kinetic energy of a moving fluid, such as falling water, to mechanical or electrical power.

Velocity: Speed of linear motion in a given direction.

Water Budget: A part of the Northwest Power Planning Council's Fish and Wildlife Program calling for a volume of water to be reserved and released during the spring, if needed, to assist in the downstream migration of juvenile salmon and steelhead.

Year-class: members of a species spawned in a given year; cohort.

Zooplankton: Microscopic animals such as cladocerans and copepods (see Plankton) that are common food sources in aquatic systems.

Annex A

Annotated Bibliography — A Review of Snake River and Regional Literature

Annotated Bibliography

Anglea, S.R. 1997. Abundance, food habits and salmonid fish consumption of smallmouth bass and distribution of crayfish in Lower Granite Reservoir, Idaho-Washington. Master's thesis, University of Idaho, Moscow.
The absolute of abundance of smallmouth bass >70 mm was determined to be about 65,401 in Lower Granite Reservoir during 1994 and 1995. An estimated 82,476 and 64,020 juvenile salmonids were consumed by smallmouth bass in 1994 and 1995 in Lower Granite Reservoir. Crayfish abundance was highest in the upstream portion and declined in a downstream direction to Lower Granite Dam.

Arthaud, D.L. 1992. Size selectivity and capture efficiency of electrofishing, gillnetting, and beach seining in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.
A detailed analysis of fish sampling gears used in Lower Granite Reservoir.

Austen, D.J., P.B. Bayley, and B.W. Menzel. 1994. Importance of the guild concept to fisheries research and management. Fisheries 19(6): 12-20.
Guilds have been developed based on reproduction, feeding, habitat use and morphology, and have been used to describe a community change in response to environmental perturbations. Use of guilds should be based on the critical environmental variables that are the most influential in determining community composition, and best evaluated with long term data sets

Bennett, D. H. 1979. Probable walleye (Stizostedion vitreum) habitation in the Snake River and tributaries of Idaho. Completion Report. Idaho Water Resources Research Institute. Moscow.
An analysis of the life history of walleye is related to existing habitat conditions in the Snake River and Idaho tributaries. Report analyzes available reports of walleye in the Columbia and Snake rivers and projects possible range expansion.

Bennett, D.H., T. Barila, and C. Pinney. 1996. Effects of in-water disposal of dredged material on fishes in Lower Granite Reservoir, Snake River. Pages 328-332 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.
A summary of effects that have been observed in Lower Granite Reservoir as a result of in-water disposal of dredged material including relative abundances of smallmouth bass and northern pikeminnow.

Bennett, D.H., P.M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of the warmwater fishery and the potential of improving warmwater fish habitat in the lower Snake reservoirs. Completion Report No. DACW68-79-C-0057. U.S. Army Corps of Engineers, Walla Walla, Washington.
An intensive analysis of relative fish abundance, reproduction, food items and sport fishery characteristics in Little Goose Reservoir with slight coverage of sport fishery and fish communities in the other three Lower Snake River reservoirs.

Bennett, D.H., J.A. Chandler, and G. Chandler. 1991. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 2 (1989). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Analysis of benthic invertebrate and fish communities in Lower Granite Reservoir based on the 2nd year of monitoring.

Bennett, D.H. and T.J. Dresser Jr. 1996. Larval fish abundance associated with in-water disposal of dredged material in Lower Granite Reservoir, Idaho-Washington. Pages 333-337 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.
A summary of the abundance of larval fishes associated with in-water disposal of dredged material in Lower Granite Reservoir.

Bennett, D.H., T.J. Dresser, Jr., S.R. Chipps, and M.A. Madsen. 1996. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Idaho-Washington Year 6 (1993). Completion Report (In press). U.S. Army Corps of Engineers, Walla Walla, Washington.
Year 6 monitoring results of in-water disposal of dredged material. Included is a summary analysis of the community changes that occurred associated with in-water disposal.

Bennett, D.H., T.J. Dresser, T.S. Curet, K.B. Lepla, and M.A. Madsen. 1993. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program Year-3 (1990). U.S. Army Corps of Engineers, Walla Walla, Washington.
Results of the 3rd year of fish monitoring in-water disposal of dredged material in Lower Granite Reservoir.

Bennett, D.H., T.J. Dresser, Jr., and M.A. Madsen. 1994. Evaluation of the 1992 drawdown in Lower Granite and Little Goose reservoirs. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Analysis of fish community sampling during the 4th year of monitoring of in-water disposal of dredged material.

Bennett, D.H., T.J. Dresser, Jr., and M.A. Madsen. 1994. Effects of reservoir operations at minimum pool and regulated inflows of low temperature water on resident fishes in Lower Granite Reservoir, Idaho-Washington. Completion Report (Draft). U.S. Army Corps of Engineers, Walla Walla, Washington.
An analysis of various factors that could affect resident fishes in Lower Granite Reservoir during their spawning and rearing period.

Bennett, D.H., T.J. Dresser, Jr., and M.A. Madsen. 1994. Evaluation of the effects of the 1992 test drawdown on the fish communities in Lower Granite and Little Goose reservoirs, Washington. Appendix P. prepared for Corps of Engineers, Walla Walla District, by University of Idaho, Department of Fish and Wildlife Resources.
Three of six study objectives addressed effects of the March 1992 drawdown on resident fishes. The principal purposes were to assess the effects of the drawdown on size and species composition of fishes in Lower Granite Reservoir, and to assess drawdown effects on distribution and abundance of white sturgeon in Lower Granite Reservoir. The biological significance of any effects noted for resident fishes was limited. However, the drawdown may have enhanced emigration of white sturgeon from Lower Granite Reservoir into Little Goose reservoir via spill or entrainment.

Bennett, D.H., and T.J. Dresser Jr., and M.A. Madsen. 1998. Habitat use, abundance, timing, and factors related to the abundance of subyearling chinook salmon rearing along the shorelines of Lower Snake River reservoirs. Completion Report. Projects 14-16-0009-1559, 14-16-0009-1579, 98210-3-4037. US Army Corps of Engineers, Walla Walla, Washington.
The temporal and spatial abundance of subyearling chinook salmon were examined relative to existing habitat conditions. Subyearling chinook salmon rear over low gradient shorelines, with

sandy substrate and low velocities. Substrates were analyzed at various river miles in Lower Granite and Little Goose reservoirs and related to subyearling chinook abundance.

Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1988. Fish and benthic community abundance at proposed in-water disposal sites, Lower Granite Reservoir. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Results of monitoring in-water disposal of dredged material into Lower Granite Reservoir.

Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1990. Lower Granite Reservoir in-water disposal test: Results of the fishery, benthic and habitat monitoring program-Year 1 (1988). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Provides a fishery and benthic invertebrate survey of selected stations in Lower Granite Reservoir following the first in-water disposal event.

Bennett, D.H., L.K. Dunsmoor, J.A. Chandler, and T. Barila. 1989. Use of dredged material to enhance fish habitat in Lower Granite Reservoir, Idaho-Washington. U.S. Army Corps of Engineers, Walla Walla, Washington.
A preliminary analysis of effects of in-water disposal of dredged material on fish and benthic invertebrates in Lower Granite Reservoir.

Bennett, D.H., M.H. Karr, and M.A. Madsen. 1994. Thermal and velocity characteristics in the Lower Snake River reservoir, Washington, as a result of regulated upstream water releases. Completion Report (Draft). U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., M.A. Madsen, S.M. Anglea, T. Cichosz, T.J. Dresser Jr., M. Davis, and S.R. Chipps. 1997. Fish interactions in Lower Granite Reservoir, Idaho-Washington. Projects 14-45-0009-1579 w/o 21 and 14-16-0009-1579 w/o 32 Completion Report (Draft). US Army Corps of Engineers, Walla Walla, Washington.
A description of how resident fishes affect juvenile salmonids including predation, dietary overlap and factors affecting their abundance.

Bennett, D.H., M.A. Madsen, T.J. Dresser, Jr., and T.S. Curet. 1995. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Idaho-Washington Year 5 (1992). Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Analysis of data collected during the 5th year of monitoring in-water disposal of dredged material in Lower Granite Reservoir.

Bennett, D.H., M.A. Madsen, and M.H. Karr. 1994. Thermal characteristics in the Lower Snake River reservoir, Washington, as a result of regulated upstream water releases: Data Volume 1. Completion Report (Draft). U.S. Army Corps of Engineers, Walla Walla, Washington.
A data volume of temporal and spatial changes in water temperature in the Lower Snake River reservoirs.

Bennett, D.H., M.A. Madsen, and M.H. Karr. 1994. Water velocity characteristics of the Clearwater River, Idaho and Lower Granite, Little Goose, Lower Monumental and Ice Harbor reservoirs, Lower Snake River, Washington, during 1991-1993 with emphasis on upstream releases: Data Volume II. Completion Report (Draft). U.S. Army Corps of Engineers, Walla Walla, Washington.

A data volume of temporal and spatial changes in water velocity in the Lower Snake River reservoirs. Temperature and velocity monitoring information associated with low temperature releases from Dworshak Reservoir. Includes changes in water temperature and water velocity on a spatial and temporal scale.

Bennett, D.H. and G.P. Naughton. 1998. Predator abundance and salmonid prey consumption in Lower Granite Reservoir and tailrace. Draft Completion Report. US Army Corps of Engineers, Walla Walla, Washington.
Absolute abundance and density of northern pikeminnow and smallmouth bass were estimated from the forebay and tailwater of Lower Granite Dam and the Clearwater and Snake River arms. Density of northern pikeminnow was highest in the tailrace whereas highest density of smallmouth bass was in the forebay. Consumption of juvenile salmonids by both species was low throughout all areas sampled and accounted for an estimated loss of about 15,000 salmonids during both 1996 and 1997.

Bennett, D.H., and F.C. Shrier. 1987. Monitoring sediment dredging and overflow from land disposal activities on water quality, fish and benthos in Lower Granite Reservoir, Washington. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Results of monitoring of 1986 suction dredging and return flows into Lower Granite Reservoir. Includes analysis of water quality changes that occur as a result of these activities.

Bennett, D.H., and F.C. Shrier. 1986. Effects of sediment dredging and in-water disposal on fishes in Lower Granite Reservoir, Idaho-Washington. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Examines effects of dredging from the literature on the ecosystem and analyzes fish and benthic invertebrate communities in Lower Granite Reservoir. Is the first known comprehensive survey of these communities in this system.

Bonneville Power Administration, U.S. Army Corps of Engineers, and U.S. Department of the Interior. 1995. Columbia River System Operation Review, Final Environmental Impact Statement. Appendix K, Resident Fish. DOE-EIS-0170.
Various alternatives to current operational guidelines for all projects in the Columbia River Basin were reviewed for their potential impacts to resident fishes. Resident fishes included both native and introduced species.

Bratovich, P.M. 1985. Reproduction and early life histories of selected resident fishes in Lower Snake River reservoirs. Master's thesis. University of Idaho, Moscow.
Analysis of timing of reproduction of various resident fishes, effects of water level fluctuations and abundance of larval fishes in Little Goose Reservoir.

Chandler, J.A. 1993. Consumption rates and estimated total loss of juvenile salmonids by northern squawfish in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.
Analysis of the influence of predation by northern squawfish on downstream migrating juvenile salmonids in the spring in Lower Granite Reservoir.

Chipps, S.R., D.H. Bennett, and T.J. Dresser Jr. 1996. Trends in resident fish abundance associated with use of dredged material for fish habitat enhancement. Pages 338-341 in Water Quality '96: Proceedings of the 11th Seminar, U.S. Army Corps of Engineers, Seattle, Washington.

An analysis of changes in fish community structure at primarily shallow water stations associated with in-water disposal of dredged material in Lower Granite Reservoir.

Chipps, S.R., D.H. Bennett, and T.J. Dresser, Jr. 1997. Patterns of fish abundance associated with a dredge disposal island: implications for fish habitat enhancement in a large reservoir. North American Journal of Fisheries Management 17: 378-386.
Patterns in resident fish community structure were assessed at sediment disposal sites and reference sites in Lower Granite Reservoir. Species richness increased following construction of the disposal island. The island increased fish community diversity by increasing local habitat complexity.

Cichozs, T.A. 1996. Factors limiting the abundance of northern squawfish in Lower Granite Reservoir. Master's thesis. University of Idaho, Moscow.
Analysis of factors that affect the abundance of northern pikeminnow at various life history stages in Lower Granite Reservoir.

Cochnauer, T. G. 1983. Abundance, distribution, growth and management of white sturgeon (*Acipenser transmontanus*) in the middle Snake River, Idaho. Ph.D. dissertation, University of Idaho, Moscow
Sturgeon abundance was highest between Bliss and C.J. Strike Dams with an estimated 2,191 fish in this area. Six fish could be harvested annually from this section of the river based on modeling whereas harvest was not recommended above Bliss Dam and downstream of *C.J. Strike Dam.*

Cochnauer, T. 1995. Gas bubble trauma monitoring in the Clearwater River drainage, Idaho, 1995. Idaho Department of Fish and Game, Lewiston, Idaho.
Species composition and incidence of Level 1 gas bubble trauma of electrofishing samples from the lower 2 miles (impounded section) of the Clearwater River is shown in tabular form. The three predominant taxa were smallmouth bass, largescale and bridgelip suckers, and chiselmouth chub. No fish in this section showed gas bubble trauma symptoms.

Coon, J.C. 1975. Movement, distribution, abundance and growth of white sturgeon in the mid-Snake River. Master's thesis, University of Idaho, Moscow.
White sturgeon were tagged with strap tags and 11 were tagged with ultrasonic transmitters to assess habit use, distribution and abundance. An estimated 8,000-12,000 white sturgeon >0.5m long resided between Lower Granite and Hells Canyon Dams. Growth was variable among individuals but rapid to 4 years and 60 cm. Growth was deemed slower than prior to construction of the Hells Canyon Dams

Corps (U.S. Army Corps of Engineers). 1989. Snake River embayment survey, river miles 59 to 90, 1988-1989. U.S. Army Corps of Engineers, Walla Walla District. 45 pp.
Some 37 ponds and embayments formed a due to railroad relocation after reservoir impoundment were surveyed systematically for a 31-mile reach roughly centered on Little Goose Dam. Data were recorded for the following parameters: type of river connection, embayment morphology, water temperature and dissolved oxygen characteristics, livestock use, recreational use, riparian vegetation, aquatic plants and algae, and observations of fish and wildlife.

Curet, T.S. 1994. Habitat use, food habits and the influence of predation on subyearling chinook salmon in Lower Granite and Little Goose reservoirs, Washington. Master's thesis. University of Idaho, Moscow.

Analysis of the temporal and spatial abundance of subyearling chinook salmon and the influence of predation from smallmouth bass or their survival.

Dauble, D.D., and D.R. Geist. 1992. Impacts of Snake River drawdown experiment on fisheries resources in Little Goose and Lower Granite reservoirs, 1992. Appendix Q. Corps of Engineers Contract No. DE-AC06-76RLO 1830. Pacific Northwest Laboratory, Richland, Washington.
This report focuses mostly on drawdown effects on salmonid spawning and spawning habitat above and below Lower Granite reservoir. Limited data are presented on relative abundance of resident species determined by electrofishing and seining in nearshore habitats below Lower Granite Dam.

Dauble, D.D. , R.L. Johnson, R.P. Mueller, W.H. Mavros, and C.S. Abernethy. 1996. Surveys of fall chinook salmon spawning areas downstream of Lower Snake River hydroelectric projects, 1995-1996 Season. Annual Report. Pacific Northwest Laboratory, Richland, Washington.
Underwater video surveys were conducted in Lower Granite, Little Goose and Lower Monumental Dam tailwaters to characterize the substrate and use for fall chinook spawning. Assessments were made associated with proposed construction projects at each site.

Dresser, T.J. 1996. Nocturnal fish-habitat associations in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.
Master of Science thesis that analyzes nighttime habitat use using multivariate statistics.

Friesen, T.A. and D.L. Ward. 1997. Management of northern squawfish and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. Paper No. 1, pages 5-27, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
Annual and total northern squawfish harvest, harvest effort, CPUE, exploitation rates, and size of harvested squawfish were evaluated for three reaches within the lower Columbia River basin. More than 1.1 million squawfish >250 mm were removed during 1991-96. Mean exploitation rate for the lower basin was 12%, and varied annually from 8.1% to 15.5%. Mean fork length of all harvested squawfish was 366 mm, with the largest fish removed by gill nets and the smallest by anglers.

Friesen, T.A. and D.L. Ward. 1997. Biological characteristics of walleye in relation to sustained removals of northern squawfish in the Columbia River. Paper No. 5, pages 90-105, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
Trends in year-class strength, abundance, population structure, growth, and mortality of walleye in the lower Columbia River in 1992-96 are reported. There was no evidence of response by walleye in these parameters to sustained exploitation of northern squawfish.

Gray, G.A. and D.W. Rondorf. 1986. Predation on juvenile salmonids in Columbia Basin reservoirs. Pages 178-185 in Reservoir fisheries management: strategies for the 80's. American Fisheries Society, Bethesda, Maryland.
Factors involved in changing the predator prey relationships in the Columbia River Basin, including the Snake River, are discussed. The role of several introduced, major predators within the predator-prey complex in creating current conditions hazardous to emigrant smolts is detailed.

Idaho Fish and Game Department. 1992. Region 2 rivers and streams investigations. Project F-71-R16. Idaho Department of Fish and Game, Lewiston, Idaho.
Data summaries are presented on studies of smallmouth bass and white sturgeon in the Snake River below Hells Canyon Dam. Size frequencies and growth metrics (PSD) are presented for smallmouth bass from various river sections. Limited information on size of white sturgeon is also briefly discussed.

Idaho Department of Fish and Game. 1998. Data summaries of white sturgeon PIT tagging and movement studies. Provided by Larry Barrett, Lewiston, Idaho.
The size frequency, PIT tagging, and recapture data for white sturgeon captured by hook and line in the Snake River from Hells Canyon Dam to Lewiston are presented. Data show time at large, tag and recapture location, growth, and distance traveled within the Snake River.

Karr, M.K., B. Tanovan, R. Turner, and D.H. Bennett. 1992. Water temperature control project, Snake River Interim report: Model studies and 1991 operations. Columbia River Inter-Tribal Fish Commission, U.S. Army Corps of Engineers, and University of Idaho, Moscow.
Results from intensive monitoring of water temperatures at 16 stations in the lower Snake River reservoirs as a result of water releases from the Hells Canyon Dam on the Snake River and Dworshak Reservoir on the North Fork Clearwater River.

Knox, W.J. 1982. Angler use, catch and attitudes on Lower Snake River reservoirs, with emphasis on Little Goose Reservoir. Master's thesis. University of Idaho, Moscow.
An intensive analysis of the sport fishery for resident fishes in Little Goose Reservoir during 1979 and 1980.

Knutsen, C.J. and D.L. Ward. 1997. Biological characteristics of northern squawfish in the lower Columbia and Snake rivers before and after sustained exploitation. Paper No. 3, pages 51-68, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
The authors tested the hypothesis that sustained removal of northern squawfish have not resulted in a density-dependent response of squawfish population structure, mortality, growth, and fecundity. All of these parameters were compared among years to identify any compensatory effects of the management program. Although annual mortality rates are higher, no density dependent responses for these parameters were observed.

Leonard, P.M., and D.J. Orth. 1988. Use of habitat guilds to determine instream flow requirements. North American Journal of Fisheries Management 8: 399-409.
Eight warmwater fishes with up to four life stages were grouped into habitat-use guilds. Guilds were identified as riffle, run, pool, and stream margin, and were identified by cluster analysis of depth, velocity, substrate, and cover criteria. When guilds are used in species selection for an instream flow analysis, incorporation of representatives from all major guild types offers the best chance for resource protection.

Lepla, K.B. 1994. White sturgeon abundance and associated habitat in Lower Granite Reservoir, Washington. Master's thesis. University of Idaho, Moscow.
A comprehensive a analysis of the abundance of white sturgeon in Lower Granite Reservoir including population estimation, mortality, age and growth and habitat analysis.

Li, H.W., C.B. Schreck, C.E. Bond, and E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. Pages 193-202 in W.J. Matthews and D.C Heins,

editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman, Oklahoma.
Structural and land use changes in Pacific Northwest watersheds have altered fish assemblages. Native fishes are classified into thermal and trophic guilds. The potential mechanisms of effects of watershed disturbance on native fishes are discussed, as are the structure of communities of exotic (introduced) fishes that largely replaced native fish communities as a result of the disturbances.

Lobb III, M.D., and D.J. Orth. 1991. Habitat use by an assemblage of fish in a large warmwater stream. Transactions of the American Fisheries Society 120: 65-78.
Habitat use patterns for a warmwater fish assemblage were correlated with habitat variables (depth, velocity, amount of vegetation, and substrate type). Five habitat-use guilds were proposed, including edge pool, middle pool, edge channel, riffle, and generalist. Selection of guilds should be based on the habitat characteristics of the specific stream under study. Complex, nearshore habitats seem most important in determining fish assemblage structure.

Palmer, D.E. 1982. Abundance, survival, distribution and movements of selected fishes in Lower Snake River reservoirs. Master's thesis. University of Idaho, Moscow.
Analysis of extensive fish sampling data including selected population analysis of some of the more important sport fishes in Little Goose Reservoir.

Parker, R.M., M.P. Zimmerman, and D.L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124: 335-346.
The widespread distribution of northern squawfish in an altered system such as the lower Columbia and Snake rivers is likely due to their broad requirements for spawning and rearing, and to feeding patterns of a trophic generalist. Differences in habitat quality and quantity and interactions with other species account for variability in most biological characteristics measured.

Poe, T.P., R.S. Shively, and R.A. Tabor. 1994. Ecological consequences of introduced piscivorous fishes in the Lower Columbia and Snake rivers. Pages 347-360 in D.J. Stouder, K.L. Fresh, and R.J. Feller, editors. Theory and application in fish feeding ecology. University of South Carolina Press, Columbia, South Carolina.
The relative abundance and dietary preferences of smallmouth bass, channel catfish, and walleye in the Columbia and Snake rivers are reviewed. The diets and potential ecological impacts of these introduced predators are contrasted with those of the northern squawfish, the major native species predator on juvenile salmonids.
abundance of resident species determined by electrofishing and seining in nearshore habitats below Lower Granite Dam.

Schuck, M.L. 1992. Observations of the effects of reservoir drawdown on the fishery resource behind Little Goose and Lower Granite Dams, March 1992. Washington Department of Wildlife, Dayton, Washington. 12 pp. + appendices.
A structural drawdown test of the dams and other structures was completed in March 1992. The drawdown concept was proposed to speed smolt movement through the pools to enhance survival during emigration. Stranded fish and dead fish were documented in embayments and shallow habitats of both pools as a result of the reduced water levels. Resident species most affected were largemouth bass and crappie. Losses of crayfish and other invertebrates were substantial.

Shively, R.S., T.P. Poe, and S.T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society 125:230-236.
The feeding of northern squawfish before and after a hatchery release of juvenile salmonids was documented. The rapid response of squawfish to the release, and the implications of the nonrandom selection by squawfish of smaller prey individuals is discussed.

Shively, R.S., and 6 co-authors. 1991. System-wide significance of predation on juvenile salmonids in the Columbia and Snake river reservoirs. Annual Report of Research. U.S. Fish and Wildlife service, Columbia River Field Station. Prepared for U.S. Department of Energy, Contract No. DE-AI79-90BP07096.
Consumption rates of northern squawfish on juvenile salmonids were indexed for each Snake River reservoir and for John Day Reservoir on the Columbia River. Fish and crustaceans dominated the diet of 1,408 squawfish digestive tracts. Consumption indices in the reservoirs were highest in forebays and tailraces.

Smith, S.S. 1996. Analysis of hybridization between northern squawfish and chiselmouth in Lower Granite Reservoir, Washington. Master's thesis, University of Idaho, Moscow.
Morphological characteristics were developed to identify northern squawfish , chiselmouth and hybrids. Mitochondrial DNA analysis showed that 67% of the F1 hybrids had northern squawfish maternity while 33% had chiselmouth maternity. F1 hybrids were piscivorous but at a larger size than northern squawfish.

Thorne, R.E., C.J. McClain, J. Hedgepeth, E.S. Kuehl, and J. Thorne. 1992. Hydroacoustic surveys of the distribution and abundance of fish in Lower Granite Reservoir, 1989-1990. Final Report. Contract No. DACW68-C-0022. U.S. Army Corps of Engineers, Walla Walla, Washington.
Estimates of fish density from down –looking and side-scanning hydroacoustic surveys using during May, June, October, and February 1990. Based on ground surveys, developed estimates of salmonids, predators, and other fishes.

Ward, D.L., editor. 1997. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
This document contains a summary of the work performed that evaluated the effects of management efforts to reduce levels of predation on salmon smolts by northern squawfish. The document presents conclusions, limitations, and recommendations resulting from the research, and is the umbrella document for six papers cited individually herein.

Ward, D.L., J.H. Peterson, and J.J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Transactions of the American Fisheries Society 124:3211-334.
The density of northern squawfish was greatest in the tailrace boat restricted zones (BRZ) of reservoirs, particularly Little Goose Reservoir. Abundance of northern squawfish in Snake River reservoirs was generally lower than in Columbia River reservoirs or from the free flowing Columbia River below Bonneville Dam.

Ward, D.L. and M.P. Zimmerman. 1997. Response of smallmouth bass to sustained removals of northern squawfish in the lower Columbia and Snake rivers. Paper No. 4, pages 69-89, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
Trends in year-class strength, density, consumption of juvenile salmonids, population structure, growth, and mortality of smallmouth bass in three basin reaches from 1990-96 are reported. No

trends in any of these parameters were identified as a result of sustained removal of northern squawfish.

Webb, T.M. and D.C.E. Robinson. 1989. Lower Granite Reservoir in-water disposal test: Design of a simulation model. Final Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Reports on development of a simulation model for the Lower Granite ecosystem. Model includes sub-models for predators and habitat.

Webb, T.M., N.C. Sonntag, L.A. Greig, M.L. Jones. 1987. Lower Granite In-water disposal test: Proposed monitoring program. Completion Report. U.S. Army Corps of Engineers, Walla Walla, Washington.
Conceptual models were developed following a workshop with 35 professional aquatic scientists to identify important linkages in the Lower Granite ecosystem. A recommended monitoring plan was developed to provide information on these linkages.

Zimmerman. M.P. 1997. Comparative food habits and piscivory of smallmouth bass, walleyes, and northern squawfish in the lower Columbia River basin. Paper No. 6, pages 106-134, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
The general food habits and piscivory of smallmouth bass, walleye, and northern squawfish were compared from 1990-96 for three reaches: the unimpounded lower Columbia River below Bonneville Dam, the impounded lower Columbia River to McNary Dam, and the impounded lower Snake River. The food habits of these species were generally consistent with those reported by other studies. Smallmouth bass and walleye consumed far fewer juvenile salmonids than did northern squawfish, although subyearling chinook were eaten by bass at a rate exceeding one per predator/day at specific areas in summer.

Zimmerman, M.P. and R.M. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the lower Columbia and Snake rivers. Northwest Science 69(1): 19-28.
Electrofishing and gill nets were used to sample introduced predators in tailrace, mid-reservoir, and forebay reaches of Snake and Columbia river reservoirs in 1990-1992. Density and relative abundance indices showed that smallmouth bass density was greatest in forebays and mid-reservoirs reaches, particularly in Snake River reservoirs, while channel catfish were distributed throughout all reservoir reaches, and also most abundant in Snake River reservoirs. Walleye were not found upstream of Ice Harbor Dam.

Zimmerman, M.P. and D.L. Ward. 1997. Index of predation on juvenile salmonids by northern squawfish in the lower Columbia River basin from 1994-96. Paper No. 2, pages 28-50, in Ward. D.L., editor. Evaluation of the northern squawfish management program: final report of research, 1990-96. Bonneville Power Administration, Portland, Oregon.
Predation by northern squawfish on juvenile salmonids at fixed sites sampled annually from 1994-96 was determined and compared to abundance and consumption determined for 1990-93. Declines in squawfish abundance, consumption rates, or both have contributed to declines in predation indices on juvenile salmonids in all areas sampled over the 1990-96 time interval. Temporal variations in predation may be due to variation in exploitation of squawfish, and annual variation in river flow, dam operations, and juvenile salmonid densities.