Volume III, Chapter 5
Northern Pikeminnow

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5.0 Northern Pikeminnow *(Ptychocheilus oregonensis)*

In Washington, the northern pikeminnow *(Ptychocheilus oregonensis)* is found in the Columbia River system and coastal and Puget Sound drainages (Wydoski and Whitney 1979). The species fares well in stream, river, and lake-like habitats, and has flourished in the mainstem Columbia River and its many tributary systems following development and varying land uses (Parker et al. 1995; NRC 1996).

Intensive predation by northern pikeminnow on juvenile Pacific salmon *Oncorhynchus* spp. has been well-documented throughout the lower Columbia River basin (Rieman et al. 1991; Vigg et al. 1991; Ward et al. 1995; Ward et al. 2002), where extensive hydropower development has greatly increased the vulnerability of migrating juvenile salmonids to predation (Raymond 1979; Rieman et al. 1991). Concern about this predation led to the development of a large-scale management program for northern pikeminnow (Beamesderfer et al. 1996; Friesen and Ward 1999; Ward et al. 2002).

5.1 Distribution

The northern pikeminnow is a cyprinind native to the Pacific slope of western North America from Oregon north to the Nass River in British Columbia (Wydoski and Whitney 1979, Simpson and Wallace 1982). A map is provided in Figure 5-1.

Northern pikeminnow have successfully evolved in a range of dynamic lentic and lotic ecosystems and successfully adapted to their varied habitat conditions. Their plasticity allowed them to flourish despite construction and operation of the Columbia Basin hydropower system (NRC 1996). Beamesderfer (1992) attributed the widespread distribution and resiliency of northern pikeminnow to their relatively broad spawning and rearing habitat requirements. Furthermore, the wide range of prey types available in the lower Columbia River (Poe et al. 1991) appears suitable to support a trophic generalist. Parker et al. (1995) reported considerable variation in life history parameters of northern pikeminnow in the mainstem Columbia and Snake Rivers, further supporting the species' adaptability.

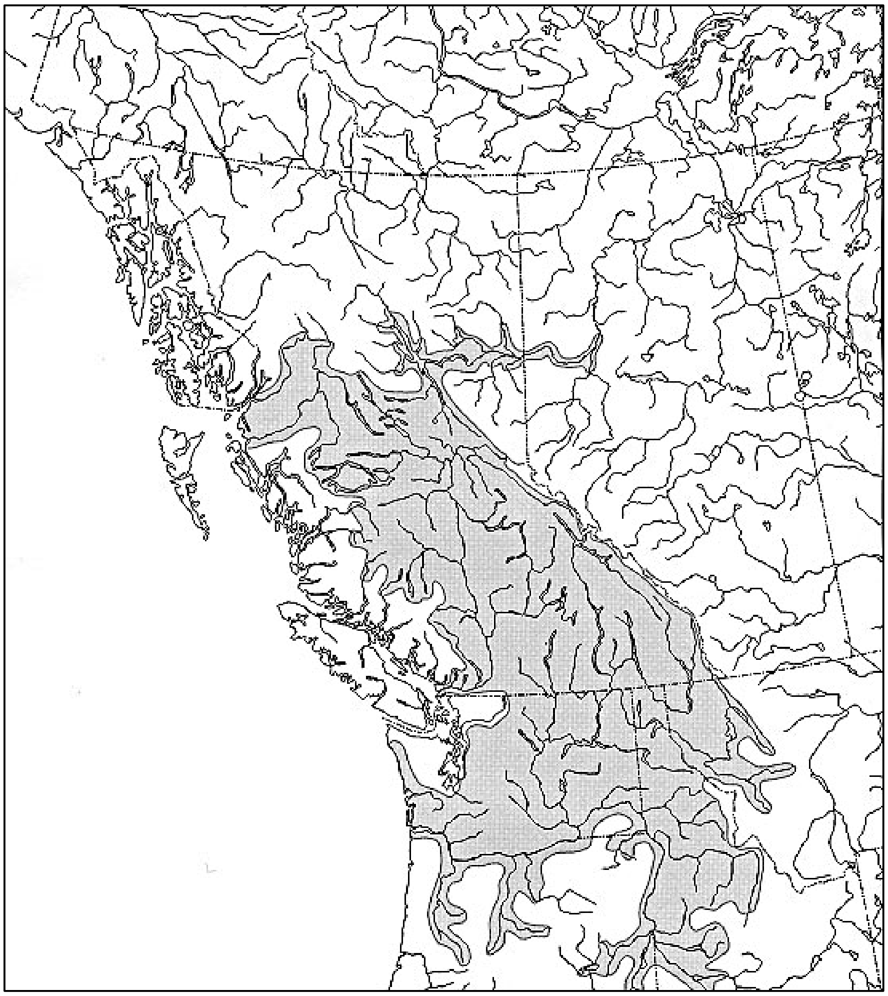

Figure 5-1. Geographical range of northern pikeminnow.

Overall objectives of the program were: 1) determining the significance of predation in Columbia River reservoirs by indexing predator abundance and comparing the index with consumption (of what) indices, 2) implementing a predator control plan, beginning with a test fishery in John Day Reservoir in 1990, and 3) evaluating the predator control program.

5.2 Life History Characteristics

5.2.1 Size & Mortality

Northern pikeminnow are large, long-lived, slow-growing predaceous minnows *(Cyprinidae)* whose unexploited populations are typically dominated by large, older individuals. In the Columbia River, maximum fork length, weight, and age are approximately 23½ in (600 mm), 5½ pounds (2.5 kg), and 16 years; annual mortality rates were reported to range from 12-31% (Rieman and Beamesderfer 1990; Parker et al. 1995). However, the maximum age of 16 years may be an underestimate based on possible underaging (Dave Ward, ODFW, personal communication). Individuals 15 in (380 mm) in length and greater constituted 12-59% of the population with FL > 9 3/4 in (250 mm) (Parker et al. 1995). Ward et al. (1995) reported that differences in life history trait expressions of northern pikeminnow among reservoirs and between free-flowing areas and impounded reaches of the Columbia and Snake Rivers underscore their ability to adapt.

Sexual maturity occurs at sizes of 8-14 in (200-350 mm) and corresponding ages of 3–8 years, with males typically reaching initial maturity before females (Beamesderfer 1992; Parker et al. 1995). Spawning generally occurs during June and July in large aggregations that broadcast eggs over clean rocky substrate in slow-moving water at a range of depths in rivers, lake tributaries, lake stream outlets, and shallow and deep littoral areas (Beamesderfer 1992). Wydoski and Whitney (1979) reported spawning over gravel areas in stream and gravel beach areas in the lake. Parker et al. (1995) reported that individual fecundity averaged about 25,000 eggs/female, whereas Wydoski and Whitney (1979) published a fecundity range of 6,700 to 83,000 eggs per female. They also reported that eggs hatch in 7 days at 65°F water, and that the young become free swimming within 14 days.

The diet of northern pikeminnow varies with their size (Ricker 1941; Falter 1969; Olney 1975; Buchanan et al. 1981). In the Columbia River, invertebrates dominate the diets of northern pikeminnow that are smaller than 11.8 in (300 mm) FL, with fishes and crayfish increasing in importance as fish size increases (Thompson 1959; Kirn et al. 1986; Poe et al. 1991, 1994). Salmonids, sculpins (*Cottus* spp.), trout perch *(Percopsis transmontana),* and suckers *(Catostomous* spp.*)* are common prey items of northern pikeminnow (Poe et al. 1991). Salmonids are generally an important diet item only for large, old northern pikeminnow (Vigg et al. 1991), and the consumption rate of juvenile salmonids increases exponentially as the size of the northern pikeminnow increases (Beamesderfer et al. 1996). Consumption rates of juvenile salmonids by northern pikeminnow correlate positively with how abundant salmonids are; in other words, the more salmonids there are, the more the northern pikeminnow eat until the pikeminnow reaches satiation (Thompson 1959; Buchanan et al. 1981; Poe et al. 1991; Vigg et al. 1991; Tabor et al. 1993; Henchman 1986; Vigg 1988; Petersen and DeAngelis 1992).

Newly-emerged larval northern pikeminnow in the Columbia River drift downriver in the nighttime hours of July. The highest overall densities of drifting northern pikeminnow larvae were collected below Bonneville Dam. In reservoirs, the highest densities of drifting larvae occurred in tailrace areas. The period of larval drift was brief, with larvae recruiting to shallow sand or fine sediment shoreline areas to rear. Age-0 northern pikeminnow rearing in littoral habitats of the upper John Day Reservoir had significantly greater growth and lower mortality in June–September 1994, a year with low flows, abundant instream vegetation, and high near-shore water temperatures.

5.2.2 Population Dynamics & Demographic Risk

Population is affected by competition from other species as well as from other members of their own species. While northern pikeminnow represent the only native piscivorous salmonid predators in Columbia River reservoirs, numerous non-native predatory fish species have been introduced into the Columbia Basin (e.g. walleye, smallmouth bass *Micropterus dolomeui,* and channel catfish *Ictalurus punctatus*).

Beamesderfer et al. (1996) found a negative correlation between concurrent year classes of walleye and northern pikeminnow, and suggested that walleye might influence (reduce) northern pikeminnow numbers by predation. Furthermore, interactions and population dynamics among native and non-native fish species and subsequent ecological responses are difficult to predict accurately (Beamesderfer et al. 1996). Potentially inextricable changes in species abundance due to the program to remove northern pikeminnow may further confound such investigations.

5.3 Status & Abundance Trends

5.3.1 Abundance

Northern pikeminnow abundance in the Columbia River downstream from its confluence with the Snake River is highest in the approximately 186 miles (300 km) from the estuary to the Dalles Dam (2,580-3,020 fish/km), and decreases significantly in the 100 miles (161 km) from the Dalles Dam to McNary Reservoir (550-690 fish/km; abundance is shown in Figure 5-2.

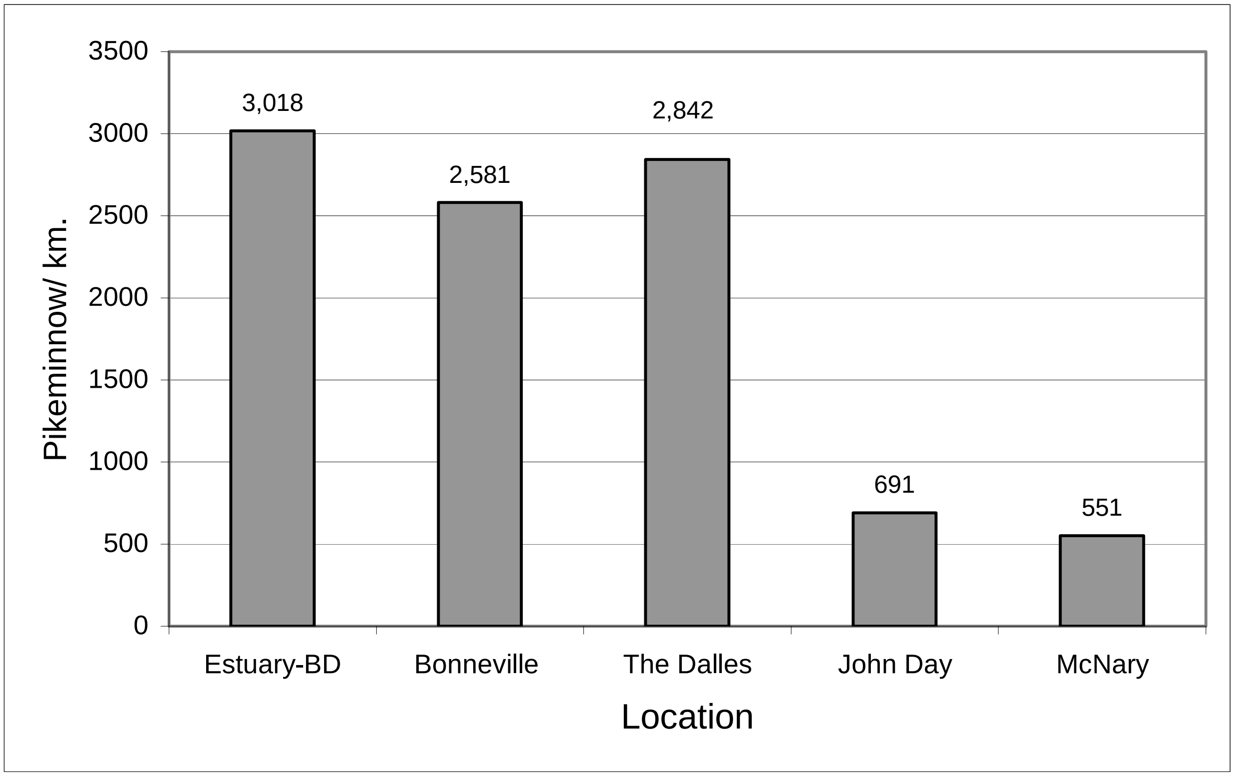

Figure 5-2. Estimated abundance of northern pikeminnow in the Columbia River downstream from its confluence with the Snake River (data from Beamesderfer et al. 1996).

However, a longitudinal trend in abundance was not noted in the four lower Snake River reservoirs. In the lower Snake River, northern pikeminnow were most abundant in Little Goose and Lower Monumental reservoirs (1,065 and 1,000 fish/km respectively) and least abundant in Ice Harbor Reservoir (255 fish/km), as shown in Table 5-1. The longitudinal northern pikeminnow abundance trend may be supported by similar trends of increasing food availability and habitat suitability in the same downstream orientation.

Table 5-1. Projected abundance of northern pikeminnow based on 1983–86 mark-recapture estimates in John Day Reservoir (Beamesderfer and Rieman 1991).

Location	Distance (km)	Fish km	Northern pikeminnow abundance (000s)
Estuary to Bonneville	224	3,018	676
Bonneville Reservoir	74	2,581	191
The Dalles Reservoir	38	2,842	108
John Day Reservoir	123	691	85
McNary Reservoir	98	551	54
Ice Harbor Reservoir	51	255	13
Lower Monumental Reservoir	46	1,065	49
Little Goose Reservoir	60	1,000	60
Lower Granite Reservoir	85	341	29
Total	*NA*	*NA*	*1,265*

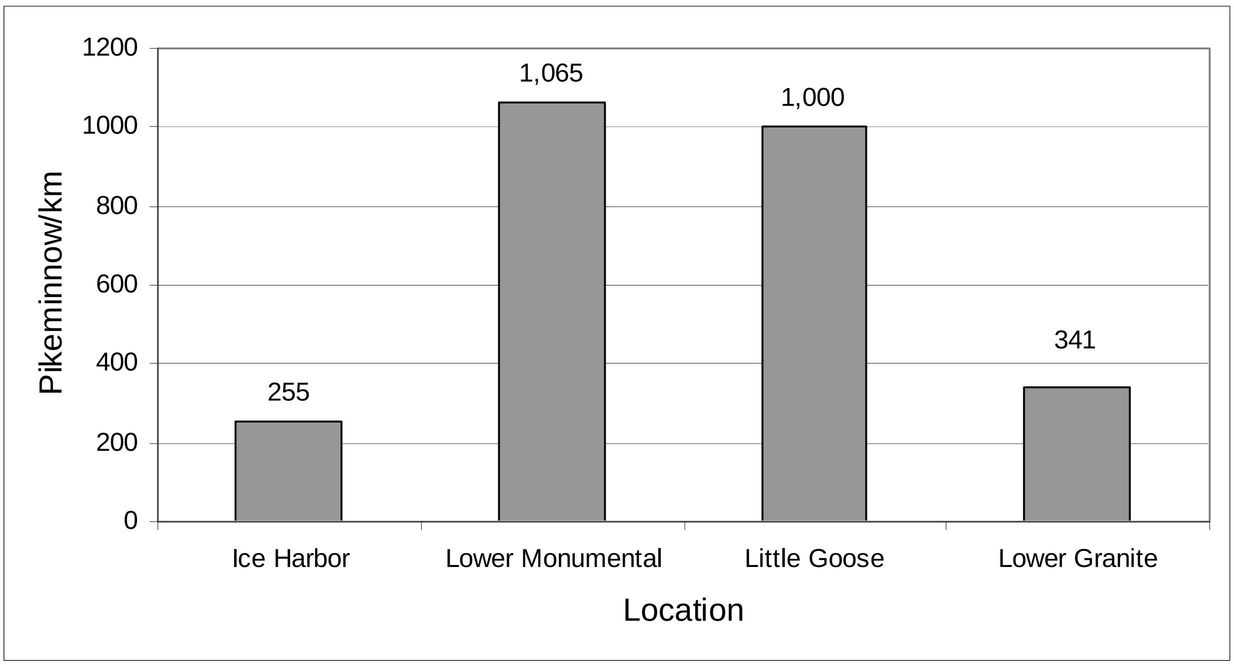

Figure 5-3. Estimated abundance of northern pikeminnow upstream from the confluence of the Columbia and Snake Rivers (data from Beamesderfer et al. 1996).

5.3.2 Productivity

Northern pikeminnow populations in the Columbia River basin do not appear to be facing any demographic risks. On the contrary, natural production appears to be strong, as reflected by the continuing rigorous prosecution of the program for their removal. The program (Ward et al. 2002) represents the most robust management activity affecting the northern pikeminnow population. Although millions of pikeminnow have been removed from the Columbia and Snake River populations, the need for removal and control continues, indicating their high productivity in these areas. The management fisheries harvested 201,164 northern pikeminnow 200 mm FL in 2002 (Takata and Friesen 2003). Beamesderfer (1992) attributed the widespread distribution, resiliency, and productivity of northern pikeminnow to their relatively broad requirements for spawning and rearing habitat.

As large fish have been removed, the size structure of northern pikeminnow populations has decreased, and no compensation in reproduction or growth has been observed (Knutsen and Ward 1999; Zimmerman et al. 2000). Similarly, no trends of increased predation, reproduction, or growth of walleye or smallmouth bass have been observed (Ward and Zimmerman 1999; Zimmerman 1999; Friesen and Ward 2000). ODFW expects to continue to collect information on population dynamics of northern pikeminnow, walleye, and smallmouth bass along with predation indexing.

5.3.3 Harvest

Since 1990, when a focused pikeminnow control and management program was implemented, over 1.7 million northern pikeminnow have been removed from the lower Columbia and Snake Rivers, with annual exploitation since 1991 averaging over 12% of fish >250 mm FL (Table 5-2). Evaluating the program involves monitoring how many and what proportion of northern pikeminnow are harvested annually for each fishery, and how their removal affects the rate at which they take other fish. The program:

- compares predation indices before and after sustained implementation of the program,
- describes the response of northern pikeminnow to sustained removals, and
- describes the response of other predators (walleye and smallmouth bass) to sustained removals of northern pikeminnow.

Table 5-2. Catch and exploitation rate in the Northern Pikeminnow Management Program, 1990–2001. Includes only fish >250 mm FL (minimum size changed to approximately 200 mm FL in 2000).

Year	Sport Reward		Dam Angling		Site Specific		Other	
1990	4,681	(—)	11,005	(—)	—	(—)	1,648	(—)
1991	153,508	(8.5%)	39,196	(2.2%)	—	(—)	7,366	(—)
1992	186,095	(9.3%)	27,442	(2.7%)	—	(—)	8,766	(—)
1993	104,536	(6.8%)	17,105	(1.3%)	—	(—)	3,460	(—)
1994	129,384	(10.9%)	15,938	(1.1%)	9,018	(1.2%)	—	(—)
1995	199,788	(13.4%)	5,397	(0.3%)	9,484	(1.9%)	—	(—)
1996	157,230	(12.1%)	5,381	(0.3%)	6,167	(0.5%)	—	(—)
1997	119,047	(8.8%)	3,517	(0.1%)	2,806	(0.5%)	—	(—)
1998	108,372	(11.1%)	3,175	(0.1%)	3,035	(0.3%)	—	(—)
1999	114,687	(12.5%)	3,559	(0.0%)	1,604	(0.1%)	—	(—)
2000[a]	121,519	(11.9%)	423	(0.0%)	554	(0.0%)	—	(—)
2001[a]	153,577	(16.0%)	2,751	(0.0%)	518	(0.0%)	—	(—)
2002	200,533				712			

[a] Although minimum size in the sport-reward fishery was decreased to approximately 200 mm FL (9 in total length) in 2000, for comparison purposes, totals for 2000 and 2001 reflect catch of fish >250 mm only. Catch of fish 200-250 mm FL totaled 67,945 in 2000 (6.6% exploitation), and 87,317 (10.6%) in 2001.

As shown in Table 5-2, annual exploitation rates since 1991 average over 12% of northern pikeminnow >250 mm FL, and the minimum goal of 10% exploitation has been met or exceeded in 9 of 11 years. All fisheries target large, piscivorous northern pikeminnow, with mean fork lengths of just under 10 in (346 mm) in the sport-reward fishery, 15 ¾ in (401 mm) in the dam-angling fishery, and 16 in (409 mm) in the site-specific fishery (Friesen and Ward 1999).

Recommendations from a review and audit of the Northern Pikeminnow Management Program (NPMP) (Hankin and Richards 2000) included decreasing the minimum size of northern pikeminnow eligible for reward from 11 inches to 9 inches total length (similar to a reduction from 250 mm to 200 mm FL), and this change was made in 2000. Exploitation rate of fish 9-11 inches total length was 6.6% in 2000 and 10.6% in 2001, resulting in overall exploitation estimates of 10.9% and 15.5%.

5.4 Factors Affecting Population Status

5.4.1 Northern Pikeminnow Management Program History

Intensive predation by northern pikeminnow on juvenile Pacific salmon *Oncorhynchus* spp. has been well-documented throughout the lower Columbia River basin (Rieman et al. 1991; Vigg et al. 1991; Ward et al. 1995; Ward et al. 2002) (Figure 5-4 andFigure 5-5).

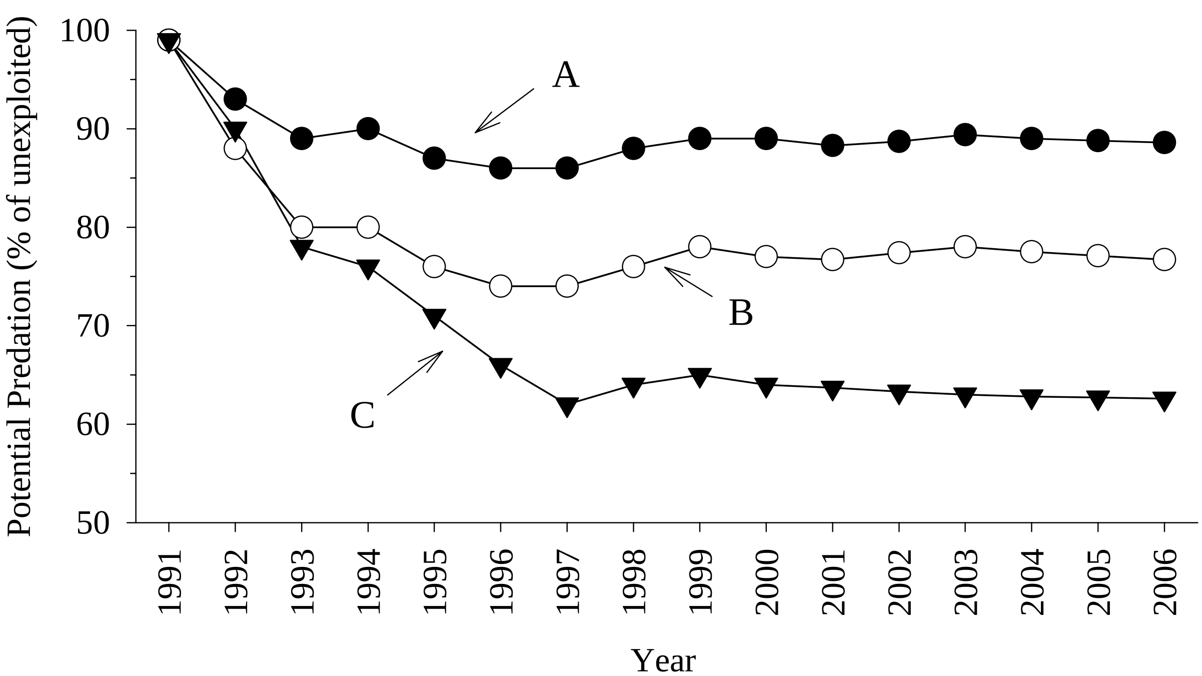

Figure 5-4. Maximum (A), median (B), and minimum (C) estimates of potential predation on juvenile salmonids by northern pikeminnow relative to predation prior to implementation of the Northern Pikeminnow Management Program. Trends after 2002 indicate predicted predation in future years if exploitation is maintained at mean 1996–2002 levels (from Takata and Friesen 2003).

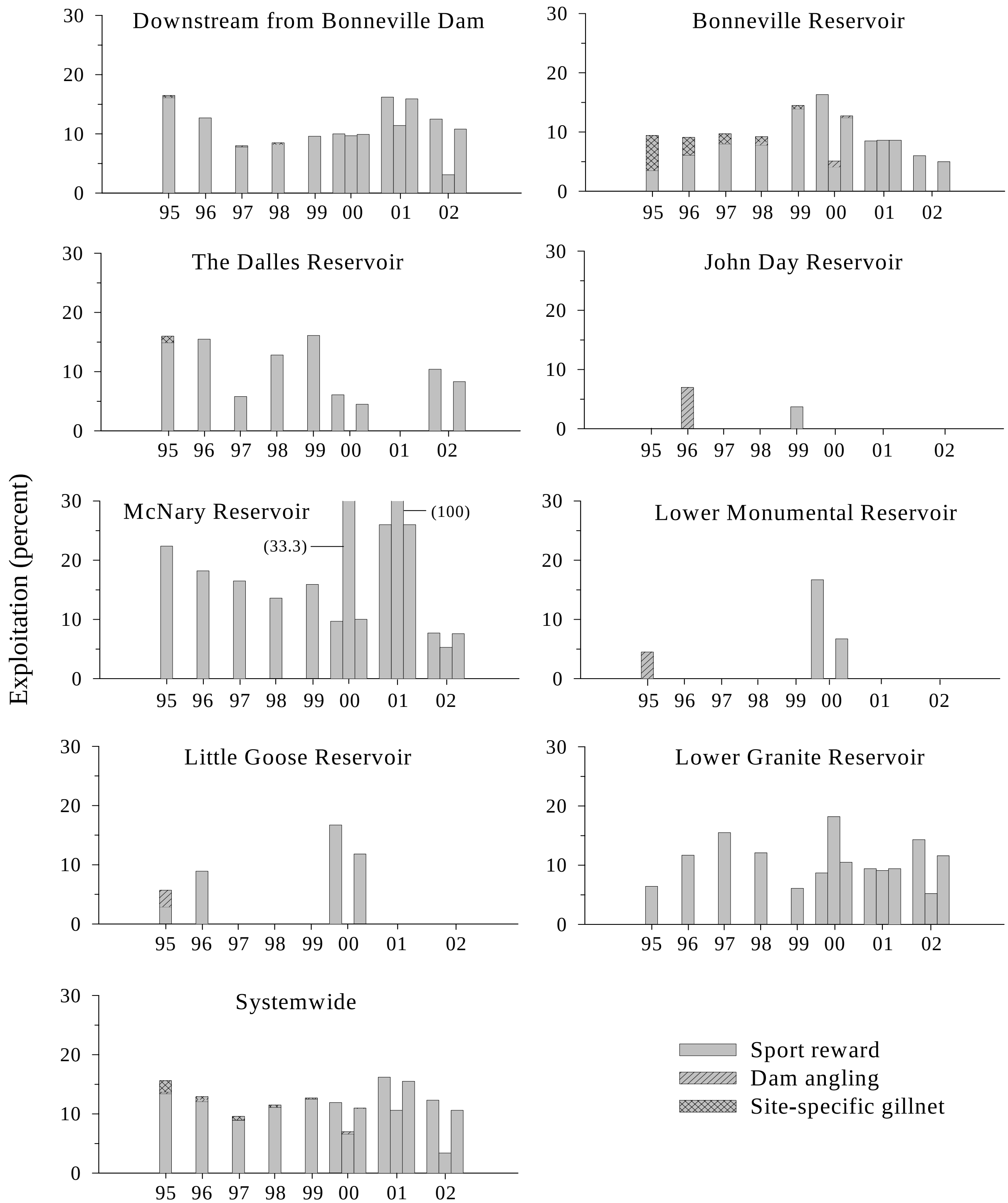

Figure 5-5. Exploitation of northern pikeminnow 250 mm FL by reservoir/area and fishery, 1995–2002. For 2000–2002, vertical bars, from left to right, show exploitation for northern pikeminnow 250 mm FL, 200-249 mm FL, and 200 mm FL. Exploitation rates were not corrected for tag loss in 2000–02 (from Takata and Friesen 2003).

The NPMP was begun in 1990 based on findings from earlier work in John Day Reservoir (Poe et al. 1991; Vigg et al. 1991; Beamesderfer and Rieman 1991; Rieman et al. 1991) and on the potential for successful predation management (Rieman and Beamesderfer 1990). The project's overall objectives were to:

- determine the significance of predation in Columbia River reservoirs through indexing predator abundance and integration with consumption indices.
- implement a predator control fishery development plan, beginning with a test fishery in John Day Reservoir in 1990.
- initiate an evaluation of the Predator Control Program.

Developing northern pikeminnow fisheries required adaptive management. Harvesting techniques were tested from 1990–93 and the most successful were continued. Because they were not able to harvest significant numbers of northern pikeminnow, lure trolling, purse seining, electrofishing, trap-netting, and tribal and commercial long-line fisheries were discontinued.

Adaptive management also has been required for the continued success of the fisheries. The sport-reward fishery was relatively unsuccessful in 1990 until the reward was raised from $1 to $3 per northern pikeminnow. From 1991–94, anglers were paid $3 for each northern pikeminnow at least 11 inches total length (similar to 250 mm FL). Tagged fish were worth $50.

In 1995, the reward changed from $3 to a tiered reward system based on total number of fish caught and this resulted in increased participation. The reward paid to successful anglers was $4 for the first 100 fish caught in the season, $5 for each fish from 101-400, and $6 per fish when catch exceeded 400. Tagged fish were still worth $50. In mid-2001, rewards were temporarily increased to $5, $6, and $8, with tagged fish increasing in value to $1,000. This was an attempt to increase exploitation as one means of partially offsetting poor migration conditions for juvenile salmonids. In 2002, the tiered reward system returned to $4, $5, and $6, with tagged fish being worth $100. The number and locations of registration stations have also changed over the years, depending on trends in effort and catch. Current locations of the stations maximize the efficiency of the fishery.

The dam-angling and site-specific fisheries have used adaptive management to maximize catches while decreasing costs. Dam-angling is concentrated in the dams' tailraces where catch per effort is highest. The site-specific fishery is also concentrated in areas where catch per effort is highest. Lessons learned through the NPMP potentially could be used for understanding and limiting predation mortality caused by other species of predators.

ODFW, the National Biological Service (NBS), and WDFW conducted initial predation indexing from 1990–93. Indexing was conducted in lower Columbia River reservoirs (1990) and downstream from Bonneville Dam (1992). Indexing was conducted before significant removals of northern pikeminnow in each area (Parker et al. 1995).

Test fisheries for northern pikeminnow initiated in John Day Reservoir in 1990 included a public sport-reward fishery, a tribal long-line fishery, and an agency-operated dam-angling fishery (John Day and McNary Dams). The dam-angling fishery also was conducted at Bonneville, The Dalles, and Ice Harbor Dams. The success of the sport-reward fishery led to implementation of the fishery throughout the lower Columbia and Snake Rivers in 1991. Dam-angling was also successful in 1990, leading to its implementation at the four lower Columbia River dams in 1991.

The long-line fishery was expanded to include Bonneville and The Dalles reservoirs in 1991. The long-line fishery was discontinued after 1991 due to lack of participation.

Other technologies for removal of northern pikeminnow were tested from 1990–93, including lure trolling, purse seining, electrofishing, trap-netting, and commercial long-lining, but none proved effective. In 1994, a site-specific gill net fishery to remove northern pikeminnow near hatchery release points and tributary mouths was implemented and considered successful. Implementation of new test fisheries was discontinued after 1994, leaving sport-reward, dam-angling, and site-specific fisheries as the methods of northern pikeminnow removal.

Since 1990, over 1.7 million northern pikeminnow have been removed from the lower Columbia and Snake Rivers with annual exploitation since 1991 averaging over 12% of fish >250 mm FL (Table 5-2). Evaluation of the program consists of monitoring the exploitation rate and size of northern pikeminnow harvested annually for each fishery, and monitoring the effects of observed exploitation rates on predation. Monitoring the effects of exploitation includes the elements described above in Section 5.3.3 Harvest and in Table 5-2.

Predation by northern pikeminnow was indexed throughout the lower Columbia and Snake Rivers each year from 1990–96 and in 1999. Indices of predation were consistently lower from 1994–96 than from 1990–93 (Zimmerman and Ward 1999). Whether piscivory by surviving northern pikeminnow has changed since implementation of the program has not been fully resolved (Zimmerman 1999; Petersen 2001).

Predation by resident fishes is known to be a substantial cause of juvenile salmonid mortality, especially in dam tailraces and at outfall locations. Funded by the ACOE, predation studies are being conducted in some areas near dams. For example, conditions in The Dalles Dam tailrace are unique compared to other projects on the Columbia or Snake Rivers. This dam has a complex basin with a series of downriver islands where predators reside. Studies have been conducted to examine the behavior of predators and estimate the relative densities of northern pikeminnow and smallmouth bass in The Dalles Dam tailrace, and to apply habitat models for these predators (Martinelli and Shively 1997; Petersen et al. 2001).

Recent studies show a relatively high number of smallmouth bass compared to northern pikeminnow in The Dalles Dam tailrace (Petersen et al. 2001). Habitat models developed for northern pikeminnow use water velocity, depth, distance to shore, and bottom substrate type as independent variables. Fitted equations were used in GIS to predict the relative quality of northern pikeminnow habitat throughout The Dalles Dam tailrace for three flow conditions (Petersen et al. 2001). Future work will attempt to improve the northern pikeminnow models by testing some assumptions and adding new data from radio-tagged predators. Habitat models also will be developed for juvenile salmonids and smallmouth bass in The Dalles Dam tailrace using recent, or planned, telemetry studies. These models will be linked to computational fluid dynamics (CFD) models of the tailrace, providing a flexible tool for management decisions. Future studies may also include work in the John Day Dam tailrace to examine predator and prey behavior in response to dam operation and to evaluate the juvenile salmonid bypass.

5.4.2 NPMP Review

In September 1999, the NWPPC[1] recommended that future funding of the NPMP depend on an independent review of the program. Completed in April 2000 (Hankin and Richards 2000), the review reported on the justification for the program and its biological performance, examined the program's cost-effectiveness, and outlined principal findings and recommendations concerning biological and economic issues. Although the review made recommendations for a program that could achieve objectives at a reduced long-term cost, reviewers found that studies suggest that the impact of northern pikeminnow predation is much likely greater than what it may have been prior to construction of dams. (The report found the review task was greatly simplified by the number of papers published in fisheries journals.)

The report also included several recommendations to increase the efficiency and reliability of program evaluation. These recommendations have been implemented and include:

- adopting a scale-age validation study.
- minor changes to the predation model.
- better estimate of the Force of Natural Mortality.
- statistical consultation to review methods of estimating exploitation rates, natural mortality, and northern pikeminnow abundance.
- reduction of the WDFW staff by one permanent full-time position and reducing one permanent full-time position to a 9-month career seasonal position.

A decrease in the minimum size of fish eligible for rewards also was recommended; this was implemented in 2000 as described above.

Economic recommendations included decreasing the costs associated with dam-angling and site-specific fisheries, and reducing the number of agencies involved in program oversight. These recommendations were implemented in 2000. Dam-angling and site-specific costs continue to decrease. The number of agencies involved in the program has decreased because:

- program oversight formerly shared by the PSMFC and the Columbia Basin Fish and Wildlife Authority (CBFWA) is now conducted solely by PSMFC.
- coordination of dam-angling and site-specific fisheries by Columbia River Inter-Tribal Fish Commission (CRITFC) has been eliminated.
- reduction in scope of dam-angling and site-specific fisheries has eliminated all tribes other than the Yakama Indian Nation.

Additional recommendations included conducting further study of the tiered reward system, and exploring the possibilities of increasing rewards by decreasing promotion costs.

5.4.3 Harvest

Under continued implementation of the large-scale predator removal program for northern pikeminnow, harvest is likely the primary determinant affecting northern pikeminnow status in the Columbia Basin, certainly in terms of management activities. Since 1990, a controlled harvest program has been in place to maintain a desired exploitation rate of northern pikeminnow as a means to increase survival of juvenile outmigrating salmonids in the Columbia River basin (Ward et al. 2002). Since 1990, over 1.7 million pikeminnow have been removed

[1] Now the Northwest Power Planning and Conservation Council

from the lower Columbia and Snake rivers, with annual exploitation since 1991 averaging over 12% of fish >250 mm fork length (Table 5-2). Thus, harvest likely plays the biggest role in affecting future northern pikeminnow population status in the Columbia River Basin.

5.4.4 Recruitment

As discussed above, Beamesderfer et al. (1996) found a negative correlation between concurrent year classes of walleye and northern pikeminnow, and suggested that walleye might influence (reduce) northern pikeminnow numbers by predation. Walleyes are a predator of salmonids, but to a much lesser extent than northern pikeminnow (Rieman et al. 1988). Thus, management favoring walleye might provide a net benefit in salmon survival. Although physical variables are known to influence walleye year-class strength (Busch et al. 1975; Koonce et al. 1977; Serns 1982), similar relations have not been demonstrated for Columbia River walleye stocks (Connolly and Rieman 1988). Species interaction potentially affecting recruitment could subsequently affect northern pikeminnow. However, the effect of recruitment limitation as a function of species interaction is assumed to be minimal compared to affects of harvest under the northern pikeminnow removal program (Ward et al. 2002).

5.4.5 Species Interactions

5.4.5.1 Predation

Perhaps because northern pikeminnow are a predator on outmigrating juvenile salmonids, and because since 1990, they have been the target of a large-scale predator removal program (Beamesderfer et al. 1996; Ward et al. 2002), relatively little attention and research have been focused on predation *on* northern pikeminnow. However, due to their robust demographic trends and relatively high and stable abundance, predation on northern pikeminnow does not appear to limit their production. WDFW instituted a predator management (tiger musky introduction) program in the Cowlitz (Mayfield Lake) and Lewis (Merwin Lake) river systems to reduce the abundance of northern pikeminnows (Jack Tipping, WDFW).

5.4.5.2 Competition

A similar argument can be made for northern pikeminnow regarding the potential negative effects of competition within and between species. If these competitive mechanisms reduce or limit natural production, their effects appear to be masked by productivity and reproductive potential that require ongoing pikeminnow removal to suppress the effects of their predation on outmigrating juvenile salmonids. In the Columbia River reservoirs, northern pikeminnow represent the only native piscivorous salmonid predators. However, numerous nonnative predatory fish species have been introduced into the Columbia Basin (e.g. walleye, smallmouth bass *Micropterus dolomeui,* and channel catfish *Ictalurus punctatus*), and interactions and dynamics among native and non-native fish species, and the subsequent ecological responses are difficult to accurately predict (Beamesderfer et al. 1996). Ward et al. (1995) reported that direct and indirect competitive interactions may affect northern pikeminnow habitat use, prey availability, or juvenile survival, which may in turn contribute to differences in growth, mortality, or recruitment of northern pikeminnow among areas and reservoirs studied.

Furthermore, Ward and Zimmerman (1999) described the response of smallmouth bass density, year-class strength, consumption of juvenile salmonids, mortality, relative weight, and growth to sustained removals of northern pikeminnow in the lower Columbia and Snake Rivers. However, resulting density, consumption, mortality, and growth rate estimates were similar to those determined before northern pikeminnow removals.

5.4.6 *Water Development*

5.4.6.1 Dams

Northern pikeminnow have successfully evolved in a range of dynamic lentic and lotic ecosystems, and have successfully adapted to varied habitat conditions within those systems, Thus, the species potential for adaptation has allowed northern pikeminnows to flourish despite construction and operation of the Columbia Basin hydropower system. Dams, and specifically the orientation and creation of protected habitat and increased prey availability (e.g. the juvenile fish bypass outlet of Bonneville Dam) create favorable areas for high densities of northern pikeminnow and salmon smolts that make the predation of northern pikeminnow more efficient, thus perhaps *enhancing,* rather than limiting, pikeminnow population growth and productivity (B. Muir, NOAA Fisheries, personal communication). In the lower Columbia River Basin, reservoirs impounded by dams in the Cowlitz and Lewis river systems (Mayfield Lake and Merwin Lake respectively) likely contributed to increased abundance and production of pikeminnow (J. Tipping reports, WDFW mid-90s).

5.4.6.2 Flow Alterations

Interannual variation in water-years, and flow alterations within and among years, may have relevant effects on northern pikeminnow population status, year-class production, and effectiveness of pikeminnow predation on juvenile salmonids in the Columbia River basin. Mesa and Olson (1993) determined prolonged swimming performance of two size-classes of northern pikeminnow, and reported that water velocities from 3.28 to 4.27 ft/sec (100 to 130 cm/sec) may exclude or reduce predation by northern pikeminnow around juvenile bypass outfalls at Columbia River dams, at least during certain times of the year. Furthermore, these authors recommend that construction or modification of juvenile bypass facilities place the outfall in an area of high water velocity and distant from eddies, submerged cover, and littoral areas for the same reason.

5.4.7 *Water Quality*

5.4.7.1 Temperature

Northern pikeminnow tolerate a wide range of temperatures.

5.4.7.2 Turbidity

Increased turbidity was demonstrated to reduce efficiency of visual predation of YOY white sturgeon by northern pikeminnow in controlled predation studies (Gadomski et al. 2000, 2001, 2002).

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