STATUS REPORT OF THE PACIFIC LAMPREY (*LAMPETRA TRIDENTATA*) IN THE COLUMBIA RIVER BASIN

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INTRODUCTION

The widespread decline of Pacific lamprey (*Lampetra tridentata*) in the Pacific Northwest, especially in the Columbia River system has led to concerns and questions from a number of regional agencies, Native American tribes, and the public. To address these concerns, new research efforts must focus on specific problems associated with this understudied species. The preservation and restoration of this species is critical for a number of reasons, including its importance to the tribes and its importance as an indicator of ecosystem health. Historically lamprey have been labeled a pest species due to the problems associated with the exotic sea lamprey, *(Petromyzon marinus)*, invading the Great Lakes.

The Pacific lamprey is native to the Pacific Northwest and has coexisted with native ichthyofauna for thousands of years. The recovery of the Pacific lamprey may be linked to salmon recovery. In contrast to the sea lamprey, the Pacific lamprey are important fish of cultural, utilitarian, and ecological significance. The following narrative includes a review of the current status of Pacific lamprey in the Pacific Northwest and a list of recommendations for research and management to restore Pacific lamprey.

Cultural Significance: The Pacific lamprey maintains a place of cultural significance in the Columbia and Snake River Basins. Tribal peoples of the Pacific Coast and interior Columbia Basin have harvested these fish for subsistence, ceremonial, and medicinal purposes for many generations (Figure 1).

Figure 1. Umatilla Indians on the Umatilla River, Oregon. Pacific lamprey (eels) drying on rack. Source: Moorehouse Collection 1903.

The tribes use the common name eel when in reference to Pacific lamprey in the Basins. The fish are often harvested at locations where the geology favors capture such as falls or barriers. Two well known places where tribal members historically harvested Pacific lamprey (eels), were at Kasuth near the mouth of the Snake River and at Wallula near the mouth of the Walla Walla River. Eeling is usually done at night when the fish are most active. Active capture methods are used such as a hook on a pole or dip nets. The fish are then prepared traditionally by drying or roasting. Eel oil is used as medicine and is often used as hair grease. Lamprey as part of the Columbia River tribal culture, are important in ceremonies and celebrations similar to many other foods. There are many legends that are associated with the eels, such as the following legend of the eel and the sucker:

"I have heard it said that long ago, before the people, the animals were preparing themselves for us. The animals could talk to each other during this time. The eel and the sucker liked to gamble so they began to gamble. The wager was their bones. The eel began to lose but he knew he could win. The eel kept betting until he lost everything. That is why the eel has no bones and the sucker has many bones."

Lamprey are an integral part of Columbia and Snake River tribal cultures and other tribes along the Pacific coast (Anglin et al. 1979; Mattson 1949; Pletcher 1963).

Utilitarian Significance: Lampreys have been valued by other user groups in the Pacific Northwest. Fur trappers seeking coyote, utilized lamprey as bait in the early days (Mattson 1949; pers. comm. Milo Bell, Univ. Washington retired). At the turn of the century, Oregon began developing artificial propagation of salmonids. Fish culturists found that ground raw Pacific lamprey was an ideal feed for young salmon. Adult lamprey were collected at Willamette Falls and then transferred to cold storage to be processed (Figure 2). During the year 1913, twenty seven tons were harvested for this use (Clanton 1913).

In the following years, lamprey became commercially important. From 1941 through 1949 on the Willamette River, a commercial fishery developed for Pacific lamprey at the Willamette Falls. From 1943 to 1949, a total of 816 tons of lamprey were harvested (Figure 3). The harvest was estimated to be between 10 to 20 percent of the total run. The primary use of the fish was for vitamin oil, protein food for livestock, poultry, and fish meal (Mattson 1949). Presently, Pacific lamprey are important for scientific research as a source for medicinal anticoagulants, for teaching specimens (North Carolina Biological Supply House regularly collects at Willamette Falls), and for food (in 1994, approximately 1800 kg were exported to Europe).

Ecological Significance: Evidence suggests that Pacific lamprey was well integrated into the native freshwater fish community and as such had positive effects on the system. It was in all probability, a big contributor to the nutrient supply in oligotrophic streams of the basin as the adults died after spawning (Beamish 1980). Lamprey were an important part of the food chain for many species (Table 1). We suspect that it was an important buffer for upstream migrating adult salmon from predation by marine mammals. From the perspective of a predatory sea mammal it has at least three virtues: (1) it is easier to capture than adult salmon; (2) it is higher

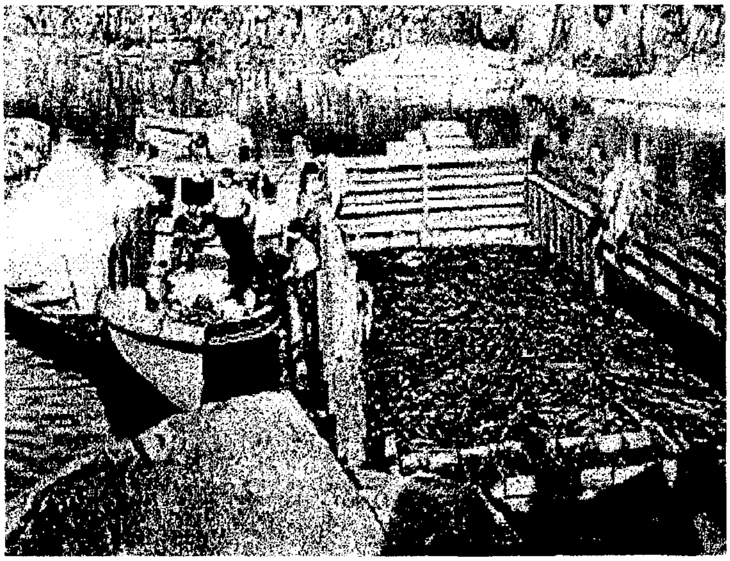

Figure 2. Fifteen tons of Pacific lamprey (eels) aboard a scow for delivery to a cold storage plant to be preserved as food for hatchery salmon fry (Clanton 1913).

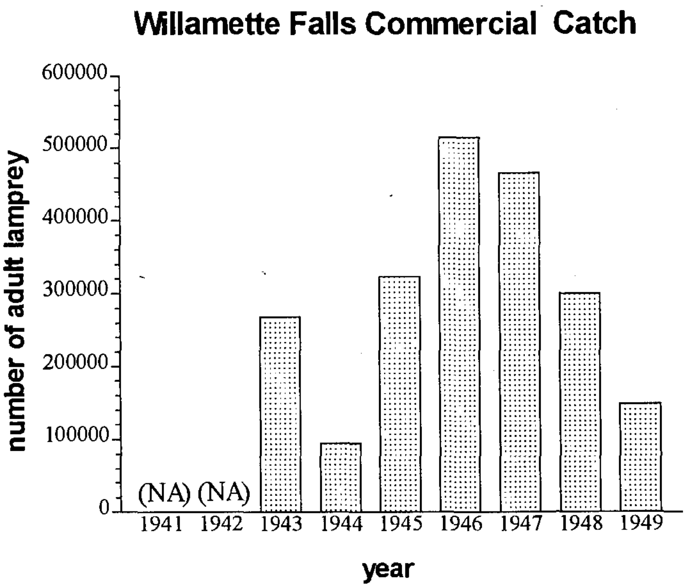

Figure 3. Commercial catch at Willamette Falls on the Willamette River, Oregon. The graph assumes 350 grams per lamprey (as determined from samples of fish captured in 1993 and 1994). The commercial catch data for 1941 and 1942 are not available. Modified after Mattson (1949).

Table 1. Predators of Lampreys

Scientific name	Common name	Comments
Ictalurus punctatus	channel catfish	exotic predator on juveniles
Ascipenser transmontanus	white sturgeon	feeds on all stages
Ptychocheilus oregonensis	northern squawfish	feeds on juveniles
Cyprinidae	minnows	egg and larval predators
Anguillidae	eels	egg and larval predators
Cottidae	sculpins	egg and larval predators
Percidae	logperch	egg and larval predators
Oncorhynchus mykiss	juvenile rainbow trout	egg and larval predators
Eumetopias jubatus	Steller sea lion	adult lampreys at mouth of rivers (82%)
Physeter catodon	sperm whale	adult lampreys
Phoca vitulina richardsi	harbor seal	adult lampreys
Zalophus californianus	California Sea lion	adult lampreys
Ardea herodias	great blue heron	adult lampreys
Sterna fosteri	Forster's tern	ammocoetes
Larus occidentalis	Western gull	ammocoetes
Larus californicus	California gull	ammocoetes
Larus delawarensis	ringbill gull	ammocoetes

in caloric value per unit weight than salmonids and (3) they migrate in schools. The lamprey is extraordinarily rich in fats, much richer than salmon. Caloric values for lamprey ranges from 5.92-6.34 kcal/gm wet weight (Whyte et al. 1993); whereas, salmon average 1.26-2.87 kcal/gm wet weight (Stewart et al. 1983). In addition, Roffe and Mate (1984) revealed that, indeed, the most abundant dietary item in seals and sea lions are Pacific lamprey. As a result, marine mammal predation on salmonids may be more severe because lamprey populations have declined. Larval stages and spawned out carcasses of lampreys were important dietary items for white sturgeon in the Snake and Fraser Rivers (Ken Witty, ODFW retired, personal communication, Galbreath 1979, Semakula and Larkin 1968).

Juvenile lampreys migrating downstream may have buffered salmonid juveniles from predation by predacious fishes and sea gulls. Lampreys are found in the diets of northern squawfish (*Ptychocheilus oregonensis)* and channel catfish (*Ictalurus punctatus)* in the Snake River system (Poe et al. 1991). Merrell (1959) found that lampreys were 71% by volume of the diet of gulls and terns below McNary Dam during early May. Juvenile lampreys may have played and important role in the diets of many freshwater fishes (Table 1). Clanton (1913) reported that ground "eel" (lamprey) was the dietary constituent that lead to the best growth of hatchery salmonid fry. Pfeiffer and Pletcher (1964) found emergent ammocoetes and lamprey eggs were eaten by salmonid fry. We speculate that wild juvenile salmonids may have found lamprey to be important prey during the spring.

Historical Distribution: Historical distribution of *L. tridentata* in the Columbia and Snake Rivers was coincident wherever salmon occurred (Simpson and Wallace 1978). Access to suitable habitat rather than distance from the ocean was suggested to be the important factor influencing regional distribution (Kan 1975). The overall distribution of Pacific lamprey is from southern California to the Gulf of Alaska and inland to central Idaho (Hammond 1979). Some specimens have been collected off Hokkaido, Japan (Wydoski and Whitney 1979).

Current Distribution: The current distribution of Pacific lamprey in the Columbia River and tributaries extends to Chief Joseph Dam and to Hells Canyon Dam in the Snake River (Figure 4). Both dams lack fishways and limit distribution of migrating fish; however, no survey to examine the actual distribution throughout Columbia River drainage has been undertaken. There are only sporadic reports of lamprey because of partial data and/or the lack of survey data. Effort is needed to compile all known information. For example, from fish trapping operations at Threemile Dam we know that lamprey are no longer or are very rarely found in the Umatilla River.

Current Status: Data reveal that Pacific lamprey are in precipitous decline in the Columbia and Snake rivers (Figures 5-10). These trends show the same consistent pattern at all dams regardless of the idiosyncratic differences in counting procedures and data processing among different monitoring protocols. Dam counts of lampreys were utilized for determining the status of the Pacific lamprey in the Columbia and Snake River basins. The dam counts should be viewed as trend data and not total counts because there has been little standardized sampling across years and counting was restricted to certain hours. For example, the first fish counters

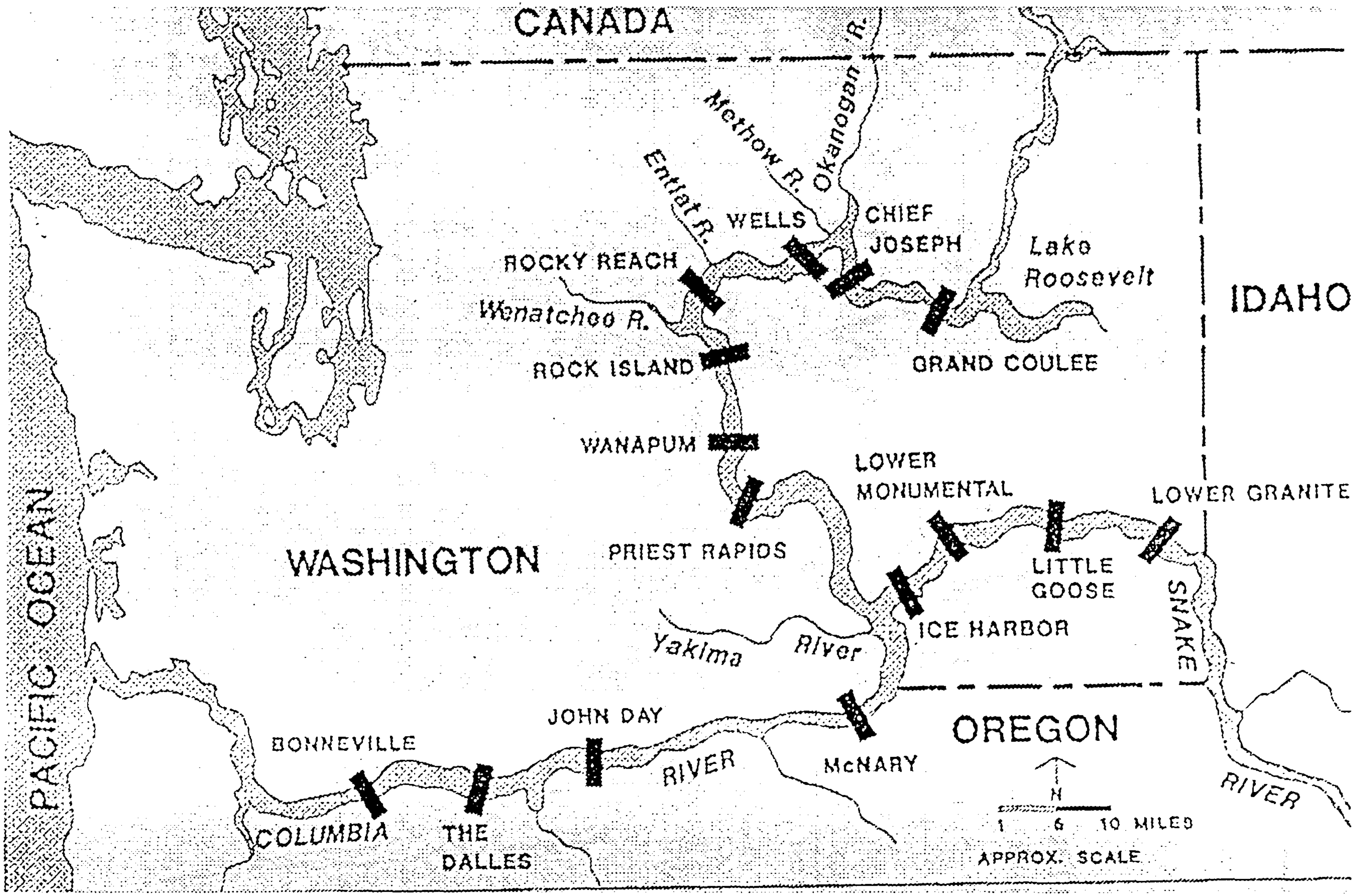

Figure 4. Hydroelectric dams on the Columbia and Snake (mainstem) rivers. Taken from Mullan et al. 1986.

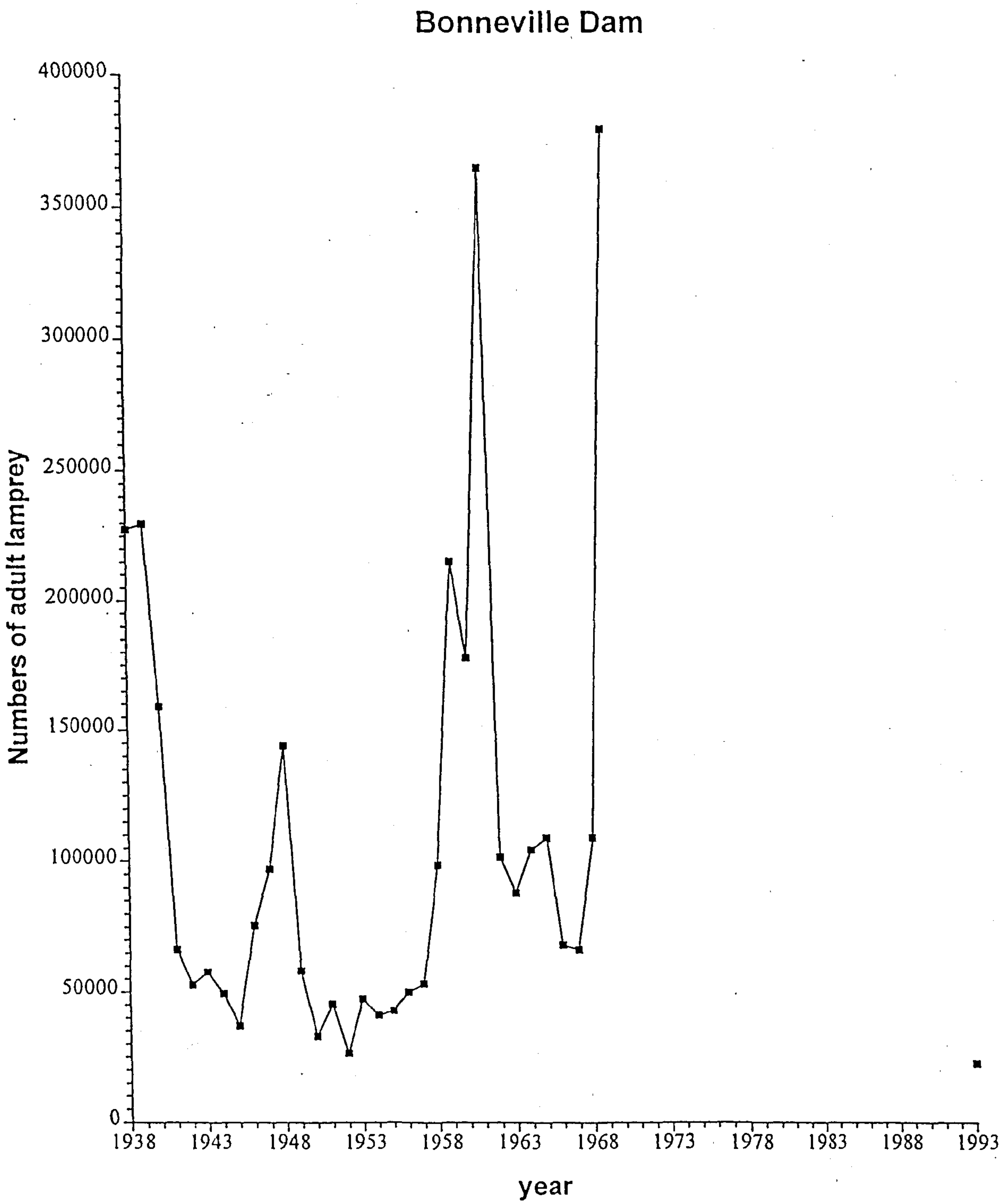

Figure 5 Number of adult lamprey counted at Bonneville Dam Fish Counting Facility (from Corps of Engineers, 1969 Annual Fish Passage Report. Counts for 1993 are based on estimated numbers from Starke and Dalen 1995).

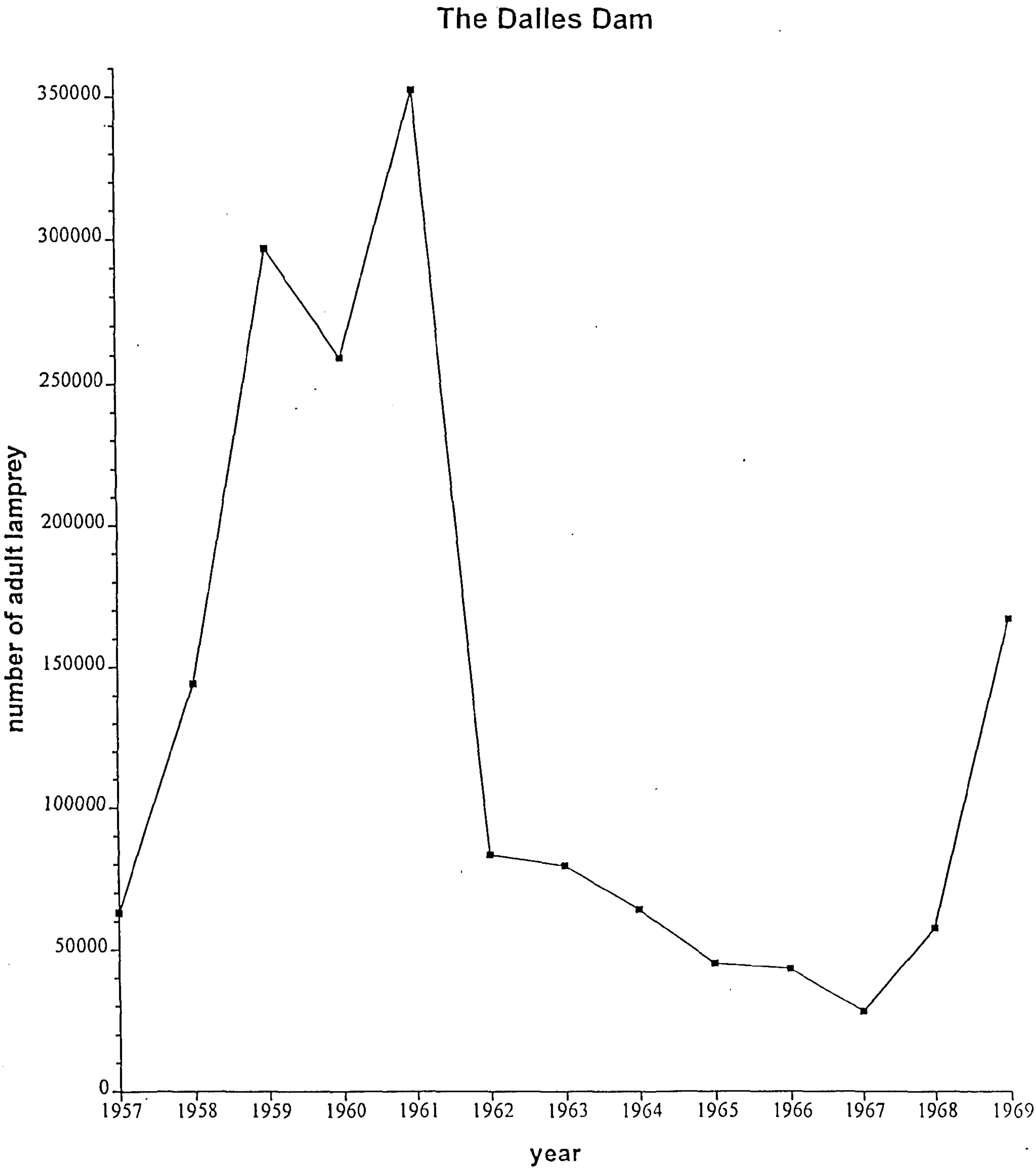

Figure 6.Number of adult lamprey counted at The Dalles Dam Fish Counting Facility (from Corps of Engineers, 1969 Annual Fish Passage Report).

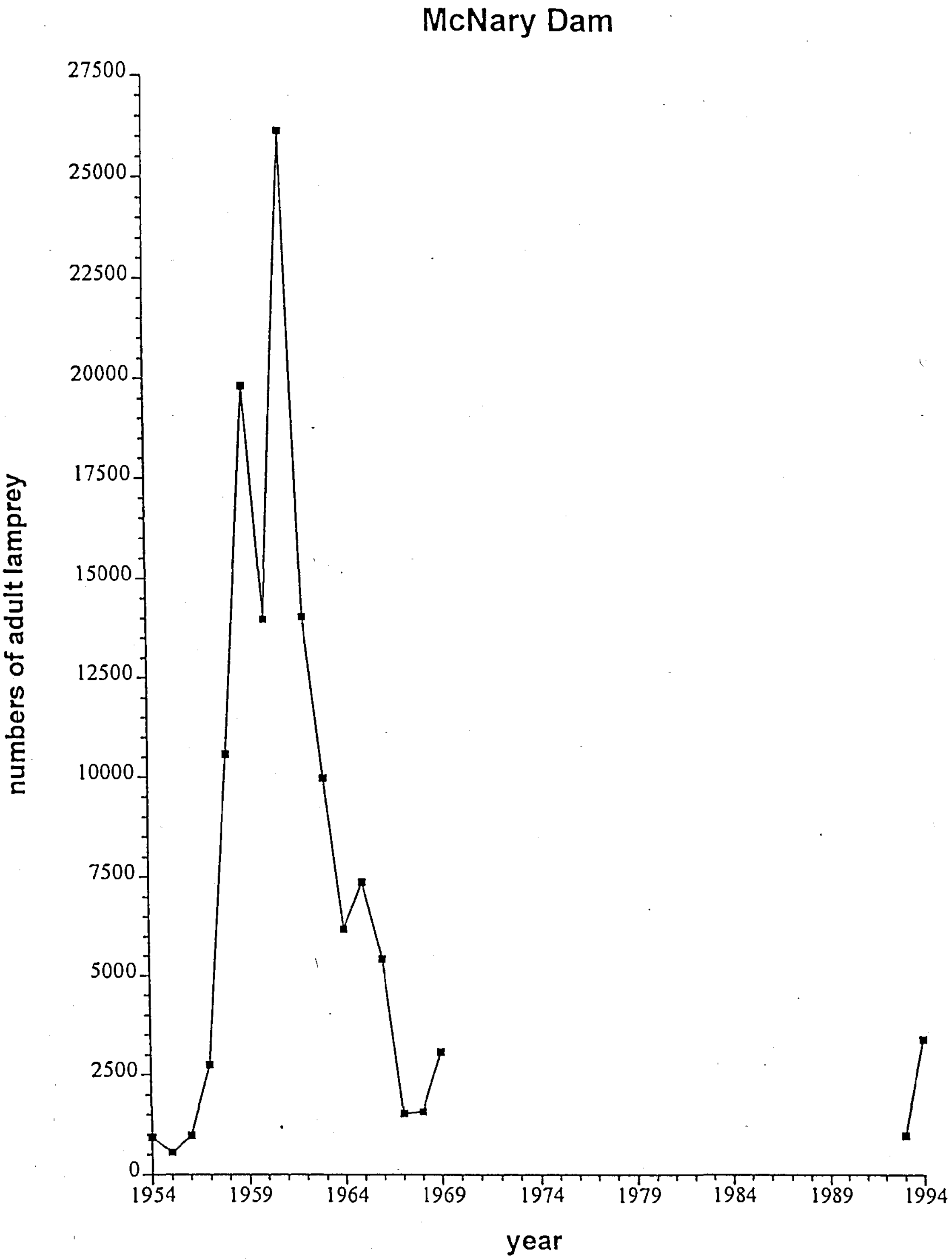

Figure 7-Number of adult lamprey counted at McNary Dam Fish Counting Facility (from the Corps of Engineers, 1969 Annual Fish Passage Report. Counts for 1993 and 1994 are from Washington Department of Fish and Wildlife).

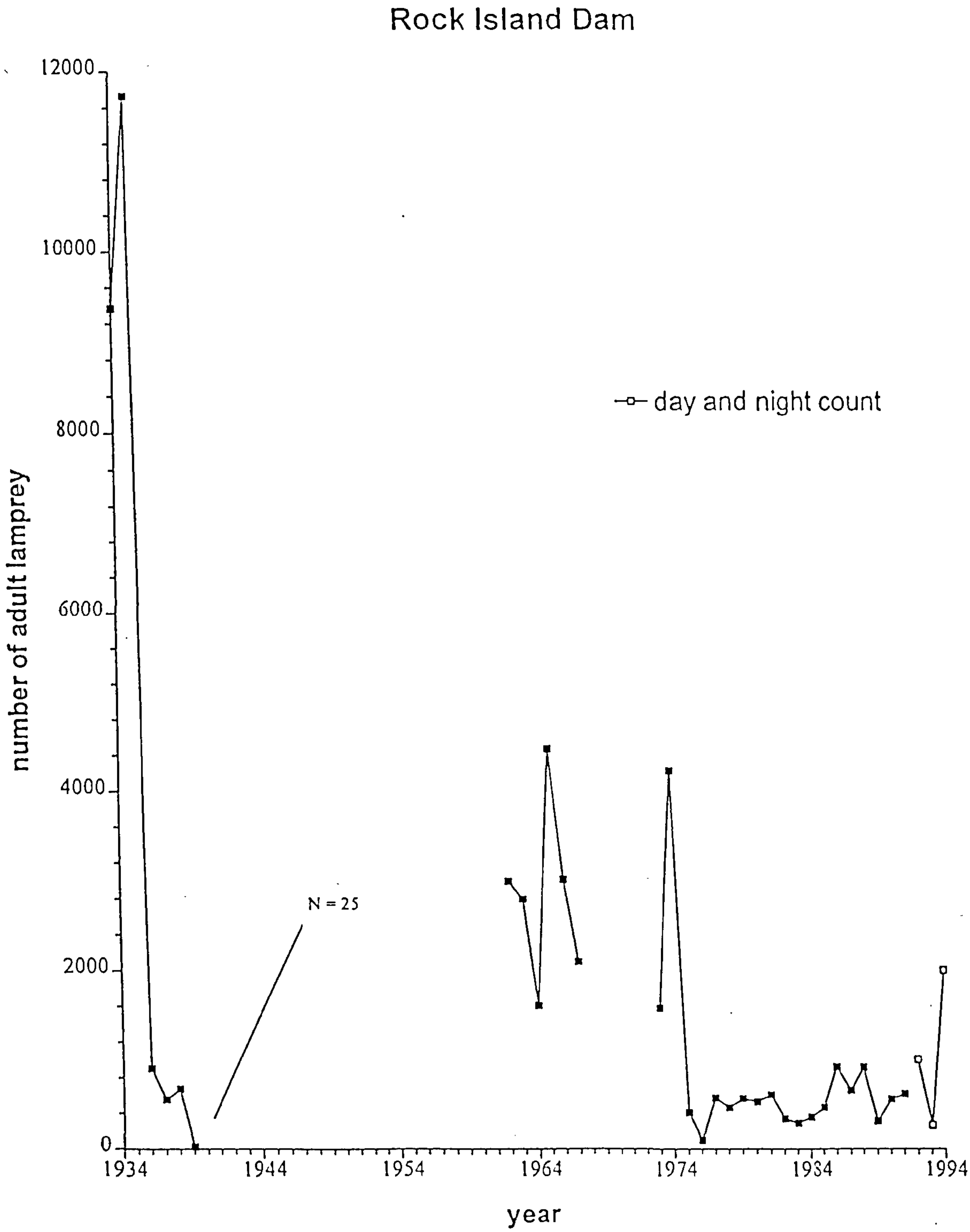

Figure 8. Number of adult lamprey counted at Rock Island Dam Counting Facility (from U.S. Fish and Wildlife Service, Leavenworth, Washington and Chelan County P.U.D.)

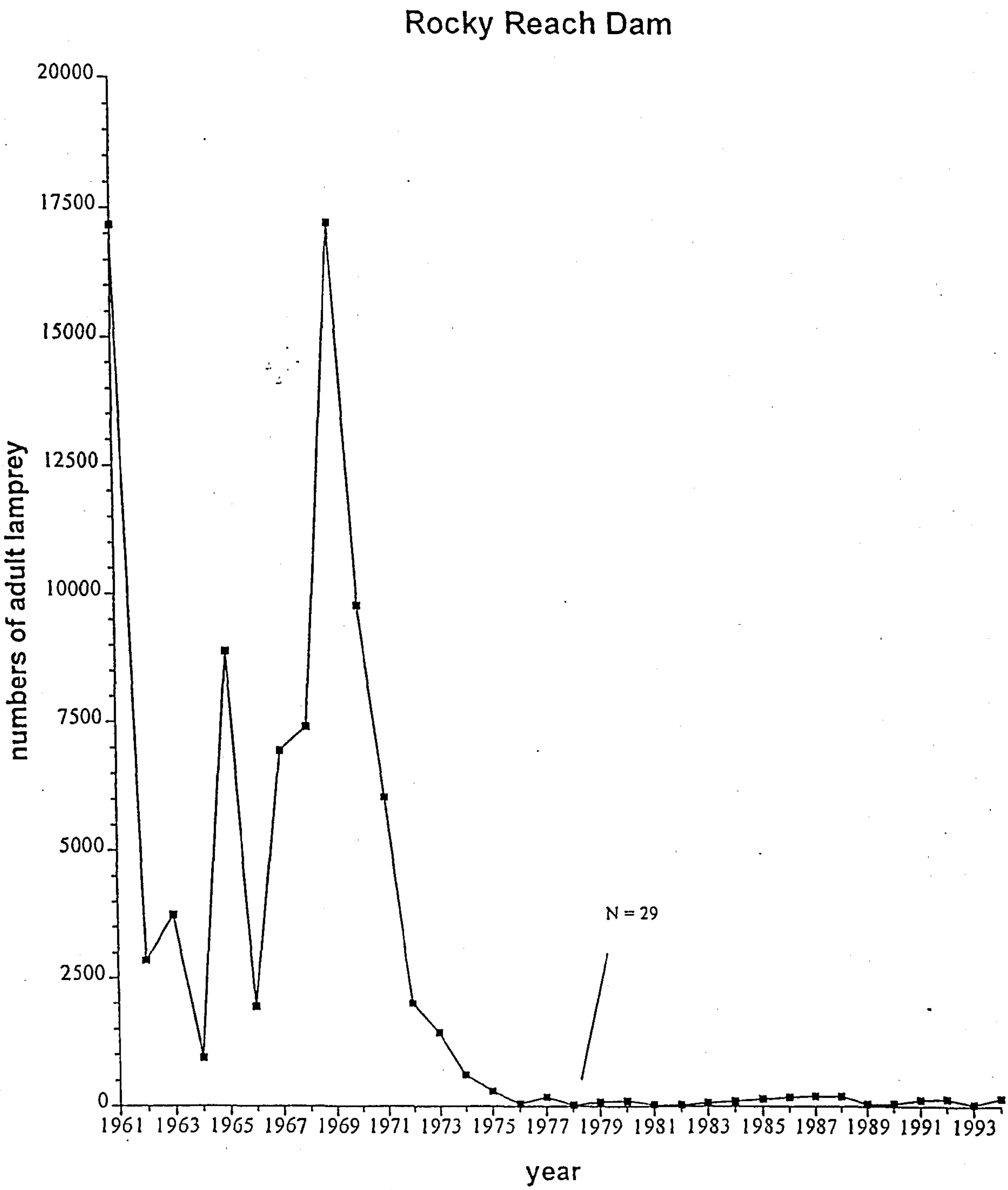

Figure 9. Numbers of adult lamprey counted at Rocky Reach Dam Fish Counting Facility (from U.S. Fish and Wildlife Service, Leavenworth, Washington and Chelan County P.U.D.)

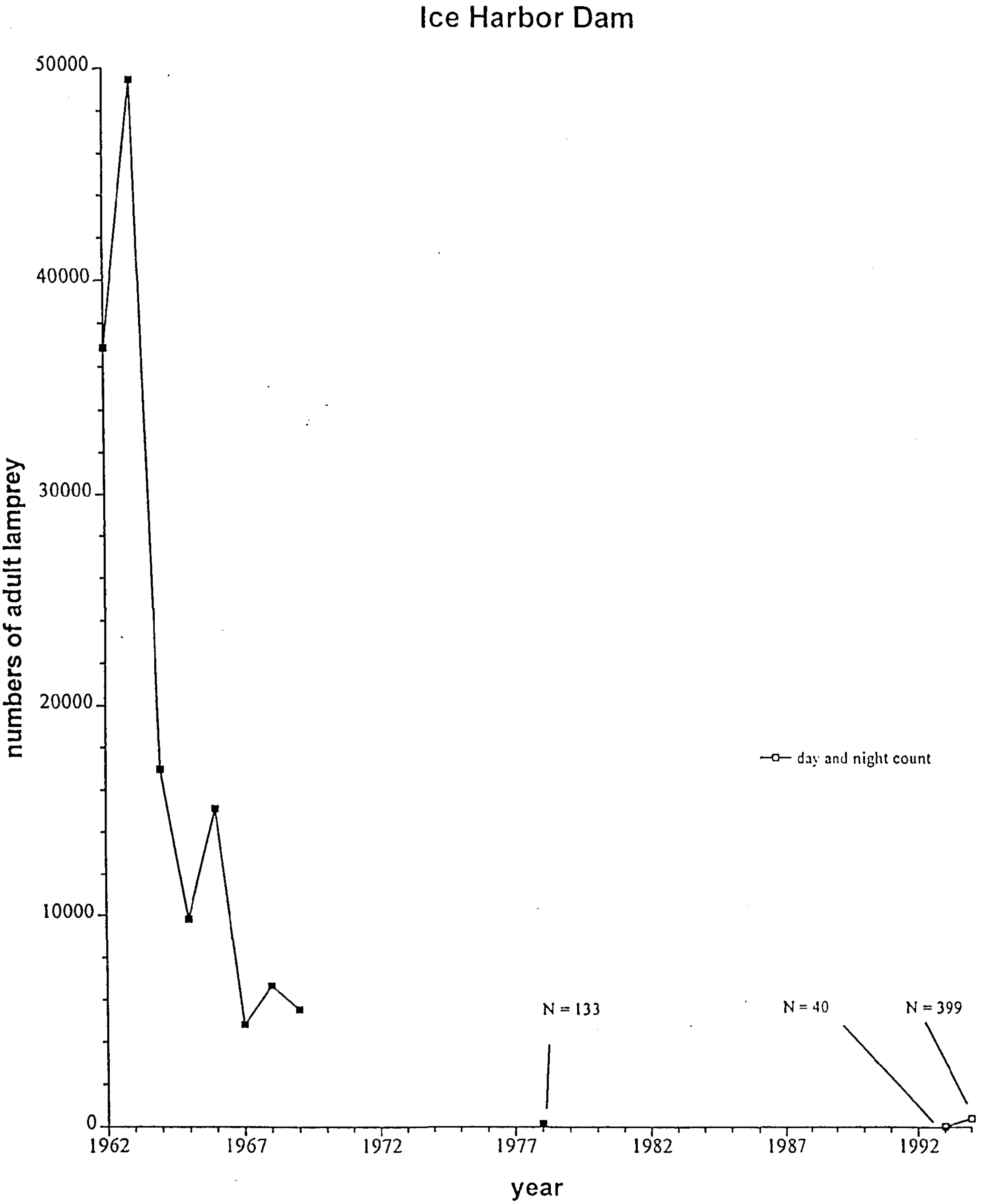

Figure 10.Number of adult lamprey counted at Ice Harbor Dam Fish Counting Facility (from Corps of Engineers, 1969 Annual Fish Passage Report. Count for 1978 from Hammond 1979. Counts for 1993 and 1994 from Washington Department of Fish and Wildlife).

counted fish passing white boards. Today there are windows in the fishway to observe fish passage (Mullan et al. 1986). The fish counters in the past counted for an 8 hour day shift in the beginning and end of the salmon runs and a 16 hour day shift for the main part of the salmon runs (Starke and Dalen 1995). The highest lamprey movement was noted to be at night and therefore lamprey numbers observed during the "salmon counts" should be considered conservative.

Many factors may account for this decline, including (1) passage problems for adult and juvenile lamprey migrating through dams; (2) declining conditions of spawning and rearing habitat in freshwater; (3) decline of the marine prey base including ground fishes, walleye pollock (*Theragra chalcogramma*), Pacific hake (*Merluccius productus)*, and salmonids due to fishing and a variety of factors; and (4) chemical "rehabilitation" (i.e., extermination by rotenone) of streams. In order to gain some perspective on the factors leading to the decline of the Pacific lamprey, we provide a synopsis of its life history followed by a discussion of potential factors that may affect the decline of lampreys based on this life history information.

LAMPREY LIFE HISTORY

Pacific lamprey is one of three species of lamprey that occur in the Columbia River basin. The other two species are the river lamprey *(L. ayresii*) and the western brook lamprey (*L. richardsoni*; Kan 1975). *L. tridentata* and *L. ayresii* are the only two parasitic lamprey in the Columbia River system. *L. richardsoni* completes its life cycle in freshwater and is nonparasitic.

Spawning: Spawning of the Pacific lamprey on the coast of Oregon usually occurs in May with temperatures between 10°C to 15°C. Pacific lamprey migrating inland in the Columbia River spawn later. Both spawning and pre-spawning fish were collected in the John Day River system in Oregon in July (Kan 1975). Mattson (1949) described spawning activity in the Willamette River during June and July. In the Babine River system in British Columbia, Pacific lamprey were observed spawning from June through the end of July (Farlinger and Beamish 1984).

Spawning Habitat: Spawning sites of *L. tridentata* generally occur in low gradient stream sections where gravel is deposited (Kan 1975). The nest sites are constructed at the tail areas of the pools and in riffles (Pletcher 1963; Kan 1975;). Pacific lamprey spawning occurs over gravel with a mix of pebbles and sand (Mattson 1949; Kan 1975). Gravel is an important feature for spawning lamprey. Lamprey held in aquaria divided with three inches of sand on one side and gravel substrate on the other, preferred gravel (Pletcher 1963). Therefore, appropriate substrate is a critical habitat feature for ensuring lamprey spawning.

Flow also seems to be an important spawning requirement. Spawning occurs in lotic habitat with velocities ranging from 0.5 to 1.0 meter per second (Pletcher 1963; Kan 1975). The depth that spawning occurs varies but ranges from 0.4 to 1.0 meter (Pletcher 1963; Kan 1975). In the Babine River system, the spawning depths ranged from 30 cm to 4 m, although most occurred at sites of less than 1 m (Farlinger and Beamish 1984). Although rare, it should be noted that *L. tridentata* have been observed spawning in lentic habitat in the Babine Lake system in Canada, where depths of the nest sites ranged from 0.5 m to 3 m and lamprey generally oriented towards the creek mouth (Russell et al. 1987). Generally, lampreys prefer flowing water for spawning (Russell et al. 1987; Manion and Hanson 1980).

Spawning Behavior: At the beginning of spawning, lamprey generally hide in the substrate or in the shade. However, as spawning proceeds, lamprey are not affected by bright sunlight (Pletcher 1963; Kan 1975). Both sexes begin moving rocks with their buccal funnel to create nests in excavated depressions (Pletcher 1963). Courting consists of a male approaching a female with a gliding motion to stimulate the female (Pletcher 1963). A male attaches his buccal funnel to a female's head, and then wraps his body around the female while releasing milt (Pletcher 1963; Russell et al. 1987; Kan 1975). During each spawning act, approximately 100 to 500 eggs are released and covered by sand and pebbles (Pletcher 1963).

Kan (1975) observed spawning of Pacific lamprey in Oregon and found that nests were approximately 30 cm wide, 3 cm in depth, and oval in shape. In the Babine Lake system of British Columbia, nests were 20-30 cm diameter and 4-8 cm deep (Russell et al. 1987). Absolute fecundity for lampreys in Oregon ranged from 98,000 to 238,400 eggs. The relative fecundity was significantly different between lamprey from coastal Oregon, the Molalla and Umpqua rivers, and lamprey from the inland John Day River. Kan (1975) suggested that the lower fecundity in the John Day lampreys may have been due to a higher cost of migration. After spawning, the Pacific lamprey dies within 3 to 36 days (Kan 1975; Mattson 1949; Pletcher 1963).

Larval Stage: Temperature controls the hatching time of *L. tridentata* eggs. Pletcher (1963) observed eggs beginning to hatch after 19 days at 15°C. The larvae leave the gravel approximately two or three weeks after hatching and drift downstream usually at night. The larvae settle in slow back water areas such as pools and eddies (Pletcher 1963).

The length of larval life of *L. tridentata* is very difficult to estimate due to the inconsistency of length frequency data and the lack of bony structures. The larval stage was estimated to range from four to six years (Richards 1980; Kan 1975; Pletcher 1963) and has been suggested to extend up to seven years (Hammond 1979; Beamish and Northcote 1989). The size of the larvae varies but ranges from 3-5 g and 13-20 cm in length (Mallatt 1983).

During the larval stage, ammocoetes are blind, sedentary, and survive by filtering food particles. Larvae usually feed on detritus, diatoms, and algae suspended above and within the substrate (Moore and Mallatt 1980). Ammocoetes possess a high entrapment efficiency due to mucus secreted by the walls of the pharynx and goblet cells within the gill filaments. The high entrapment efficiency is coupled with low food assimilation. Larvae digested only 30-40% of the food intake while passing large amounts of undigested food (Moore and Mallatt 1980).

Habitat Use: Ammocoetes drift into slow current areas and burrow into the substrate. The slow current allows the larvae to maintain position while burrowing. Under experimental conditions, emergent larvae of size 7-10 mm preferred mud (0.004 cm) over sand (0.005 cm) and gravel (1-0.5 cm) substrate (Pletcher 1963). Current greater than 0.305 m/s prohibited burrowing by emergent larvae in all substrates. When no current was present, larvae of sizes 10-15 mm and 25-30 mm burrowed into the mud faster than larvae of size 40-50 mm. The smallest size group required the most time for burrowing in the sand. With a current of 0.305 m/s, only the 40-50 mm larvae could burrow in the sand, but all groups burrowed into the mud substrate (Pletcher 1963). The current over ammocoete beds in Oregon streams ranges from 0.1 to 0.5 m/s (Kan 1975).

The density of larvae was highest in shallow areas along the banks of the Chemainus River in British Columbia. Ammocoetes <75 mm in length were found in the shallows but only larger larvae >75 mm were found in the deeper middle portion of the river (Richards 1980). Higher densities of ammocoetes are found in the lower sections of rivers with low gradients opposed to sections with steeper gradients (Richards 1980).

Ammocoetes, like other fishes, react to differences in the partial pressure of oxygen. Low oxygen tensions (7-10 mm Hg) caused ammocoetes to emerge and die; whereas higher tensions (18-20 mm Hg) were tolerated at 15.5°C (Potter et al. 1970).

Ammocoetes are usually found in coldwater but have been collected in waters ranging up to 25°C in Idaho (Mallatt 1983). Pacific lamprey ammocoetes held at 14°C and 4°C grew 41% and 11% of body weight per month on a variety of foods in laboratory studies (Mallat 1983). Larval sea lamprey preferred a summer temperature of 20.8° C and ranged from 17.8 to 21.8°C (Holmes and Lin 1994).

Metamorphosis: Transformation of Pacific lamprey from the larval to juvenile life stages generally occurs during July through October (Richards and Beamish 1981; Hammond 1979). However, Pletcher (1963) observed metamorphosis from July to November in this species from the Chemainus River, British Columbia. During this period, the larvae go through morphological and physiological changes to prepare for a parasitic life style in salt water. External signs of metamorphosis are similar in most species of lampreys. The process occurs in seven stages according to external observations (Yousson and Potter 1979). The changes occur first in the mouth, with the oral hood changing into an oval mouth. The development of the eye and the length of the oral disc increase during stages 1-4. Condition factor begins to drop after reaching stage 4 in transforming fish. After four weeks (stage 5), teeth and tongue begin to develop (Richards 1980). The teeth remain soft through stage 6, with cornification occurring near the end of stage 6. When the teeth harden and turn yellow, stage 7 is complete (Richards 1980).

Internal changes such as a development of the foregut during stage 6 coincides with the ability to osmoregulate in salt water (Richards 1980; Richards and Beamish 1981). Changes in the blood proteins occur during metamorphosis (Richards 1980). The gallbladder and the bile duct disappear as the fish transforms to a young adult (Bond 1979). The respiratory system changes from a unidirectional system, in which water flows over the gills, moves through the pharynx, and flows out the gill pores, to a tidal flow system, in which water enters and exits the branchiopores (Lewis 1980). The transformation is associated with a new preference of habitat. Transforming fish are associated with larger substrate and move into higher velocity areas (Richards and Beamish 1981; Potter 1980). By stage 6, Pacific lamprey from the Qualicum River in British Columbia moved from mud and silt areas to 1-4 cm gravels in faster flows (Beamish 1980).

Young Adult/Downstream Migration: While waiting to migrate to the ocean, young adults burrow in cobble and boulder substrate (Pletcher 1963). After completing metamorphosis in October and November, young adults migrate to the ocean between late fall and spring. In the Nicola River of British Columbia, 99% of all young adults migrated by April and May (Beamish and Levings 1991). Increased discharge is associated with migration of young adults and distribution of ammocoetes (Potter 1980; Applegate 1950; Beamish and Levings 1991). In the Fraser River system, 99% of the young adults left the substrate and began migration during the night with increased discharge (Beamish and Levings 1991). Pacific lamprey, like other species of lamprey, rely on currents to be carried downstream (Beamish and Levings 1991). Out-migrating sea lamprey do not actively swim downstream; instead, they drift downstream tail first (Applegate 1950).

The young adults from some populations can stay in freshwater up to 10 months after metamorphosis, although different populations in British Columbia vary in their ability to survive confinement in freshwater (Beamish 1980). Confined Babine River lamprey did not survive past February, while Chemainus River fish survived until July (Clarke and Beamish 1988). The onset of mortality was associated with decrease in plasma sodium concentration and condition factor (Clarke and Beamish 1988).

Downstream migration of young adult lampreys occurs at night in the Columbia River system (Long 1968). Young adults can be sampled from March to June in collection facilities at John Day and Bonneville dams on the Columbia River (Hawkes et al. 1991; Hawkes et al. 1992; Hawkes et al. 1993). Information on winter emigration of lampreys is lacking because collection facilities do not operate all year. It has been suggested that only 10 % of the migrants use the bypass systems located at the Columbia River dams (pers. comm. Bill Muir, NMFS). Long (1968) found that most migrating lamprey enter turbine intakes near the center and bottom. Therefore, salmonid bypass systems may not be adequate for Pacific lamprey juveniles.

Ocean Life: The ocean phase has been estimated to last for periods of up to 3.5 years for Pacific lamprey in the Strait of Georgia in British Columbia (Beamish 1980). Off the coast of Oregon, the duration of the ocean phase was estimated to range from 20 to 40 months (Kan 1975). The timing of entrance into salt water may differ among populations of Pacific lamprey due to environmental conditions (pers. comm., R.J. Beamish, Nanaimo Biological Station, Nanaimo, B.C., Canada). Kan (1975) suggested that coastal populations enter salt water in the late fall, while inland populations enter in the spring. After entrance into salt water, Pacific lamprey move into water greater than 70 m in depth. Young adults have been captured off the Pacific coast of

Canada at depths ranging from 100 to 250 m (Beamish 1980). Pacific lamprey have been collected at distances ranging from 10 to greater than 100 km off the Oregon coast and up to 800 m in depth (Kan 1975). Despite the occurrence of deep water collections, Pacific lamprey are generally considered to be mid-water fish associated with plankton layers (Beamish 1980).

Feeding: Adult lamprey locate their prey by means of olfaction, electroreception, and vision similar to elasmobranch fishes. Sea lampreys, stimulated by amines from prey fish located in water added to tanks, oriented their bodies towards the source of the smell (Kleerekoper 1958). Lampreys possess electroreceptors on head and trunk regions that may be useful in finding prey (Bodznick and Preston 1983). Farmer (1980) suggested lamprey use vision to locate prey items.

Feeding of lamprey can occur in fresh water and salt water, although freshwater feeding is not common. Freshwater feeding occurred above Dworshak Dam on the North Fork of the Clearwater River in Idaho when migration was cut off in 1969 (Wallace 1978), and above dams in British Columbia that stopped migration of young adults to the ocean (Beamish and Northcote 1989). Wallace (1978) suggested that many of the attachments were unsuccessful in Dworshak reservoir. Eventually, Pacific lampreys became extinct in both drainages.

Pacific lampreys attach to fish ventrally near the pectoral area (Roos et al 1973; Beamish 1980). Lampreys create suction in the buccal funnel by changing the volume in the oral cavity (Hardisty and Potter 1971). The tongue contains denticles that rasp to create tissue damage and buccal glands secrete anticoagulant to assist in feeding of blood (Farmer 1980).

Upstream Migration: Beamish (1980) has suggested that lampreys enter fresh water between April and June, and complete migration into streams by September. In the Chemainus River of British Columbia, lampreys migrated into fresh water beginning in late April and 81% of the catch occurred during two days in May (Richards 1980). It is not clear how flow impacts freshwater immigration. Pacific lampreys are considered weak swimmers compared to other fish. Burst swimming speed was calculated to be approximately 2.1 m/sec for lamprey (Bell 1990). On the Fraser River in British Columbia, Pacific lamprey were estimated to migrate 8 km/day (Beamish and Levings 1991). In the Columbia River, the same species was estimated to migrate 4.5 km/day (Kan 1975).

Pacific lamprey overwinter in fresh water and spawn the following spring (Beamish 1980). During the winter, Columbia River dams de-water fishways for maintenance, and it is common for Pacific lamprey to be found and removed at this time (Starke and Dalen 1995). Pacific lamprey generally overwinter in deep pool habitat until spring (R.J. Beamish, personal communication, Dept. of Fisheries & Oceans Nanaimo, British Columbia).

Pacific lamprey do not feed during the spawning migration. The fish utilize carbohydrates, lipids, and proteins for energy (Read 1968). Beamish (1980) observed 20% shrinkage in body size from the time of freshwater entry to spawning.

POTENTIAL FACTORS AFFECTING LAMPREY DECLINE

Poor Habitat Conditions--The decline of Pacific lamprey may be associated with factors similar to those affecting the decline of anadromous salmonids. Since inland salmon populations were negatively affected by the early 1900's due to agricultural water withdrawals (Lichatowich and Mobrand 1995), it is conceivable that Pacific lamprey were affected as well. It is clear that good water quality is necessary for Pacific lamprey. These fish prefer cold temperatures below 20° C (Mallat 1983). Spawning gravels are needed for reproduction of lamprey as is the case for salmonids. In many parts of eastern Oregon and Washington, stream water is diverted for irrigation which lowers flow and habitat volume, increases sediment deposition, and elevates stream temperatures -- especially in low gradient stream reaches at lower elevations. The highest densities of larval lamprey are found in these stream reaches (Pletcher 1963). Unfortunately, these areas are the most affected by people. Poor grazing practices, and intensive logging are other human activities that can raise stream temperatures and increase the stream's sediment load.

Fish Poisoning Operations--From the late 1940's through the 1980's, the Oregon Fish Commission (ODFW) removed non-game fishes (so-called "rough fish control") by means of rotenone across the state. In 1967 and 1974, approximately 90 and 85 miles of the Umatilla River were chemically treated. The 1967 treatment killed one million fish, which was estimated to be a 95% kill in treated area (ODFW, unpublished). Since larval life of lampreys in the streams can be from 4 to 6 years, these treatments during September may have decimated several age classes of larvae, young adults, as well as adults returning to spawn. The Umatilla River is one example out of many where treatments are suspected to have contributed to the demise of lamprey.

Water Pollution--It is unknown how pollution in the Columbia and Snake rivers has affected Pacific lamprey. Extensive mining, refinery, and radioactive waste discharge have created pollution in the form of heavy metals and radionuclides in the Columbia River (Johnson et al. 1994). The industrialization of the Columbia River has caused it to become a sink for heavy metals and radionuclides. Diatoms and organic matter were reported to take up divalent metals (Johnson et al. 1994). Other sources of pollution include agricultural runoff and environmental estrogens from breakdown products of herbicides.

Dam Passage--The hydroelectric dams along the Columbia and Snake rivers (Figure 4) have impacted anadromous fish. In some systems, such as the Umatilla River, inadequate fish passage facilities contributed to the extirpation of anadromous salmonids and perhaps lamprey in the upper reaches of the river. The migration to the ocean may be delayed due to the change in the hydrograph caused by the impoundments. Long (1968) reported lamprey on route to the ocean entrained in the turbines. It is unknown how well young adults survive passage through a turbine unit. Hammond (1979) reported lamprey impinged on traveling screens at the dams used to bypass anadromous fish. Obstructions designed to inhibit passage of adult lamprey were built in the fish ladders of some dams (pers. comm., Milo Bell, Univ. Washington, retired). These obstructions were in the form of grates and velocity barriers that forced lampreys to climb up moist walls of fish ladders using oral suction to the next resting pool. Conceivably, this could increase the rate to exhaustion and decrease migration rate.

Ocean Conditions--The availability of food varies with ocean conditions. Lamprey abundance may track the prey abundance closely. Not only have salmon declined but intense commercial harvest of Pacific hake and walleye pollock may have depleted the prey base for lamprey, sea birds, and sea mammals. The fishery for walleye pollock in the Bering Sea is the largest fishery in the world averaging 15 million tons in the past 15 years (Springer 1992). The U.S. share of the catch rose from 1% to 99% of the world's share since 1980. Springer (1992) argues that walleye pollock is a keystone species in the pelagic food web. Other fisheries are likewise being intensively harvested, and other food web shifts may be occurring that impact lamprey abundance. The rise of sea mammal populations and increased commercial fishing may interact to cause a lack of alternative prey for both sea mammals, lamprey, and other predators, which in turn increases competition for food. In addition, other predators may have increased predation on lamprey during severe food shortages. However, declines in the lamprey in the Umpqua River followed a negative exponential curve from 1967 to present (37,000 lamprey in 1967, 473 fish in 1993; ODFW unpublished data) which does not support the shifting food web hypotheses in this system because the time period spans several years of favorable oceanic conditions off of Oregon as well as times of low upwelling. Despite the Umpqua River example, we know so little about the oceanic ecosystem that poor ocean conditions cannot be excluded as a factor that has contributed to lamprey decline.

II. Recommendations for Immediate Management and Enhancement Actions

1. Immediately begin lamprey abundance monitoring at all dams where counting of other species is already conducted (see Recommendations for Research below).

2. Immediately compile information (e.g., oral histories, historic field data files, existing biological sampling efforts) which would define past and current distribution of lamprey in tributaries (see Recommendations for Research below).

3. All obstructions and/or activities that may still be inhibiting passage of adult lamprey in fish ladders must be immediately removed or halted.

4. Any remaining fish poisoning operations targeted at removing "rough fish" in tributaries must cease immediately.

5. A moratorium must be placed on any existing commercial lamprey harvest (e.g., biological supply companies, fish export). Prohibit gathering of lamprey by sport fishermen.

6. BPA, COE and other responsible parties immediately fund research to address critical uncertainties related to lamprey abundance, distribution, passage impediments, habitat limiting factors, artificial production, and transplantation/supplementation (see Recommendations for Research below).

7. Fund efforts to immediately define implementation actions for lamprey restoration pilot projects in selected tributaries and to identify research needs associated with monitoring the results of these restoration actions (see Recommendations for Research below).

III. Recommendations for Research and Data Gathering

Minimal current information on Pacific lamprey in the Columbia Basin suggests that populations are severely depressed or no longer exist in numerous tributaries. Understanding the cause of decline through various data gathering and research efforts will be critical to implementing effective restoration actions. A summary of general research recommendations for Pacific lamprey in the Columbia River Basin follows:

Table 2. Recommended Research and Anticipated Results for Columbia Basin Pacific Lamprey

Recommended Research	Anticipated Results
Determine current abundance	Understanding magnitude of remaining populations
Determine current distribution	Understanding locations of remaining populations
Determine passage limiting factors	Understanding locations and severity of impediments to migration and identification of critical passage improvement needs
Determine other habitat limiting factors	Understanding of suitability of current tributary habitat and identification of critical habitat enhancement needs
Identify potential applications of transplantation	Identification of transplantation actions including methodology, source/donor stocks, target locations, and follow-up monitoring and evaluation needs
Identify potential applications of artificial production	Identification of artificial production actions including techniques, donor stocks, target locations, supplementation options, and monitoring & evaluation needs

The following details goals, anticipated study objectives and study approach for each Pacific lamprey research recommendation identified above:

A. Abundance Studies

Goal: Determine the current abundance and passage trends of adult and juvenile lamprey at mainstem Columbia and Snake River dams.

Objectives: (Adult)

1. Coordinate with organizations currently involved with fish passage/trapping at mainstem Columbia and Snake River dams, and obtain and/or record fish passage video tapes.

2. Review tapes to obtain adult lamprey passage data and determine population abundance above each dam.

3. Estimate diel, seasonal and annual variations in adult lamprey migration at each facility.

4. Estimate adult lamprey length frequencies from video tapes.

Approach: (Adult)

Abundance estimates of adult lamprey will be made at several fish counting stations located at mainstem Columbia and Snake River dams. Much of the adult lamprey migration occurs during periods when on-site counting is not conducted. During much of the year, video tape records of nighttime fish passage are being made at Bonneville, Ice Harbor, Lower Granite, Rock Island and Wells dams. These records are being reviewed and fish ladder passage estimated by the Washington Department of Fish and Wildlife and by Chelan and Douglas County Public Utility Districts.

This study will coordinate with these organizations to obtain video tapes to review for lamprey passage. A stratified random sampling design will be employed to sample video records and estimate lamprey passage at the above mentioned facilities. Length frequency estimates will be made from video records. Length frequency estimates will also be compared both temporally, and spatially. These data will help in determining if different stocks of lamprey exist, and the timing of lamprey passage will be identified. Once this is known, impacts from systems operation will be analyzed.

Objectives: (Juvenile)

1. Coordinate with agencies currently involved with juvenile fish passage facilities at mainstem Columbia and Snake River dams to integrate juvenile lamprey sampling needs with existing operations.

2. Collect data on abundance, passage trends, length frequencies and life phases of juvenile lamprey at the various passage facilities.

3. Collect length frequency information from juvenile lampreys using the standardized subsampling techniques incorporated during smolt sampling.

4. Document life phase and the extent of transformation of juvenile lamprey examined at each facility.

5. Calculate lamprey guidance efficiencies and abundance estimates at the various juvenile passage facilities.

6. Document juvenile lamprey's diel, weekly and seasonal passage trends for each project.

Approach: (Juvenile) Abundance, passage trends and length frequencies will be collected at smolt collection facilities on mainstem Columbia and Snake River dams. Since juvenile lamprey are often collected incidentally with juvenile salmonids, data collections can be conducted with existing personnel and facilities. Passage indices will be calculated for lamprey from existing fish guidance efficiency tests conducted at mainstem Columbia and Snake River dams. These indices in conjunction with sampled juvenile lamprey will be used to calculate abundance estimates for each project. Currently, smolt collection facilities exist at Rock Island, Lower Granite, Little Goose, Lower Monumental, McNary and Bonneville dams. Gatewell collections are periodically conducted at Wanapum, Priest Rapids, and John Day dams. Collections from these facilities are conducted by personnel of Chelan County PUD, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Idaho Department of Fish and Game, and the National Marine Fisheries Service. Past information regarding lamprey collections exists for a number of these projects.

B. Distribution Studies

Goal: Document past and determine current presence and distribution of lamprey in Columbia and Snake River tributaries above Bonneville Dam.

Objectives:

1. Conduct literature review regarding historical lamprey presence or absence.

2. Collect information from tribal members, current/past fisheries biologists, and landowners (oral histories and/or survey forms).

3. Collect information from existing efforts (fish screening operations and maintenance or other ongoing research involving fish population sampling).

4. Conduct spot checks (electroshock, seine, etc.) to document presence/absence and relative abundance.

5. Document general tributary habitat conditions relative to lamprey presence/absence information collected above.

Approach: Past and current presence and distribution of lamprey in northeast Oregon tributaries will be documented through a literature search and oral histories. Tribal elders will be interviewed and fisheries management agencies records will be analyzed to establish historical information. Current lamprey presence will be analyzed by review of all existing efforts that involve sampling/counting fisheries populations. If no current lamprey population information is known, field sampling may be conducted to document presence or absence. Lamprey distribution information will be correlated with data from stream habitat studies (discussed later) to see if presence/absence directly relates to specific stream conditions.

C. Passage Studies

Goal: Evaluate adult and juvenile lamprey migration and identify possible passage impediments and improvements at mainstem Columbia and Snake River dams and reservoirs.

Objectives: (Adult)

1. Conduct literature review regarding adult lamprey passage, physiology, migration, and research techniques.

2. Test marking/tagging techniques for monitoring adult lamprey migration in a controlled environment.

3. Develop study plan for evaluating adult lamprey migration and passage in the mainstem Columbia and Snake rivers.

4. Implement adult lamprey passage study plans at various mainstem hydroelectric projects. Study to include tagging lamprey and documenting behavior, timing, and success of movement through the dams and reservoirs.

5. Sample adult lamprey at dams to examine external physical condition and clinical indicators of stress and exhaustion.

6. Identify structural passage impediments and causes of impairment.

7. Compare lamprey migration of a healthy run at Willamette Falls to those experiencing observed impairments at Columbia and Snake River dams and make recommendations for passage improvement.

Approach: (Adult)

An information search (including scientific literature, agency reports and interviews) will be conducted to acquire biological and life history information. Priority will be placed on seeking information relevant to: 1) adult lamprey migration and potential causes of physiological exhaustion impacting upstream passage in the Columbia and Snake rivers; 2) methodology for monitoring behavior and upstream migration of adult lamprey to identify passage impediments.

Application of tools and techniques to examine migration of adult lamprey will be tested in a laboratory setting. Findings from this effort will be applied to develop a passage research plan in the Columbia and Snake rivers. Means of tracking individual fish will be tested through use of various tagging devices. Fish behavior and migration will be evaluated from tracking tagged fish under various facility operating conditions. Passage problems due to structural impediments or particular hydraulic conditions will be identified. Bonneville Dam will likely be evaluated first due to all upriver lamprey having to pass this location. The Willamette River may also be included as a control or comparative river system where more healthy lamprey populations have remained. It is hoped that evaluation of adult lamprey migration at "good" passage locations versus locations with passage impairments will result in identification of specific passage problems and recommendations for improvement.

Objectives: (Juvenile)

1. Conduct literature review regarding juvenile lamprey passage, physiology, migration, and research techniques.
2. Test marking/tagging techniques for monitoring juvenile lamprey migration in a controlled environment.
3. Capture juvenile lamprey at existing smolt collection facilities.
4. Explore the use of PIT (Passive Integrated Transponder) tags to track the survival of juvenile lamprey through dams. Compare juvenile lamprey survival at dams through release of tagged individuals.
5. Explore the use of underwater video monitors to check for fish impingement on traveling screens.

6. Check condition of lampreys at fish passage facilities for sores and lesions. Examine the potential of comparing the general condition of juvenile lampreys in fish collection facilities at successive dams downstream.

7. Test for lamprey swimming capacity and behavior at various water velocities. Characteristics examined will include attraction/repulsion and ability to swim away from danger.

8. Determine downstream migration patterns through time and space in the river.

Approach: (Juvenile) Literature review and test marking/tagging will be similarly conducted for juveniles as described for adult passage evaluation. Juvenile lamprey will be collected at existing smolt facilities at mainstem Columbia and Snake River dams. Passage indices will be calculated from existing fish guidance efficiency tests utilizing lamprey as discussed under abundance studies. The general approach discussion for tagging and tracking of adults will also apply to juveniles. However, due to the small size of juvenile lamprey these techniques will require extensive testing. Video technology will also be employed to monitor fish bypass effectiveness and impingement on traveling screens.

D Habitat Studies

Goal: Determine habitat factors impacting lamprey production in Columbia and Snake River tributaries above Bonneville Dam.

Objectives:

1. Compile and analyze existing stream habitat data (surveys, temperature, flow records, etc.)

2. If adequate stream habitat information does not exist, examine use of on-the-ground aerial videography methodology to conduct Hankin and Reeves (1988) type of physical habitat surveys.

3. Compare findings from lamprey distribution studies with tributary habitat conditions to better understand relationships between physical and biological data.

4. Identify habitat factors which have and/or are likely still impacting lamprey populations.

5. Identify tributaries which currently have adequate habitat for lamprey reestablishment.

6. Identify tributaries which currently do not have adequate habitat conditions to support lamprey populations and identify habitat enhancement needs.

Approach: Lamprey abundance, distribution, and passage studies will help define where lamprey currently are and are not present. The passage and habitat studies will help answer the "why question" regarding depressed or extirpated lamprey populations. Habitat condition in tributaries are generally known from temperature, flow, and stream survey records. This information will be gathered, summarized, and compared with lamprey presence/absence findings. If general habitat conditions are not available or data is not adequate, aerial videography will be proposed to provide detailed information on stream channel morphology and riparian vegetation characteristics. To quickly target efforts on what habitat "works" and what is "broken", particular attention on habitat conditions or features will be made where moderate or abundant lamprey populations still exist. Also, from old data, photographs and oral histories, we will define where lamprey were once abundant and examine habitat changes that have occurred since that time. Habitat enhancement recommendations will be made based on these findings.

E. Transplantation

Goal: Utilize transplantation to begin reestablishment or supplementation of lamprey in selected tributaries above Bonneville Dam where populations have been extirpated or are at extremely low levels.

Objectives:

1. Conduct literature review regarding lamprey capture, handling, transport, release, and transplantation efforts.

2. Utilize presence/absence and habitat suitability data (discussed earlier) to identify a few ideal tributaries for initial lamprey transplantation projects.

3. Identify available and most appropriate donor population(s).

4. Develop transplantation techniques and an implementation plan for selected tributaries.

5. Develop an evaluation plan to monitor the success of lamprey transplantation projects.

6. Implement plans (capture, transplant, and evaluate).

Approach: Any information on transplantation of lamprey will be sought through an extensive literature review process. Recommended procedures on lamprey capture, handling, transport, and release will be compiled. The location of applying transplantation procedures will depend on the results of lamprey distribution, habitat suitability, and genetics studies. The selection of donor lamprey stocks will be made based upon 1) the remaining population status; 2) the geographic location and life history characteristics of the potential donor stock; 3) baseline genetic information from potential donor stocks; and 4) the availability of potential donor stocks. State of the art techniques will be used for describing genetic variation among different groups of lamprey. An implementation plan will be developed which will include target locations, donor locations and stocks, capture/hauling/release methodologies, and recommendations for follow-up monitoring and evaluation.

Transplantation is a likely method for reestablishment of lamprey populations above Bonneville Dam. It is critical that efforts to define implementation actions for pilot projects are dealt with immediately in order to expedite restoration and allow some research to address on-the-ground project results.

F. Artificial Production

Goal: Utilize artificial production as a part of the lamprey rebuilding effort in Columbia and Snake river tributaries above Bonneville Dam.

Objectives:

1. Conduct literature review of artificial propagation of lamprey.

2. Identify propagation techniques applicable to implementing Pacific lamprey supplementation projects in Columbia and Snake River tributaries.

3. Identify necessary criteria and possible locations for propagation facilities.

4. Identify candidate tributaries to supplement natural lamprey production by means of artificial propagation.

5. Identify available and most appropriate stocks for artificial propagation programs.

6. Utilize above information to compile an implementation plan for selected tributaries.

7. Develop an evaluation plan to monitor the success of lamprey supplementation projects.

8. Implement plan (acquire broodstock, artificially propagate, outplant, and evaluate).

Approach: Artificial propagation of lamprey may be necessary for restoration of natural production, for domestic consumption, and may be an inevitable necessity in order to prevent extinction (Pillay 1990). Due to the greatly different life history compared to commonly cultured fishes, considerable research will be required prior to development and implementation of a lamprey hatchery. Initial research will entail compilation of literature related to artificial holding or propagation of lamprey. Specifics identified will minimally include requirements for lamprey holding, rearing, and spawning, etc. Potential propagation facility sites that meet defined criteria will be defined. Identification of candidate tributaries for supplementation will depend on the results of lamprey distribution, habitat suitability, and genetics studies. The selection of broodstocks will be based on the same factors as described in the "transplantation approach". An implementation plan will be developed which will include facility needs/technologies, potential facility locations, broodstock sources, production goals, target supplementation locations, and recommendations for monitoring and evaluation of artificial propagation and supplementation projects.

IV. Conflicts with Restoration and Recovery of Columbia River Salmonids

It is unlikely that restoration of the Pacific lamprey will impede the recovery of Columbia River salmonids. There should be little fear that the Pacific lamprey will mimic the role of the sea lamprey, after its invasion into the Laurentian Great Lakes (e.g., Eschmeye 1955, Moffett 1956, Coble et al. 1990). That was a case of an entire community of naive prey being exposed to an exotic predator; whereas, the Pacific lamprey has co-evolved with its community. Beamish (1980) could find no evidence that increased lamprey production in the Skeena River would lead to predation problems on its sockeye salmon. Although Pacific lamprey will prey on salmonids, lamprey prefer to feed on midwater species such as Pacific hake *(Merluccius productus)* and walleye pollock *(Theragra chalcogramma)* in the open ocean (Table 3). The role that intense commercial harvest of Pacific hake and walleye pollock has had on the food chain dynamics of the north Pacific and on Pacific lamprey is likely significant.

Table 3. Lamprey Prey (from Beamish 1980)

Scientific name	Common name	Comment
Oncorhynchus nerka	sockeye salmon	0-66% population scarred
O. kisutch	coho salmon	17-45% population scarred
O. gorbuscha	pink salmon	20-44% population scarred
O. tschawytscha	chinook salmon	+
O. mykiss	steelhead	+
Sebastes aleutianus		+
S. reedi		+
Gadus macrocephalus	Pacific cod	+
Ophiodon elongatus	lingcod	+
Hippoglossus stenolepis	Pacific halibut	+
Rienhardtius hippoglossoides	greenland turbot	+
Anoplopoma fimbria	sable fish	+
Atheresthes stomias	arrowtooth flounder	+
A. evermanni	Kamchatka flounder	+
Sebastes alutus	Pacific ocean perch	+

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