A STATUS OF PACIFIC LAMPREY IN THE MID-COLUMBIA REGION

Final

ROCKY REACH HYDROELECTRIC PROJECT
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SECTION 1: INTRODUCTION

The Pacific lamprey (*Lampetra tridentata*) is a jawless anadromous fish widely distributed in western North America and eastern Asia. It is one of three species of lamprey in the Columbia River basin along with the anadromous river lamprey (*L. ayresii*) and the resident brook lamprey (*L. richardsoni*) (Wydoski and Whitney 1979). Because of the negative effects associated with the exotic sea lamprey (*Petromyzon marinus*) in the Great Lakes, many considered the Pacific lamprey a "pest species." In contrast to the sea lamprey, Pacific lamprey are important fish of cultural, utilitarian, and ecological significance. For example, Indian tribes of the Pacific Coast and interior Columbia Basin harvested Pacific lamprey for subsistence, ceremonial, and medicinal purposes (Close et al. 1995; Jackson et al. 1996). Anadromous salmonids, sturgeon, lamprey, whitefish, trout, and suckers made up about half of the Colville Indian subsistence (Post 1938; Ray 1977). During the 1940's, a commercial fishery harvested tons of lamprey (Close et al. 1995). The catch was used as food for livestock and cultured fish. Ecologically, the lamprey brings marine-derived nutrients to nutrient-poor streams and is a prey item for marine and freshwater predators.

This report summarizes information on the biology of Pacific lamprey in the mid-Columbia region.[1] We attempt to integrate and synthesize the array of information, with special reference to dam passage. Surprisingly, little is known of the life history and biology of Pacific lamprey in the Columbia River basin. What follows is mainly from Close et al. (1995), who summarized available information on the status of Pacific lamprey in the Columbia River basin. We begin this report by describing the abundance and distribution of Pacific lamprey in the region. We then describe their life history characteristics in freshwater and salt water. Finally, we discuss possible causes for their decline. We have not attempted to convert all measurements to either English or metric systems. Readers will find both in the report.

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[1] For the purposes of this report, "Mid-Columbia" means the region from Rock Island Dam upstream to Chief Joseph Dam, and tributaries.

SECTION 2: DISTRIBUTION AND ABUNDANCE

2.1 Historical Distribution

The historical distribution of Pacific lamprey in the Columbia River basin coincided with the distribution of Pacific salmon (Simpson and Wallace 1978; Close et al. 1995). Kan (1975) noted that access to suitable habitat rather than distance from the ocean influenced regional distribution. Therefore, it is likely that Pacific lamprey occurred historically throughout the Wenatchee, Entiat, Methow, and Okanogan basins. If we assume that Pacific lamprey and chinook salmon (*Oncorhynchus tshawytscha*) used the same streams historically, we would conclude that Pacific lamprey occurred in the Wenatchee River, Chiwawa River, Nason Creek, Little Wenatchee River, White River, Icicle Creek, Peshastin Creek, and Mission Creek in the Wenatchee River basin. In 1937, the Washington Department of Fisheries (1938) collected several lamprey that were bypassed from irrigation ditches in Icicle Creek, Peshastin Creek, and the lower mainstem Wenatchee River. Pacific lamprey would have also used the Entiat and Mad rivers in the Entiat Basin and the Methow River, Twisp River, Chewuch River, Wolf Creek, Lost River, and Early Winters Creek in the Methow Basin. In the Okanogan Basin, lamprey may have used the Okanogan River, Similkameen River, Salmon Creek, and Omak Creek. It is possible that they also used the lower Chelan River and the mainstem Columbia River.

Pacific lamprey probably occurred in the upper Columbia River basin upstream from present-day Grand Coulee Dam. How far upstream on the Columbia River they occurred is unknown. However, Fish and Hanavan (1948), reported that Grand Coulee Dam blocked anadromous fish from about 1,140 lineal miles of spawning and rearing streams. Therefore, following the logic above, we would assume that Pacific lamprey were widely distributed in the upper Columbia River basin.

Because Grand Coulee Dam was built without fish passage facilities, the Fish and Wildlife Service developed the Grand Coulee Fish Maintenance Project (GCFMP) (Fish and Hanavan 1948). This program trapped all salmon and steelhead at Rock Island Dam. These fish were mixed and relocated to the four major tributaries between Grand Coulee Dam and Rock Island Dam. Interestingly, Fish and Hanavan (1948) do not mention the capture of lamprey. Apparently these fish were allowed to pass Rock Island Dam. They either found spawning areas downstream from Grand Coulee Dam or perished in attempting to pass it.

2.2 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 (Close et al. 1995). Both dams lack fishways and limit the distribution of anadromous fish. Within the mid-Columbia region the distribution of lamprey is not well known. We know that they still exist in the Wenatchee, Entiat, and Methow systems, but the distributions within those systems are mostly unknown. Below we use anecdotal information to describe the extent of Pacific lamprey distribution in the mid-Columbia region. We caution that the following description may be confounded by the presence of river lamprey. In most cases, observers reported the occurrence of lamprey but did not identify the species. Thus, the descriptions below may apply to both species.

In the Wenatchee River basin, lamprey occur primarily downstream from Tumwater Dam. Jackson et al. (1997) indicated that they have observed no Pacific lamprey passing Tumwater Dam during the last decade. Because they monitored fish movement at Tumwater Dam between May through September, it is possible that they missed lamprey that migrate upstream to spawning areas during the spring. However, Washington Department of Fish and Wildlife (WDFW) captured no lamprey in the lower Chiwawa River during the 1992-1999 trapping period or near the mouth of Lake Wenatchee (C. Peterson, WDFW, personal communication). Hillman and Chapman (1989) surveyed the entire Wenatchee River during 1986 and 1987 and found no lamprey upstream from Tumwater Dam. This is consistent with the work of Mullan et al. (1992), who found no lamprey in the mainstem or tributaries of the upper Wenatchee River basin.

Pacific lamprey have been observed in the lower Wenatchee River. Hillman (unpublished data) found many ammocoetes in the Wenatchee River near the town of Leavenworth and adult lamprey in the lower Wenatchee River (near RM 1.0). Kelly (USFWS, personal communication) found an adult Pacific lamprey in the Wenatchee River near the golf course in Leavenworth. WDFW collected ammocoetes in a trap near the town of Monitor (C. Peterson, WDFW, personal communication). Apparently lamprey spawn in the irrigation canal just upstream from Monitor. These observations indicate that lamprey currently exist in the lower Wenatchee River (RM 0-27) and perhaps in the lower portions of Icicle, Peshastin, and Mission creeks.

Lamprey currently use the Entiat River basin. Kelly (USFWS, personal communication) found juvenile lamprey near RM 16 on the Entiat River. Although the USFWS has observed no adult lamprey near the hatchery, they occasionally find ammocoetes in settling ponds during spring high-flows (W. Edwards, USFWS, personal communication). Mr. Todd, an irrigator in the Entiat valley, described the occurrence of juvenile lamprey (ammocoetes) in the irrigation system when the intake was in the Entiat River. After the intake was moved to Rocky Reach pool, he found no ammocoetes in the irrigation system. These observations suggest that Pacific lamprey exist at least in the lower 16 miles of the Entiat River.

Pacific lamprey also live in the Methow River system. McGee et al. (1983) captured Pacific lamprey ammocoetes near RM 5 on the Methow River. They commented that the occurrence of ammocoetes in the catch increased with rapid rises in water level. In 1995, Hubble and Harper (1999) collected lamprey near the mouth of the Chewuch River during the period April through July. They captured no lamprey during the period August through November. Weist (WDFW, personal communication) found ammocoetes in the Methow rearing pond along the Methow River just downstream from the town of Twisp. Although unconfirmed, it is likely that lamprey also exist in the Twisp River.

It appears that lamprey do not presently use the Okanogan system. Sampling by McGee et al. (1983) found no lamprey there. Hillman (unpublished data) electrofished portions of the Okanogan and Similkameen rivers and collected no adult lamprey or ammocoetes. Messrs. Cleveland (Cassimer Bar Hatchery Manager, personal communication) and Truscott (Colville Confederated Tribes, personal communication) found no evidence that Pacific lamprey currently exist in the Okanogan system. Although no lamprey have been observed in the Okanogan system recently, suitable spawning and rearing habitat appear to be available.

2.3 Abundance

There is little information on the abundance of Pacific lamprey in the mid-Columbia region. Abundance estimates are limited to counts of adults and juveniles at dams. There are no estimates of redd counts or juvenile and adult counts in tributaries. We compiled juvenile and adult counts at dams throughout the Columbia River and at Ice Harbor Dam on the Snake River. Data are from Close et al. (1995), Jackson et al. (1996, 1997), Chelan PUD, Douglas PUD, and the Army Corps of Engineers. We have no counts at Priest Rapids and Wanapum dams because lamprey cannot be counted consistently and accurately there (C. Carlson, Grant PUD, personal communication).

Counts of adult lamprey at dams cannot be considered total counts because there was no standardized sampling across years and counting was restricted to certain hours. For example, fish counters in the past counted for an 8-hr-day shift at the beginning and end of the salmon runs and a 16-hr-day shift for the main part of the salmon runs (Close et al. 1995). Because the highest movement of lamprey occurs at night (Close et al. 1995), these day counts should be considered conservative estimates. Currently, fish counting occurs throughout the 24-hr period. At Rocky Reach and Rock Island dams, video tape or digital video record fish passage during the day and night. Day and night surveillance began at Rock Island in 1992 and at Rocky Reach in 1996.

Additional problems with adult counts exist because some lamprey pass dams undetected. For example, adult lamprey can move near the bottom of the fish counting chamber making it difficult to detect them (Jackson et al. 1996). They can also bypass counting station windows by traveling behind the picketed leads at the crowder (Starky and Dalen 1995). Both upstream and downstream movements of adults create problems with enumeration. At Bonneville Dam, for example, Jackson et al. (1996) found that for every adult lamprey observed, there was only a 3% chance that it resulted in a net upstream count. Because of these shortcomings, we view adult counts at dams as only crude indices of abundance.

Counts of juvenile lamprey at dams also suffer from sampling inconsistencies. Collection of juvenile lamprey at mainstem dams is incidental to sampling juvenile salmonids. Thus, numbers of migrants outside the juvenile salmonid migration period are unknown. In addition, unknown guidance efficiencies of juvenile lamprey and unknown spill passage to turbine passage ratios reduce precise estimates of abundance. Also, juveniles tend to hide in various locations in the bypass systems (Jackson et al. 1997). These problems, combined with highly variable sampling rates during periods of juvenile salmonid passage, confound estimates of juvenile lamprey abundance. Therefore, we view juvenile counts at dams as only crude indices of abundance.

We present passage counts of adult and juvenile lamprey at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Rock Island, Rocky Reach, and Wells dams in Figures 2-1 to 2-8. These data suggest that although numbers fluctuate widely at each project, there appears to be a general decreasing trend in numbers of adults counted at each project. For unknown reasons, large declines occurred during the late 1960's and early 1970's. During the period between about 1974 and 1993, numbers of adult lamprey counted at Rock Island and Rocky Reach dams were quite low (Figure 2-6 & Figure 2-7). Counts of adults have increased slightly since that time; however, this increase corresponds closely with the time that the projects began day and night counts. Thus, the increase may be more closely related to changes in counting procedures than to actual increases in abundance of lamprey in the region.

Comparing counts among different projects is problematic because of sampling inconsistencies, the behavior of lamprey in counting stations, and the ability of lamprey to bypass counting stations undetected. However, Jackson et al. (1997) closely examined the numbers of lamprey passing certain projects on the Columbia River in 1997. They found large decreases in numbers of adult lamprey passing dams as the run progressed upstream. For example, they estimated a 65% reduction in numbers of Pacific lamprey between Bonneville and The Dalles dams. Radio telemetry work indicated a similar reduction in numbers (66%) in this reach (Vella and Stuehrenberg 1997). Another large reduction in counts (72%) occurred between John Day and McNary dams. In the mid-Columbia region, Jackson et al. (1997) reported a 40% reduction between Rock Island and Rocky Reach dams. The reason for the large reductions is unknown, but Jackson et al. (1997) suspect that large numbers of adult lamprey spawn in tributaries between counting stations. This would suppose that a sizable population of lamprey spawn in the Wenatchee River, between Rock Island and Rocky Reach dams. It could also be that adult mortality is relatively high between these counting stations, although there are no data to support this speculation. Another reason could be that adults pass stations undetected. For example, in 1996, Jackson et al. (1996) reported that 2,121 adult lamprey passed Rock Island Dam, 593 passed Rocky Reach Dam, and 979 passed Wells Dam. This suggests that adult lamprey may be able to pass Rocky Reach Dam undetected.

In summary, counts of juvenile and adult lamprey fluctuate widely. It is unknown whether these fluctuations represent inconsistent counting procedures, actual population fluctuations, or both. Even though there are inconsistencies in counting methods, adult numbers show a general decreasing trend throughout the Columbia Basin. In addition, the data suggest that large reductions in numbers of adults occur between certain projects, perhaps because of tributary spawning, mortality, or undetected passage at dams.

Before we identify possible factors that may contribute to the general decline in Pacific lamprey counts, we provide a synopsis of their life history characteristics.

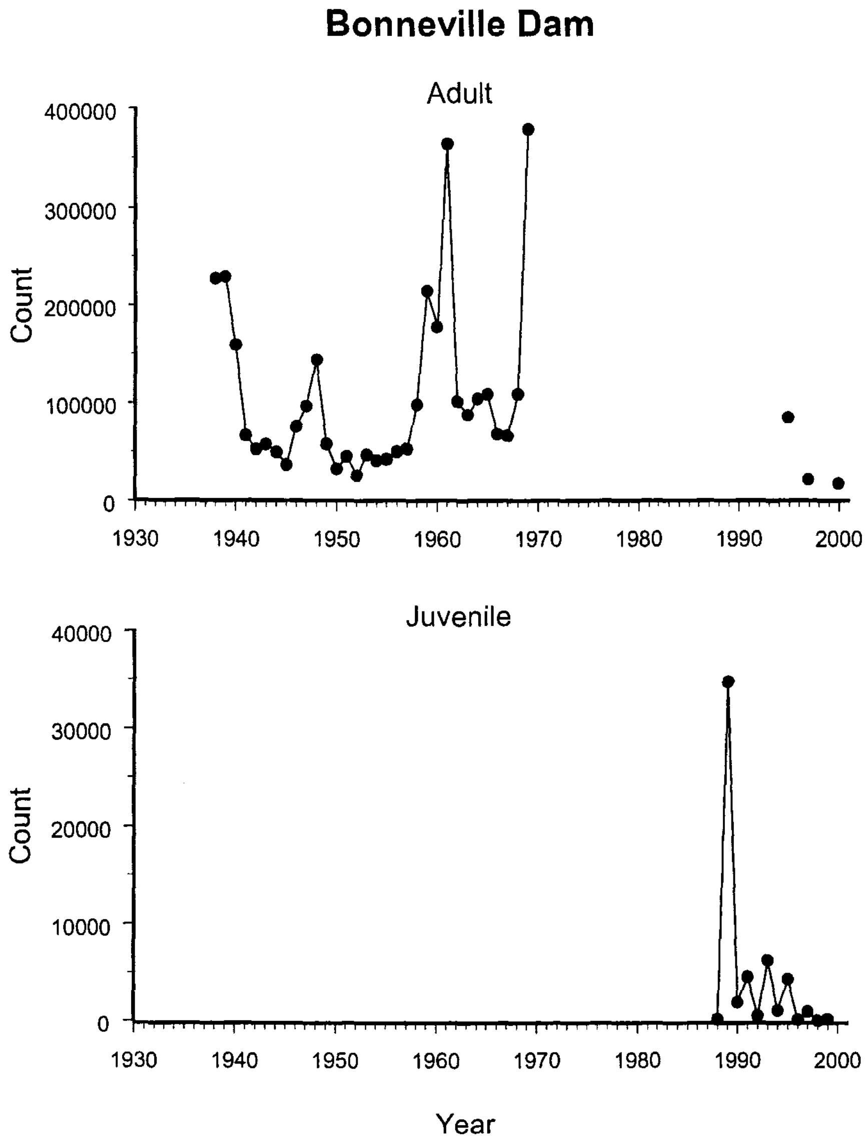

Figure 2-1: Numbers of adult and juvenile Pacific lamprey counted at Bonneville Dam.

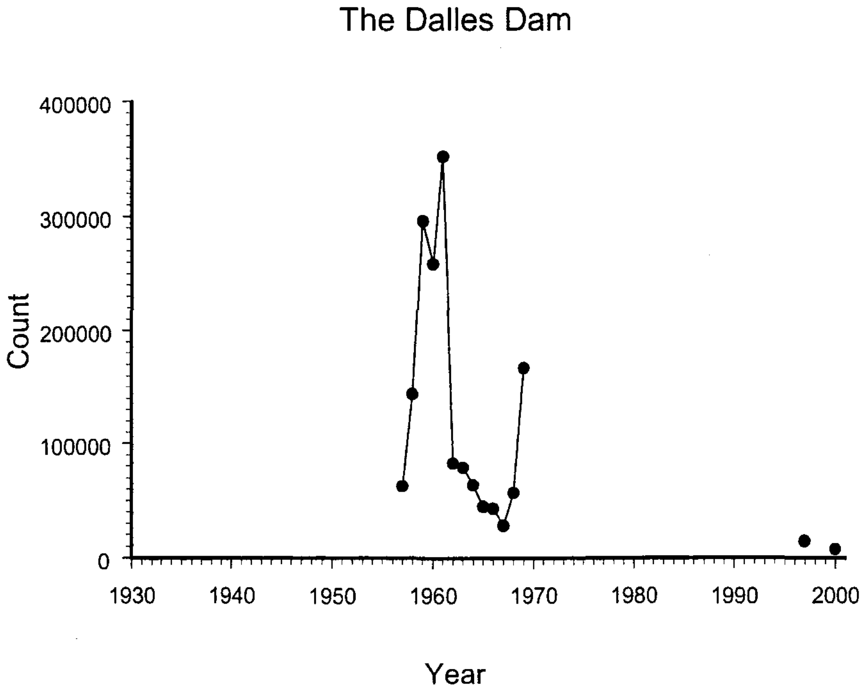

Figure 2-2: Numbers of adult Pacific lamprey counted at The Dalles Dam.

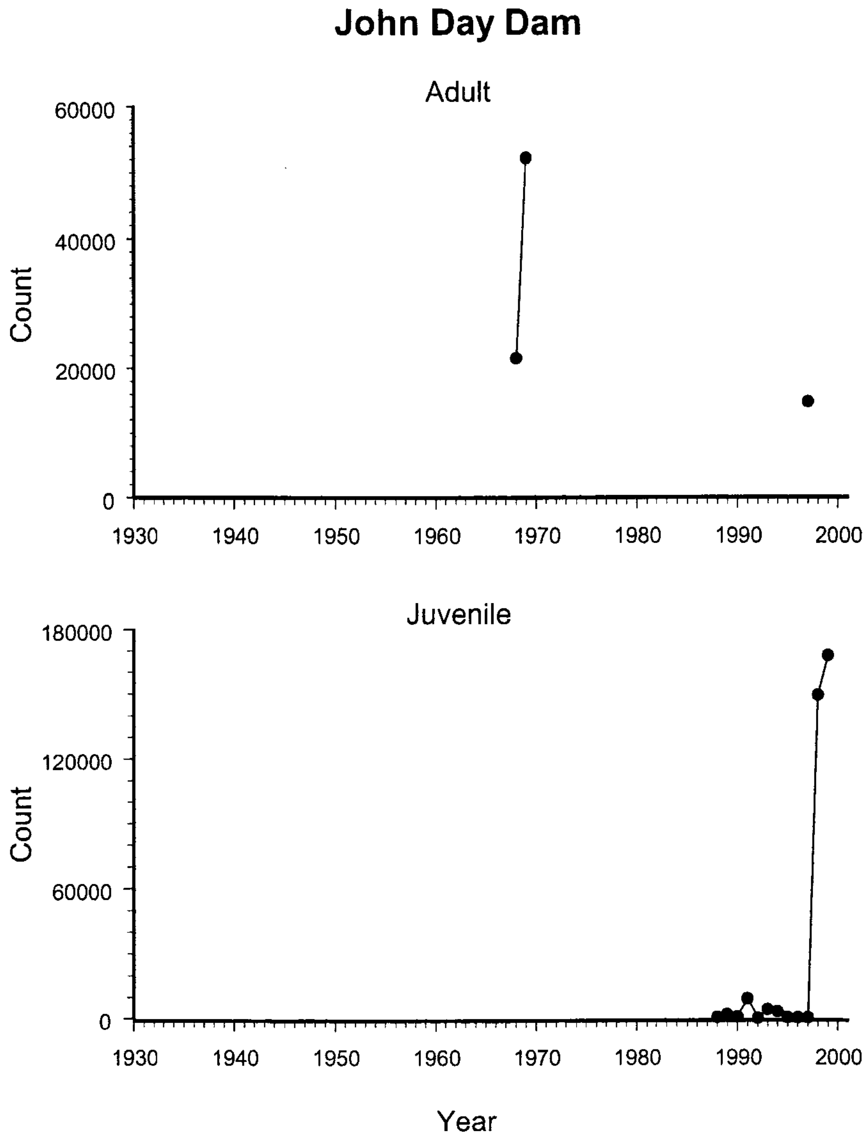

Figure 2-3: Numbers of adult and juvenile Pacific lamprey counted at John Day Dam.

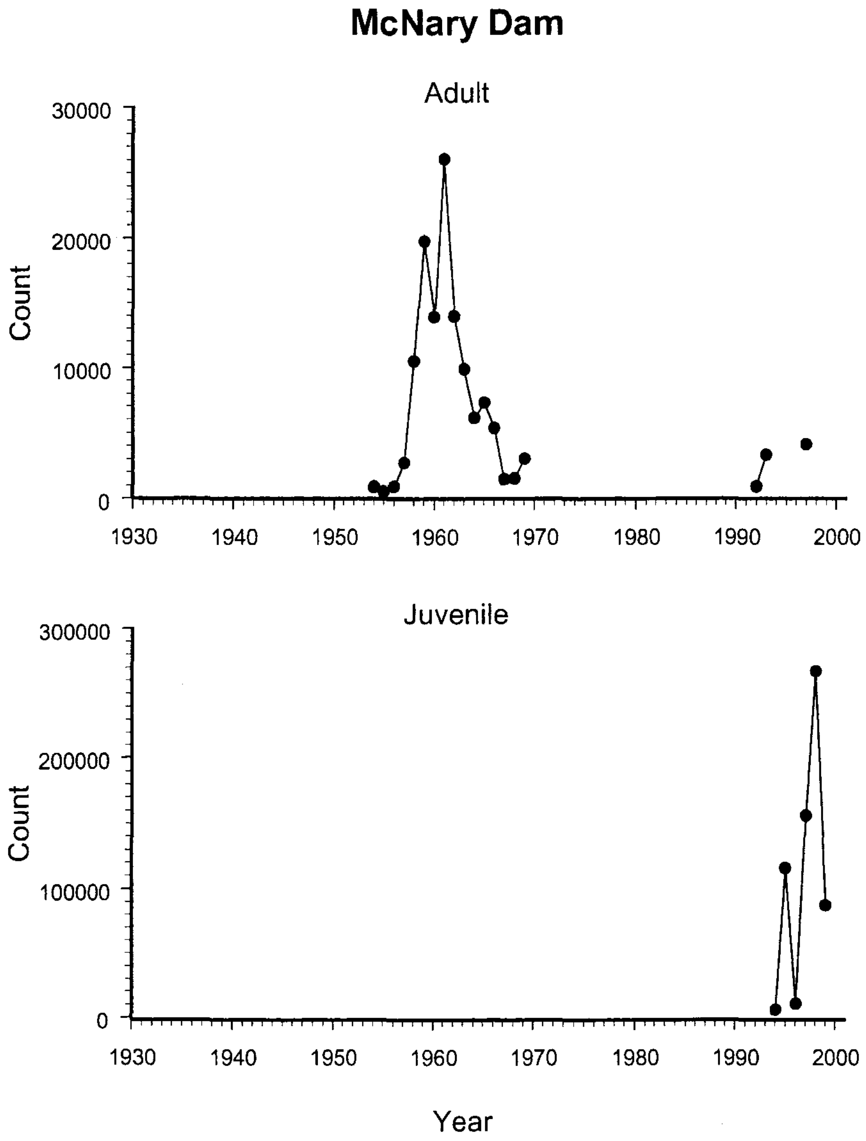

Figure 2-4: Numbers of adult and juvenile Pacific lamprey counted at McNary Dam.

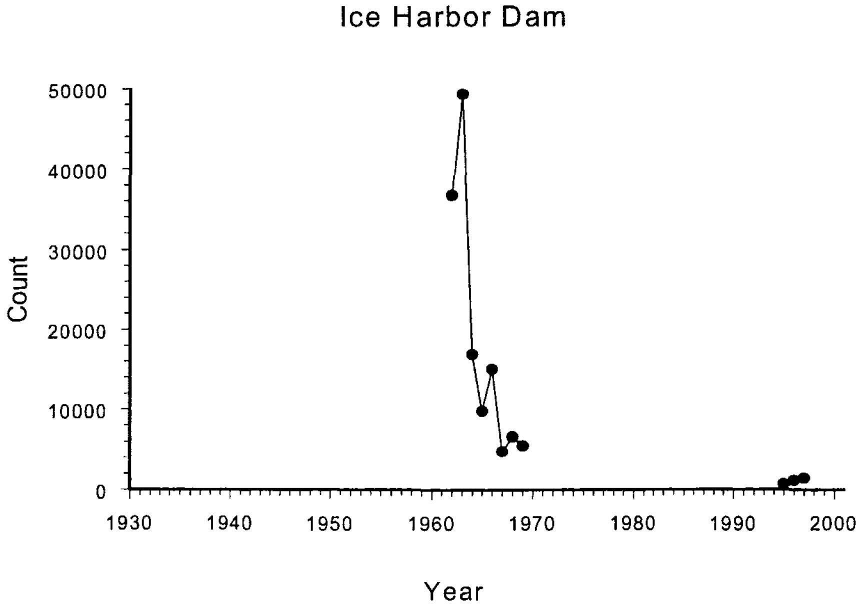

Figure 2-5: Numbers of adult Pacific lamprey counted at Ice Harbor Dam on the Snake River.

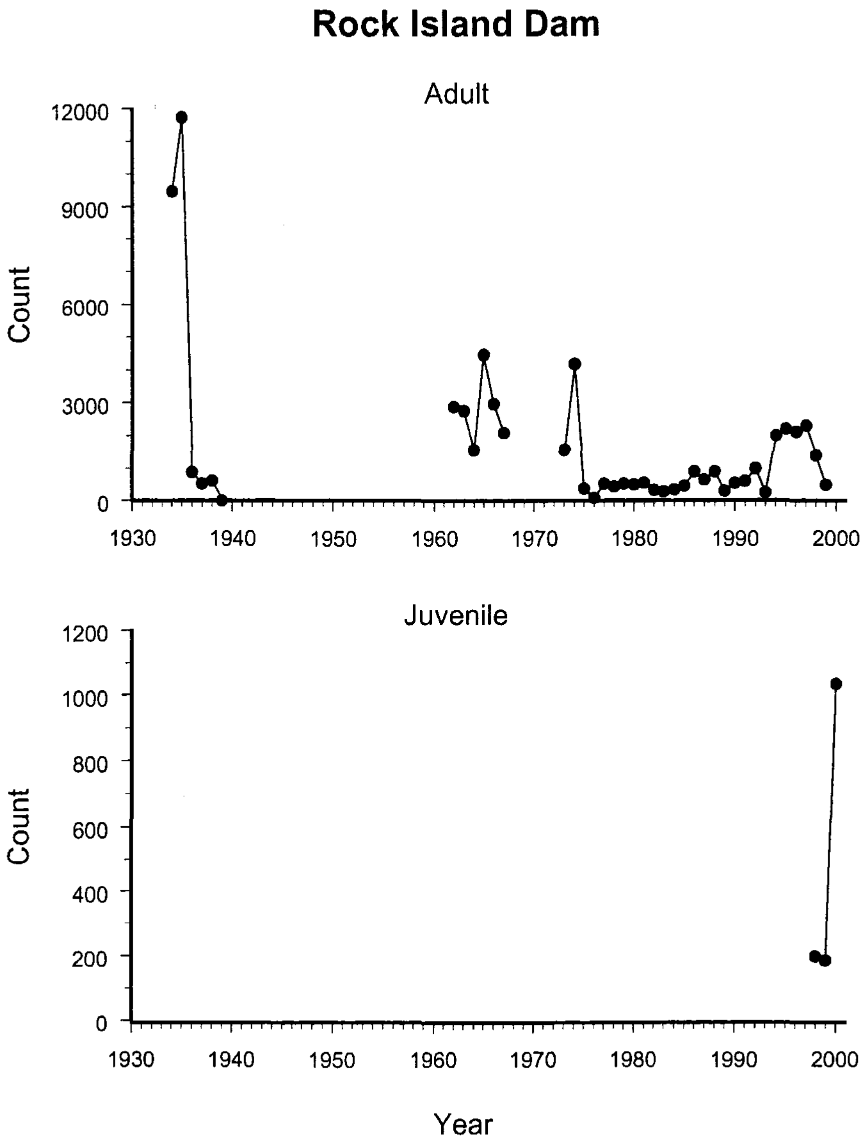

Figure 2-6: Numbers of adult and juvenile Pacific lamprey counted at Rock Island Dam.

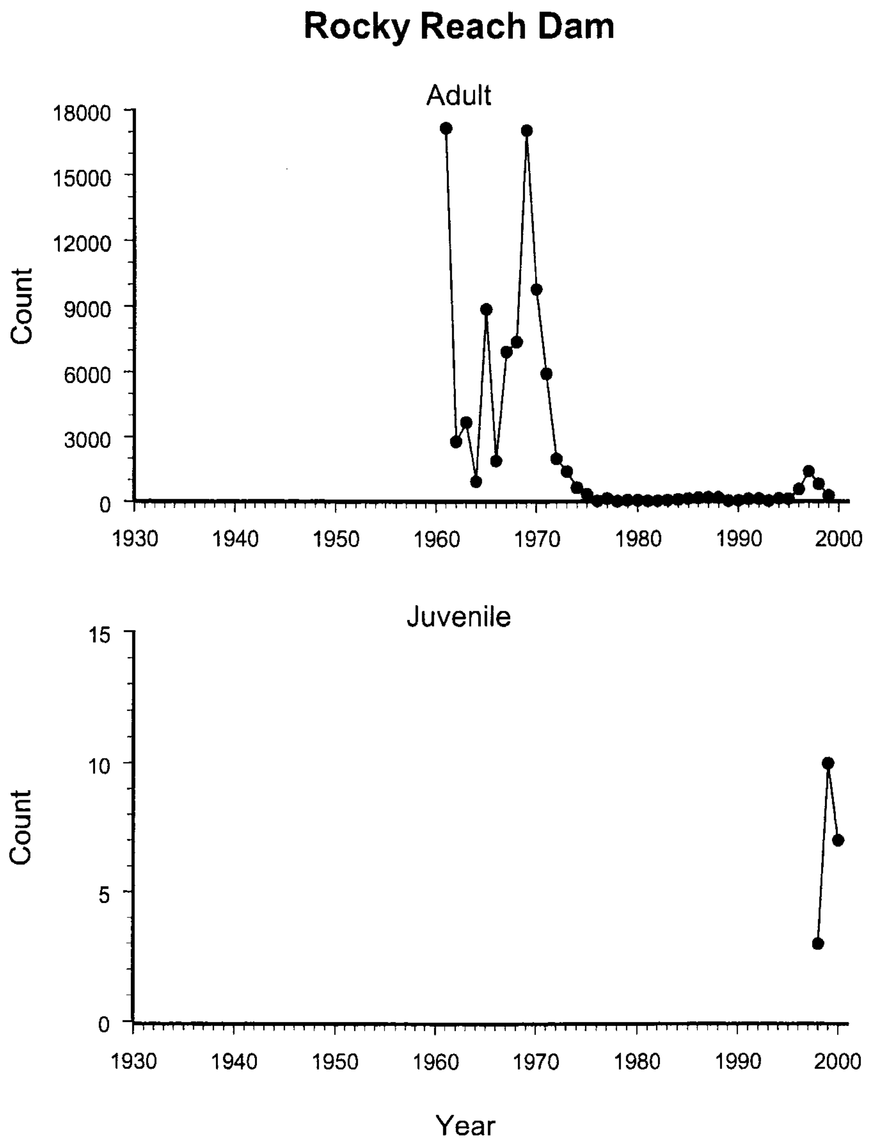

Figure 2-7: Numbers of adult and juvenile Pacific lamprey counted at Rocky Reach Dam.

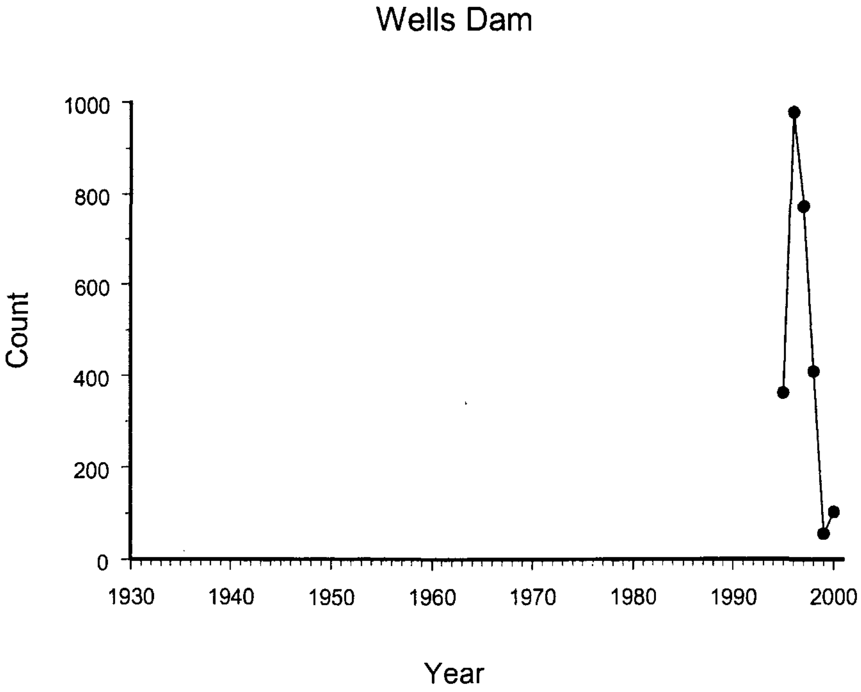

Figure 2-8: Numbers of adult Pacific lamprey counted at Wells Dam.

SECTION 3: LIFE HISTORY CHARACTERISTICS

3.1 Spawning

Pacific lamprey that migrate inland in the Columbia River spawn later than those in coastal streams (Close et al. 1995). Pacific lamprey along the Oregon coast generally spawn in May at temperatures between 10° and 15°C. In the Columbia River basin, lamprey typically spawn during June and July (Wydoski and Whitney 1979). Kan (1975) collected both spawning and pre-spawning fish in the John Day River system in July. Mattson (1949) described lamprey spawning in the Willamette River during June and July. In the Babine River system in British Columbia, Pacific lamprey spawned from June through the end of July (Farlinger and Beamish 1984). They probably spawn in the mid-Columbia region in June and July.

3.1.1 Spawning Habitat

Pacific lamprey usually select low-gradient stream sections for spawning (Kan 1975; Close et al. 1995). They construct nests at the tail areas of pools and riffles (Pletcher 1963; Scott and Crossman 1973; Kan 1975), and, if given a choice, prefer spawning in gravels (Pletcher 1963). Pacific lamprey generally select spawning sites with water velocities and depths that range from 0.5 to 1.0 m/s and 0.4 to 1.0 m, respectively (Pletcher 1963; Kan 1975). In the Babine River system, lamprey spawned at depths that ranged from 0.3-4.0 m, although most spawned at sites with depths less than 1.0 m (Farlinger and Beamish 1984).

To the best of our knowledge, no one has documented the spawning sites selected by lamprey in the mid-Columbia region. They likely spawn in the lower reaches of the Wenatchee, Entiat, and Methow rivers. Quite possibly they spawn in the Wenatchee River near Leavenworth (RM 23.9-26.4), because both adults and ammocoetes occur there (see Current Distribution). This area consists of well-sorted gravels and cobbles. Lamprey may also spawn in the Gunn Ditch near Monitor (C. Peterson, WDFW, personal communication). It is also possible that Pacific lamprey spawn in the lower Chelan River and in the Columbia River between Rocky Reach Dam and Wells Dam. During summer/fall chinook salmon surveys, Giorgi (1992) described a gravel shelf located on the west side of the Columbia River (between RM 514-515) downstream from Wells Dam. Although Giorgi (1992) found no lamprey on the gravel shelf, his description of the habitat there leads us to believe that it is suitable for lamprey spawning.

Although rare, Pacific lamprey may spawn in lakes (Close et al. 1995). In the Babine Lake system, Russell et al. (1987) observed lamprey spawning in shallow water in two areas of the lake system. Nests were subject to wave action but not an obvious unidirectional flow. It is unlikely that Pacific lamprey spawn in lakes in the mid-Columbia region. Spawning in Lake Wenatchee is unlikely because lamprey do not occur upstream from Tumwater Canyon. Lake Chelan is off limits because of migration barriers in the Chelan River. It is also unlikely that they spawning in Lake Osoyoos because lamprey apparently do not currently exist in the Okanogan basin.

3.1.2 Spawning Behavior

After reaching spawning areas, lamprey generally remain hidden in the substrate or in the shade until spawning begins (Scott and Crossman 1973; Close et al. 1995). As spawning proceeds, both males and females move rocks with their buccal funnel to create nests in excavated depressions (Pletcher 1963; Kan 1975). In Oregon, Kan (1975) found that lamprey nests were about 30 cm diameter, 3 cm deep, and oval in shape. In the Babine Lake system, lamprey nests were 20-30 cm diameter and 4-8 cm deep (Russell et al. 1987).

During courtship, the female attaches to a rock and orients across the nest. A male approaches the female with a glide motion (called "gliding-feeling") to stimulate her (Pletcher 1963). The male then attaches his buccal funnel to the head of the female and wraps his body around her while releasing milt (Pletcher 1963; Kan 1975; Russell et al. 1987). The adhesive fertilized eggs fall to the nest and cling to stones. During each spawning act, approximately 100 to 500 eggs are released and covered with sand and pea-size gravel (Pletcher 1963). Lamprey complete spawning over a period of about 12 hours. Males generally spawn with more than one female in different nests (Pletcher 1963). After spawning, Pacific lamprey die within 3 to 36 days (Pletcher 1963; Kan 1975).

Lamprey fecundity varies widely and is probably related to female size and migration distance (Scott and Crossman 1973; Close et al. 1995). The mean number of eggs produced by a female is about 34,000, but can be as many as 106,000 for a 16-inch female (Wydoski and Whitney 1979). The absolute fecundity for lamprey in Oregon ranged from 98,000 to 238,400 eggs (Close et al. 1995). The relative fecundity was significantly different between lamprey from coastal Oregon and the John Day River (Kan 1975). Kan (1975) suggested that the lower fecundity for lamprey in the John Day may be related to a higher cost of migration.

3.2 Larval Stage

Water temperature controls the hatching time of Pacific lamprey eggs. Pletcher (1963) observed eggs hatching after 19 days at 15°C. Generally, hatching occurs within 2-3 weeks (Scott and Crossman 1973). Therefore, we would expect eggs to hatch sometime during late-June to mid-August in the mid-Columbia region. After hatching, the larvae disperse from the gravels, drifting downstream usually at night. The larvae settle in quiescent back-water areas such as pools and eddies (Pletcher 1963). At this stage of life, the larvae are blind, sedentary, and filter feeders (Close et al. 1995). Food consists of detritus, diatoms, and algae suspended above and within the substrate (Moore and Mallatt 1980). Although mucus secretions in the pharynx and on gill filaments increase entrapment efficiency during filter feeding, assimilation of food is low. Moore and Mallatt (1980) found that larvae digested only 30-40% of the food intake; most food passed undigested.

The length of larvae life of Pacific lamprey is mostly unknown because of inconsistent length frequency data and the lack of bony structures (Close et al. 1995). The larvae stage appears to range from about four to six years (Pletcher 1963; Kan 1975; Richards 1980), but may extend up to seven years (Beamish and Northcote 1989). They grow slowly, reaching a size less than 2 cm in the first year (Figure 3-1). Age-length data for lamprey in the Thompson and Nicola rivers suggest a mean annual growth rate of about 15 mm per year (Figure 3-1). Mallatt (1983) found that the size of larvae varies but typically ranges from 3-5 g and 13-20 cm in length. He noted that ammocoetes held at 14°C and 4°C grew a respective 41% and 11% of body weight per month on a variety of foods in laboratory studies.

3.2.1 Rearing Habitat

Ammocoetes prefer the smallest substrates for rearing habitat. Pletcher (1963) found under experimental conditions that emergent larvae of size 7-10 mm preferred mud over sand and gravel substrates. Hillman (unpublished data) found larvae in the Wenatchee River near the town of Leavenworth in shallow areas along the river margin in mud and silt substrate. Hillman collected no larvae in coarse substrates or in deeper water. This is consistent with the observations of Richards (1980), who found the highest densities of larvae in shallow areas along the banks of the Chemainus River in British Columbia.

3.2.2 Freshwater Predation

Several freshwater fishes and avian predators eat juvenile Pacific lamprey (Close et al. 1995) (Table 3-1). Merrell (1959) found that lampreys made up 71% by volume the diet of gulls (*Larus* spp.) and terns (*Sterna* spp.). Poe et al. (1991) found that northern pikeminnows (*Ptychocheilus oregonensis*) and channel catfish (*Ictalurus punctatus*) ate juvenile lamprey in the Snake River system. Pfeiffer and Pletcher (1964) found that salmonid fry ate emergent ammocoetes and lamprey eggs. Trout fisherman have used ammocoetes as bait, suggesting that lamprey constitute a component of the diet of adult trout (Pletcher 1963). It is quite likely that juvenile salmonids eat lamprey during the spring. Although sculpins (*Cottus* spp.) probably eat both lamprey eggs and larvae, Hillman (1989) found no evidence that they consumed lamprey in the Wenatchee River. White sturgeon (*Acipenser transmontanus*) eat juvenile lamprey. Semakula and Larking (1968) found lamprey in white sturgeon in the Fraser River. Some commercial fishermen on the Fraser River found ammocoetes to be the best bait for catching sturgeon (Pletcher 1963). All these predators live in the mid-Columbia region and we expect that they consume juvenile Pacific lamprey there. However, we found no information on the effects of predators on the survival of lamprey in the mid-Columbia region.

Table 3-1: A list of predators of Pacific lamprey (from Beamish 1980; Close et al. 1995).

Common name	Scientific name	Life stage eaten
Northern pikeminnow	*Ptychocheilus oregonensis*	Juveniles
White sturgeon	*Ascipenser transmontanus*	All life stages
Channel catfish	*Ictalurus punctatus*	Juveniles
Minnows	*Cyprinidae*	Eggs and larvae
Logperch	*Percina spp.*	Eggs and larvae
Rainbow trout	*Oncorhynchus mykiss*	Eggs and larvae
Sculpins	*Cottus spp.*	Eggs and larvae
Sable fish	*Anoplopoma fimbria*	Adults
Spiny dogfish	*Squalus scanthias*	Adults
Sperm whale	*Physeter catodon*	Adults

Common name	Scientific name	Life stage eaten
Harbor seal	*Phoca vitulina*	Adults
California seal lion	*Zalophus californianus*	Adults
Steller sea lion	*Eumetopias jubatus*	Adults
Great blue heron	*Ardea herodias*	Adults
Forster=s tern	*Sterna fosteri*	Ammocoetes
Western gull	*Larus occidentalis*	Ammocoetes
California gull	*Larus californicus*	Ammocoetes
Ringbill gull	*Larus delawarensis*	Ammocoetes

3.3 Metamorphosis

Transformation of Pacific lamprey from larvae to juvenile or young adult generally occurs during July through October (Pletcher 1963; Beamish 1980; Richards and Beamish 1981). During transformation, larvae go through morphological and physiological changes to prepare for a parasitic life in salt water (Close et al. 1995). The process occurs in several stages (Yousson and Potter 1979), beginning with the oral hood changing into an oval mouth. The eyes then develop and the oral disc increases in length. After about 4 weeks, teeth and tongue develop. Internal changes such as development of the foregut, changes in blood proteins and the respiratory system, and loss of gallbladder and bile duct prepare the fish for life in salt water (Richards 1980; Richards and Beamish 1981; Close et al. 1995). During the end of transformation, the teeth harden and turn yellow (Richards 1980).

There appears to be a relationship between growth of larvae and age at metamorphosis. Beamish and Levings (1991) found that the average size of lamprey that metamorphosed at an older age was smaller than those that metamorphosed earlier, suggesting that slower-growing ammocoetes metamorphose at older ages.

Pacific lamprey occupy different habitat during the transformation process. Transforming fish select larger substrates and higher water velocities (Potter 1980; Richards and Beamish 1981). At this time, they are about 122-303 mm long (Scott and Crossman 1973). In the Qualicum River, British Columbia, Beamish (1980) reported that transforming lamprey moved from mud and silt to 1-4 cm gravels and faster water currents.

3.4 Downstream Migration

After metamorphosis in October and November, young adults migrate to the ocean between late fall and late spring (Close et al. 1995). Fyke net sampling at Wells Dam indicates that lamprey pass the dam during most months that sampling occurs, but the greatest numbers usually pass during April through July (Table 3-2). Most pass Rocky Reach Dam in late May and June (CPUD 1991). Young adults are sampled from March to June in collection facilities at John Day and Bonneville dams (Hawkes et al. 1991; Hawkes et al. 1992; Hawkes et al. 1993). In the Nicola River, British

Columbia, Beamish and Levings (1991) found that 99% of all young adults migrated by April and May. We could not find information on winter emigration.

At the beginning of the migration, most young adults leave the substrate over a short period during the night (Beamish and Levings 1991). Initially, migration is mostly nocturnal (Moursund et al. 2000). As the migration proceeds towards salt water, more groups amalgamate, resulting in a more uniform migration that continues day and night. Beamish and Levings (1991) found that the young adults that left the stream first were larger than those that migrated later. They also noted that sizes of migrants varied among years.

Downstream migration appears to correlate with increased discharge but not temperature (Hammond 1979; Potter 1980; Beamish and Levings 1991; Close et al. 1995). In the Fraser River system, 99% of the young adults left the substrate and began migration during the night with increased flows (Beamish and Levings 1991). In the Methow River, McGee et al. (1983) found that catches of lamprey increased with rapid increases in flow. Young lamprey rely on currents to carry them downstream (Beamish and Levings 1991). They do not actively swim downstream; rather, they drift downstream tail first.

Young adult lamprey migrate in the lower portions of the water column (Close et al. 1995). This is probably because they lack a swim bladder and cannot easily regulate their location in the water column (Moursund et al. 2000). At Wells Dam, fyke nets set in deep water (>90 ft) most often captured lamprey (Table 3-2). This is consistent with fyke net sampling at Rocky Reach Dam (C. Peven, Chelan PUD, personal communication). These observations support the work of Long (1968), who found that most migrating lamprey enter turbine intakes near the center and bottom. Long (1968) found that migrating lamprey and juvenile salmonids were spatially separated, with only minor overlap at the mid-point area of the turbine intake.

It is unknown how long young adult lamprey spend in the estuary. Beamish and Levings (1991) noted that young adults migrated both day and night near the mouth of the Fraser River. Beamish (1980) believes that young adults move quickly through the estuary into deeper water and start feeding immediately. At this time, lamprey can be up to 30 cm long (Scott and Crossman 1973), although Beamish (1980) reported that the average size at entry into salt water is about 13 cm.

Table 3-2: Numbers of juvenile lamprey captured in fyke nets set at different depths at Wells Dam. Sampling intensity was not equal among sampling periods (dates).

	Depth of fyke net (ft)							
Date	80.0	88.5	97.0	105.5	114.0	122.5	131.0	Total
Jun 87	0	0	0	3	2	3	2	10
Jul 87	7	30	13	10	9	6	10	85
Aug 87	0	0	0	0	0	0	0	0
Apr 88	0	1	1	2	17	3	4	28

	Depth of fyke net (ft)							
May 88	0	0	5	4	15	10	1	35
Jun 88	0	0	2	0	3	8	2	15
Jul 88	0	0	0	0	0	2	2	4
Aug 88	0	0	0	0	0	2	3	5
Apr 89	0	2	3	6	2	2	13	18
May 89	0	42	57	56	41	40	13	249
Jun 89	0	22	37	58	50	37	10	214
Jul 89	0	1	0	2	5	3	0	11
Aug 89	0	0	1	1	0	2	0	4
Sep 89	0	0	0	0	0	0	0	0
Apr 90	0	0	0	0	1	2	5	8
May 90	1	58	129	65	1	43	22	319
Jun 90	0	3	12	17	4	28	10	74
Jul 90	0	1	5	8	3	19	6	42
Aug 90	0	0	0	0	0	1	1	2
May 91		16					2	22*
Jun 91			4	9	2	7		134*
Jul 91						6		12*
Aug 91								5*
Mar 96	0	0	0	0	1	1	0	2
Jun 96	0	1	18	29	5	0	11	64
Jul 96	0	0	0	5	3	3	3	14
Aug 96	0	0	2	0	1	2	1	6
Apr 97	0	0	1	6	2	6	2	17
Aug 98	0	0	0	0	0	0	0	0
Mar 99	0	0	0	0	3	3	0	6
Apr 99	0	0	1	2	9	4	0	16

	Depth of fyke net (ft)							
Aug 99	0	0	0	1	1	5	5	12
Mar 00	0	1	0	0	1	9	6	17
Apr 00	0	0	0	0	2	4	2	8
Aug 00	0	0	0	0	0	1	0	1
Sep 00	0	0	0	0	0	1	0	1

*Juvenile lamprey collected in nets of unknown depth.

3.5 Ocean Life

The ocean life of Pacific lamprey from the mid-Columbia region is unknown. In general, Pacific lamprey spend about 12 to 40 months in the ocean (Wydoski and Whitney 1979; Close et al. 1995). Beamish (1980) found that Pacific lamprey spent up to 3.5 years in the Strait of Georgia, British Columbia. Lamprey off the coast of Oregon spent 20 to 40 months in the ocean (Kan 1975).

Time of entry into salt water varies among populations (Close et al. 1995). Kan (1975) suggested that coastal populations enter salt water in the late fall, while inland populations enter in the spring. After entrance, Pacific lamprey move into water greater than 70 m deep (Close et al. 1995). Beamish (1980) reported captures of young adults off the Pacific coast at depths from 100 to 250 m. Despite their occurrence in deep water, they generally occupy mid-water plankton layers (Beamish 1980).

There is little information available on the migration of Pacific lamprey in the ocean. They have been collected at distances that ranged from 10 to more than 100 km off the Oregon coast and at depths to 800 m (Kan 1975). Larkins (1964) recorded catches of Pacific lamprey during high-seas salmon sampling. Beamish (1980) surmised that lamprey move offshore and that some stocks migrate considerable distances.

3.5.1 Ocean Feeding

Adult Pacific lamprey are parasitic, feeding on the blood and fluids of other marine vertebrates (Scott and Crossman 1973; Wydoski and Whitney 1979). They use olfaction, electroreception, and vision to locate their prey (Close et al. 1995). They usually attach to prey ventrally near the pectoral area (Beamish 1980) and create suction in the buccal funnel by changing the volume in the oral cavity. The denticles on the tongue rasp the tissue of the host and buccal glands secrete anticoagulant to prevent blood clotting (Farmer 1980). When the lamprey is attached to a host, respiration occurs by pumping water in and out through the gill openings (Scott and Crossman 1973).

Pacific lamprey appear to be opportunistic feeders. Pacific lamprey attack rockfish (*Sebastes aleutianus*) and (*S. reedi*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), chinook salmon, pink salmon (*O. gorbuscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), lingcod (*Ophiodon elongatus*), sable fish (*Anoplopoma fimbria*), steelhead, Pacific halibut (*Hippoglossus stenolepis*), turbot (*Reinhardtius hippoglossoides*), Pacific hake (*Merluccius productus*), arrowtooth flounder (*Atheresthes stomias*), Kamchatka flounder (*A. evermanni*), and Pacific ocean perch (*S. alutus*) (Beamish 1980). Although no studies identify the feeding preference of Pacific salmon, Beamish (1980) remarked that walleye pollock was the most common prey in his studies. Both walleye pollock and Pacific hake occur frequently in midwater areas in association with layers of plankton (Beamish 1980), which may explain why young adult Pacific lamprey move to these areas shortly after entering salt water.

We found little information on the number of prey killed during the ocean-feeding phase. Marine predators and scavengers quickly consume prey that are weakened from lamprey attacks (Wydoski and Whitney 1979). Nevertheless, lamprey-scarred salmon are observed in rivers of the Pacific Northwest, even as far inland as Idaho. Scott and Crossman (1973) reported that predation on Pacific salmon varied between species, being more important for sockeye than for pink salmon. Williams and Gilhousen (1968) found that lamprey had attacked about 66% of the sockeye and 20% of the pink salmon in the Fraser River. Approximately 6% of the wounds on sockeye and 2% of the wounds on pink salmon were severe. The researchers calculated that about 1.8% of the fish died during upstream migration. Up to 20% of the coho salmon examined in British Columbia had scars from Pacific lamprey (Scott and Crossman 1973). Mason (1974) reported that 14% of the coho returning to Lymn Creek, Vancouver Island, in 1971 had lamprey scars, while 45% returning in 1972 had scars. Beamish (1980) reported results of laboratory feeding studies in which one Pacific lamprey in its first year in salt water killed one salmon of 15-20 cm in length about every 2-4 days. Although there are no studies that estimate the loss of commercially important fishes from Pacific lamprey predation, Beamish and Levings (1991) opined that it may be significant.

Although Pacific lamprey are not considered important predators of mammals, they do attack whales (Scott and Crossman 1973; Beamish 1980). For example, between 25 and 89% of fin (*Balaenoptera physalus*), sei (*B. borealis*), blue (*B. musculus*), humpback (*Megaptera novaeangliae*), and sperm (*Physeter catodon*) whales examined off the coast of British Columbia had Pacific lamprey scars (Pike 1951).

3.5.2 Ocean Predation

The extent that other animals prey on Pacific lamprey is unknown. However, various accounts suggest that lamprey are consumed readily by other animals (Table 3-1). Beamish (1980) reported that 82% of the observed feedings of Steller sea lions (*Eumetopias jubatus*) at the mouth of the Klamath River, California, were on Pacific lamprey. Pacific lamprey have also been found in the stomachs of sperm whale (Pike 1950) and seals (*Phoca vitulina*) (Hubbs 1967). Roffe and Mate (1984) indicated that Pacific lamprey were the most abundant item in seals and sea lions. Beamish (1980) also found that spiny dogfish (*Squalus scanthias*) and sable fish actively fed on Pacific lamprey.

3.6 Adult Migration

Adult lamprey enter freshwater between April and June, and complete migration into streams by late fall (Beamish 1980). In the Chemainus River, British Columbia, lamprey migrated into freshwater beginning in late April, with 81% of the catch occurring during two days in May (Richards 1980). Beamish and Levings (1991) observed that adult lamprey first returned to the Nicola River (a tributary of the Fraser River) in August, suggesting that they entered the Fraser River in June. In the Columbia River, adult lamprey pass Bonneville Dam (RM 146) between April and October, and mid-Columbia River dams (RM 453-515) between April and November (Jackson et al. 1996, 1997). Most lamprey pass mid-Columbia River dams in August and September.

Although adult lamprey enter rivers during higher flows, it is unclear how flows affect upstream migration. Lampreys are weak swimmers compared to other fish (Close et al. 1995; Mesa et al. 1999). Bell (1990) calculated burst swimming speed for lamprey as about 2.1 m/s. Mesa et al. (1999) estimated the critical swimming speed of Pacific lamprey (mean length of 63 cm) as 0.86 m/s (1.4 body lengths per second) at 15°C. Mesa et al. (1999) concluded that lamprey probably have difficulty negotiating high water velocities in fishways.

The rate at which adult lamprey migrate upstream is probably related to flow and migration obstacles. In the Fraser River system, Beamish and Levings (1991) estimated that adult lamprey migrated about 112 km in 2 weeks, or about 8 km/d. Kan (1975) estimated that lamprey migrated 4.5 km/d in the Columbia River. Recently, Jackson et al. (1997) estimated that adult lamprey in the lower Columbia River migrated at rates that ranged from 0.2 to 65.4 km/d (average, 15.6 km/d). Migration rates of lamprey in the mid-Columbia region are unknown.

Pacific lamprey typically spend the winter in freshwater and spawn the following spring (Beamish 1980). Parker (CRITFC, personal communication), however, radio-tracked an adult lamprey that remained in freshwater nearly two years before spawning. In contrast, some spawn the same year that they enter freshwater (Bayer and Seelye, undated). These early spawners appear to be the first to enter freshwater. At the time of freshwater entry, adults range in size from about 12 to 72 cm (Beamish 1980). They do not feed during the upstream migration and usually reside in deep pools throughout the winter (Close et al. 1995). During this time they use carbohydrates, lipids, and proteins for energy (Read 1968). Beamish (1980) observed 20% shrinkage in body size from the time of freshwater entry to spawning. He also noted a disproportionate reduction in length of females (23%) compared to males (15%).

Lamprey that return to the mid-Columbia region are probably about 9-12 years old. Because they enter freshwater in spring and spawn the following spring or summer, they reside in freshwater about 1 year. If lamprey remain in saltwater about 3.5 years, then they live from the onset of metamorphosis to death after spawning for about 5 years. If we assume the larvae live for 4-7 years before metamorphosis, then returning adults live for about 9-12 years.

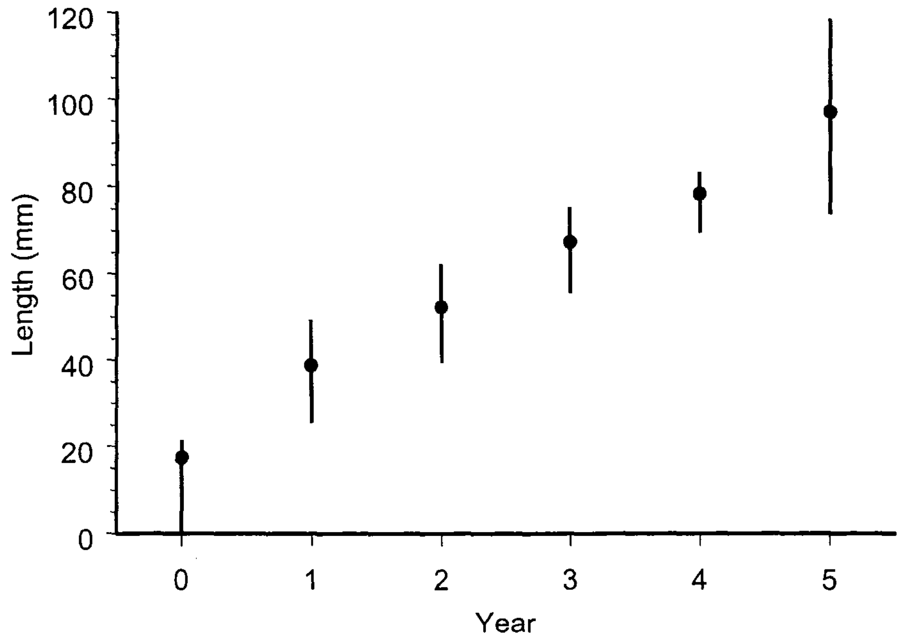

Figure 3-1: Age-total length relation for Pacific lamprey ammocoetes in the Thompson and Nicola rivers (data from Pletcher 1963).

SECTION 4: POSSIBLE CAUSES OF DECLINE

Close et al. (1995) identified four major factors that may account for the decline in counts of Pacific lamprey in the Columbia River basin: (1) poor spawning and rearing habitat, (2) pollution and chemical eradication, (3) reductions in prey in the ocean, and (4) juvenile and adult passage problems at dams. In this section we examine each of the listed factors as they relate to Pacific lamprey in the mid-Columbia region. At this time we cannot accurately assign numerical or proportional responsibilities to various agents of decline. We can, however, generally discuss their importance.

4.1 Habitat Conditions

The decline of Pacific lamprey in the mid-Columbia region may be associated with factors similar to those that affect anadromous salmonids. Like anadromous salmonids, Pacific lamprey require cool, clean, connected, and complex habitat. Mullan et al. (1992) considered habitat degradation in tributaries as relatively unimportant as a cause of decline in mid-Columbia River chinook salmon. While we do not disagree, we suggest that the intensive agricultural developments in the river valleys used by lamprey may have contributed to reduced habitat carrying capacity. For example, removal of riparian vegetation has degraded the quality of habitat in some areas (Chapman et al. 1994a, 1994b; Bugert et al. 1998). Sedimentation probably accelerated with development. Irrigation withdrawals probably affected spawning and rearing habitat by reducing streamflows, increasing sediment deposition, and elevating water temperatures. In addition, unscreened irrigation intakes entrained ammocoetes. Near the turn of the twentieth century, WDFG (1902-21) noted that most of the fish released from the Methow Hatchery (near the confluence with the Twisp River) ended in irrigated fields. We suspect that many juvenile lamprey also ended in these fields.

Mullan et al. (1992) estimated that tributary dams and irrigation reduced anadromous salmonid habitat by 12%, 3%, and 0% for the Wenatchee, Methow, and Entiat rivers, respectively. They offer no estimates for the Okanogan River system. WDW et al. (1990) state that development has much reduced salmonid productivity in the Okanogan River tributaries. They identify extensive riparian and instream habitat degradation and warm temperatures as the most important. These factors likely also affected the production of Pacific lamprey in the region.

4.2 Pollution/Poisoning

Close et al. (1995) identified pollution in the Columbia and Snake rivers as a factor that has reduced Pacific lamprey in the basin. In most of the mid-Columbia region, water quality is generally considered good to excellent (Bugert et al. 1998). Water quality in the Wenatchee River occasionally exceeds state 303(d) standards for dissolved oxygen, pH, and temperature criteria. Fecal coliform is occasionally a problem in Chumstick, Mission, and Brender creeks, and DDT occurs occasionally in Mission Creek. In the Entiat River, temperature and pH have exceeded state standards, while water quality remains quite good in the Methow River. However, the state has rated portions of the Methow River and the lower Twisp River as water-quality limited because of low instream flows. It is unclear how these factors affect the production of Pacific lamprey in these systems. Temperature may be a concern as Pacific lamprey prefer temperatures below 20°C (Mallat

1983). Temperatures in the lower portions of the Wenatchee, Entiat, and Methow rivers occasionally exceed 20°C (Hillman and Chapman 1989; Mullan et al. 1992).

Water quality may limit the production of Pacific lamprey in the Okanogan system. The state has listed the Okanogan River, Similkameen River, and Omak Creek on the 303(d) list of impaired water bodies (Bugert et al. 1998). Fecal coliform, total bacteria, pH, temperature, and dissolved oxygen levels all exceed state and federal water quality criteria. In addition, suspended sediments, nitrate/nitrite, and total phosphorous appear high. This may be one reason why Pacific lamprey have not been observed in the Okanogan system.

It is unknown what effect agricultural chemicals applied to orchards along the rivers and streams may have on lamprey production. We should think that because ammocoetes spend 4-7 years filter-feeding in these systems, they would potentially be vulnerable to chemicals that bioaccumulate. In addition, we found no information on the effects of fire-retardant chemicals on the survival of lamprey in the systems. These chemicals release free cyanide that can exceed criteria limits for freshwater organisms (Little and Calfee 2000).

Close et al. (1995) relay information on the use of fish toxicants by the Oregon Fish Commission (now ODFW) to remove non-game fishes throughout the state of Oregon. According to Close et al. (1995), the Commission poisoned about 90 and 85 miles of the Umatilla River in 1967 and 1974, respectively. Close et al. (1995) presume that several age classes of Pacific lamprey were destroyed. The Idaho Department of Fish and Game also used fish toxicants to eradicate fish in some Idaho lakes and streams (Chapman et al. 1990). We found no evidence that managers used toxicants to eradicate non-game fishes in the mid-Columbia region.

4.3 Ocean Conditions

Close et al. (1995) identified ocean conditions and the abundance of prey as factors that may have contributed to the decline of Pacific lamprey in the Columbia River basin. They reasoned that the abundance of lamprey may closely track the abundance of prey, which is tied to ocean conditions. Thus, ocean conditions unfavorable for the production of prey would likely reduce adult lamprey survival. Ocean fisheries may also reduce potential prey. Close et al. (1995) indicated that intense commercial harvest of Pacific hake and walleye pollock may have depleted the prey base for Pacific lamprey. The rise in 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 as other prey items became scarce. We cannot exclude ocean conditions as a factor contributing to the decline of Pacific lamprey.

4.4 Dam Passage

Mullan et al. (1986) thought that dams may importantly affect the survival of juvenile and adult Pacific lamprey in the mid-Columbia region. Because juvenile lamprey apparently do not actively migrate downstream (they drift passively with the current; Beamish 1980), reservoirs may have delayed their downstream migration. Delayed migration rates probably increase encounters with predators, although we found no survival estimates for juvenile lamprey in reservoirs. We also found no survival estimates for juvenile lamprey that travel through turbines, over spillways, or through bypass systems. Travel through turbines is potentially high because juvenile lamprey swim low in the water column (Long 1968). The effects of saturated gas concentrations on juvenile lamprey survival also remains unknown.

On the other hand, it is well known that large numbers of juvenile lamprey are impinged on traveling screens at dams used to bypass anadromous fish (Hammond 1979; Jackson et al. 1996; Moursund et al. 2000). Moursund et al. (2000) found that 70% and 97% of test lamprey impinged on bar screens at velocities of 1.5 ft/s for 1-min and 12-hr exposures, respectively. They noted that because the average maximum burst speed of juvenile lamprey was less than the average perpendicular velocity at the face of screens, juvenile lamprey easily impinged on the screens. The tendency of juveniles to use their tails for locomotion resulted in some individuals becoming permanently wedged between the bar spacings. Approximately 98% of juvenile lamprey were unable to free themselves from screens at velocities of ≥1.5 ft/s when exposed to flows for extended periods of time (Moursund et al. 2000).

Dams may also impede the upstream passage of adult lamprey in the Columbia River basin (Close et al. 1995). Recent research by Vella et al. (1999a, 1999b) suggest that up to 80% of radio-tagged adult lamprey fail to pass the fishways at Bonneville Dam. Ocker et al. (undated) reported that only 79 of 200 radio-tagged lamprey passed Bonneville Dam, 18 passed The Dalles Dam, and 4 passed John Day Dam. Of those passing Bonneville Dam, 39 passed via the Washington shore ladder and 40 passed via Bradford Island ladder. Ocker et al. (undated) noted that 22 lamprey backed down the ladders and 16 fell back. The researchers concluded that lamprey have difficulty negotiating the transition areas from the tailrace to the collection channel and from the collection channel to the ladder, as well as the area of the counting window.

Pacific lamprey appear to have problems traveling through submerged orifices. Vella et al. (undated) used underwater video to assess lamprey swimming behavior through submerged orifices at Bonneville Dam. After releasing 42 lamprey into the bypass ladder, they found that 29 passed successfully; 6 did not pass. Total passage time between the area 18 inches downstream of the monitored orifice to 12 inches upstream of the orifice averaged 3.9 minutes. This compares to an average of 0.04 minutes for adult salmonids. Lamprey swam through the submerged orifice in a repeated series of motions consisting of attaching to the ladder floor with their mouths, surging forward, and re-attaching.

Pacific lamprey use excessive energy in negotiating fishways during their upstream migration. Mesa et al. (1999) found that the physiological responses of adult Pacific lamprey to exhaustive exercise were immediate, sometimes severe, and short-lived. They estimated the critical swimming speed of adult lamprey as 0.86 m/s at 15°C. Water velocities in fishways at Bonneville Dam can reach 1.8-2.4 m/s (Mesa et al. 1999). Vella et al. (undated) found that in experimental PVC pipe fishways, lamprey passage was low at high water velocities (6-6.5 ft/s) and shallow water depths (1-2 in) within stepped transition sections. This indicates that Pacific lamprey probably have difficulty negotiating the high water velocities in fishways at Bonneville Dam. The work by Mesa et al. (1999) indicates that lamprey recover quickly from a single stress. However, the response of lamprey to several bouts of exhaustive stress remains unclear.

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