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Predation by Northern Pikeminnow on Hatchery and Wild Coho Salmon Smolts in the Chehalis River, Washington

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Abstract.—One explanation for the low smolt-to-adult survival rates of hatchery and wild coho salmon *Oncorhynchus kisutch* originating from the Chehalis River, Washington, is predation by northern pikeminnow *Ptychocheilus oregonensis*. To evaluate this hypothesis, we studied predation by northern pikeminnow on emigrating coho salmon smolts in the undammed, lower main-stem Chehalis River (river kilometers [rkm] 27–82) during April and May of 1988 and 1989. Where only wild coho salmon smolts were available, we estimated that northern pikeminnow ate 0.2% of the 1,100,000 wild coho salmon smolts migrating through this reach in 1989. In the reach where both hatchery and wild fish were present, northern pikeminnow ate about 0.9% of the hatchery and wild coho salmon available in this area in 1989. Thus, the total estimated loss of coho salmon smolts due to northern pikeminnow predation in the lower main-stem Chehalis River in 1989 was approximately 18,200 fish. This was about two orders of magnitude less than the loss that we predicted to occur if northern pikeminnow were primarily responsible for the low survival rates of coho salmon in this basin. Evidence suggested that most of the predation was occurring on hatchery origin fish below rkm 42. We conclude that northern pikeminnow were not responsible for the low survival rates of coho salmon smolts in the Chehalis River Basin, but they do have a more significant impact on the survival of hatchery-produced coho salmon than on the survival of wild coho salmon.

Predation by northern pikeminnow *Ptychocheilus oregonensis* is an important source of juvenile salmon *Oncorhynchus* spp. mortality in a variety of habitats (Ricker 1941; Thompson 1959; Eggers et al. 1978; Poe et al. 1991; Rieman et al. 1991; Petersen 1994; Beamesderfer et al. 1996; Friesen and Ward 1999). Predation appears to be especially high where habitats have been heavily modified because such modifications alter the natural behavior patterns of northern pikeminnow and juvenile salmon (Brown and Moyle 1981; Beamesderfer et al. 1996; Beamesderfer 2000). For example, in the Columbia River Basin, predation is particularly significant around dams and diversions (Brown and Moyle 1981; Petersen 1994; Ward et al. 1995) where juvenile salmonids are concentrated, injured, disoriented, and stressed, and thus more vulnerable to northern pikeminnow (Vigg et al. 1991; Mesa 1994).

In habitats that have not been heavily modified, the importance of northern pikeminnow predation is less clear. Some studies suggest northern pikeminnow eat relatively few juvenile salmonids in these types of habitats (Brown and Moyle 1981; Buchanan et al. 1981), while other work suggests that higher levels of predation can occur (Tabor et al. 1993; Ward et al. 1995; Shively et al. 1996; Zimmerman and Ward 1999). One relatively unmodified basin where northern pikeminnow predation may be a significant source of mortality is the Chehalis River, Washington. In this basin, the smolt-to-adult survival rates of coho salmon *O. kisutch* are low compared with those of other coho salmon populations in the region. For example, Seiler (1989) reported that the smolt-to-adult survival rates of both wild and hatchery-produced coho salmon originating from the Chehalis River between 1980 and 1983 were approximately one-half those of coho salmon originating from the nearby Humptulips River. Northern pikeminnow predation may account for the low survival rates of coho salmon in the Chehalis River Basin because northern pikeminnow occur in the lower Chehalis River but are absent in the Humptulips River (K. Fresh, unpublished data).

Our major objective was to test the hypothesis that northern pikeminnow predation was responsible for the low smolt-to-adult survival rates of Chehalis River coho salmon. A secondary objective was to ascertain if northern pikeminnow predation could account for the 2–4 times higher survival rates that wild coho salmon smolts have compared with those of hatchery coho salmon smolts in the basin (Seiler 1989). Because hatchery-produced juvenile salmon can be more susceptible to predators than naturally produced juvenile salmon

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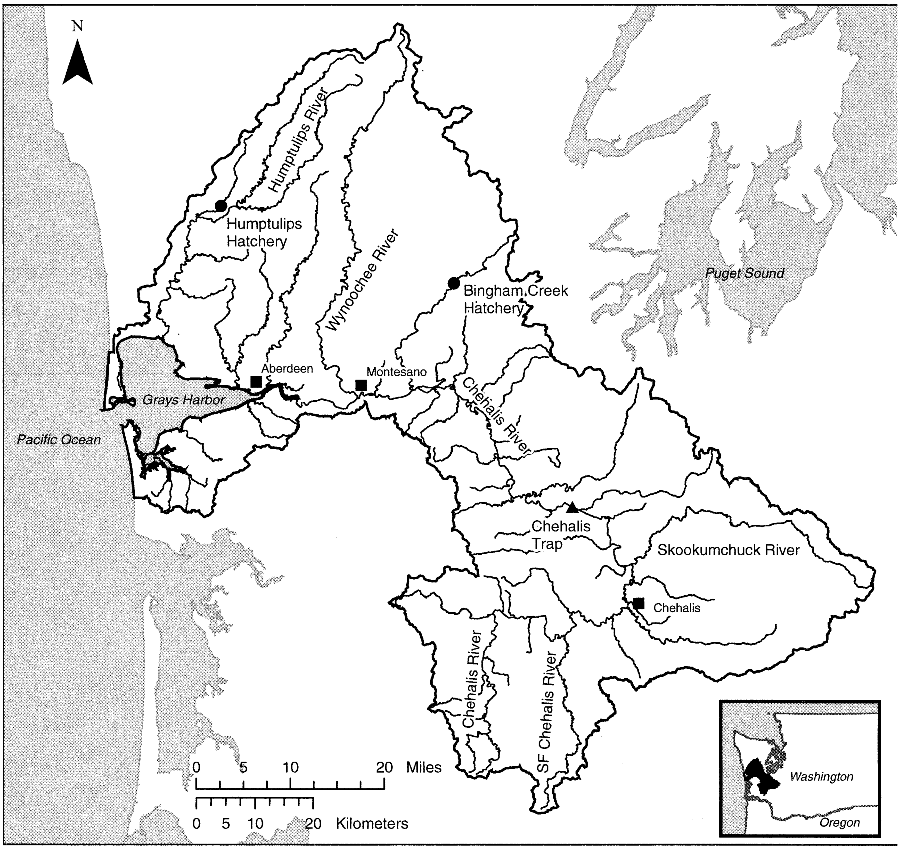

FIGURE 1.—Map of the Chehalis River Basin in southwest Washington showing the location of the study area.

(Thompson 1966; Thompson and Tufts 1967; Berejikian 1995; Collis et al. 1995; Shively et al. 1996), we postulated that the survival difference between the Chehalis River hatchery and the wild coho salmon could be a function of differential predation by northern pikeminnow.

Study Area

The Chehalis River Basin drains an area of about 5,709 km^2 and empties into Grays Harbor, a large, drowned, river valley estuary located on the southwest Washington coast (Figure 1). With the exception of several dams on headwater streams, the flow of water in the basin is unobstructed by artificial structures. The monthly average flows on the main-stem Chehalis River during this study were 181.4 m^3/s in April 1988, 149.4 m^3/s in April 1989, 69.3 m^3/s in May 1988, and 35.3 m^3/s in May 1989 (USGS Gauge 12031000 at Porter, Washington, on the lower Chehalis River).

Our study was conducted in the main-stem Chehalis River between rkm 27 and rkm 82 (Figure 1) because northern pikeminnow are abundant in this area. Below rkm 27, increasing salinities reduced the efficiency of our sampling gear (electrofishing). We expected that the abundance of northern pikeminnow would decline rapidly downstream of this point as a result of higher salinities. The upper limit of the study area was established at rkm 82 because a trap located near this point (Seiler 1989) provided estimates of the abundance, size, and timing of wild coho salmon smolts migrating through the river. Some northern pikeminnow occur above this point, but their numbers decline due to such factors as higher channel gradient, smaller stream channels, and cooler water temperatures. During this study, hatchery-produced coho salmon smolts were released from the Bingham Creek Hatchery, located at rkm 31 on the Satsop River, which enters the main-stem Chehalis River at rkm 42 (Figure 1). The study area was subdivided into an upper reach (rkm 42–82) and lower reach (rkm 27–42, the point where the Satsop River enters the main-stem Chehalis River) because both hatchery and wild fish were present in the lower reach, while only wild fish occurred in the upper reach.

Methods

We studied predation by northern pikeminnow in the Chehalis River during April and May of 1988 and 1989 because coho salmon smolts migrate to sea through the lower Chehalis River at this time (D. Seiler, Washington Department of Fish and Wildlife, unpublished data). Sampling conducted in 1988 was used to help develop an approach for estimating the consumption of coho salmon smolts by northern pikeminnow, which was then conducted in 1989. Separate estimates of consumption and percent mortality were developed for the upper and lower study reaches. In the lower river, consumption and percent morality were estimated separately for the periods before and after the hatchery fish were released.

The number of coho salmon smolts eaten by northern pikeminnow was estimated using a meal turnover approach (Diana 1979). The number of smolts eaten (N) was calculated as follows:

$$N = E \cdot C \cdot A \cdot P,$$

where E is the number of meals of coho smolts that a northern pikeminnow (that was feeding on coho salmon) could eat during the period coho salmon were available, C is the average meal size of smolts expressed as the average number of smolts consumed per northern pikeminnow, A is the abundance of northern pikeminnow determined from a mark–recapture population estimate, and P is the percentage of northern pikeminnow that had eaten smolts based upon analyses of northern pikeminnow digestive tracts.

The percent mortality of coho salmon smolts (M) was then estimated as

$$M = N/S,$$

where N is the estimated number of smolts eaten and S is the number of smolts migrating downstream through a study reach. The following describes how the different components of the consumption and percent mortality estimates were derived.

Diet of northern pikeminnow.—Northern pikeminnow were collected for digestive tract analyses between dawn and dusk in April and May of 1988 and 1989 using Smith-Root and Coffelt boat electroshockers. In 1988, northern pikeminnow digestive tracts were only collected below rkm 42; in 1989, they were collected from rkm 27 to rkm 82.

The fish stunned during electroshocking were netted, held in live wells, and processed within 2 h of capture. Fork length (FL) and sex were determined for each specimen and the contents of the entire digestive tract examined. All identifiable prey were counted and the length of any fish recovered largely intact from a digestive tract was measured. Although the digestive tracts of northern pikeminnow greater than 230 mm FL were examined, only the results for fish greater than 300 mm FL are reported because we found northern pikeminnow smaller than this size did not consume coho salmon smolts.

Abundance of northern pikeminnow.—In 1989, the abundance of northern pikeminnow greater than 300 mm FL between rkm 27 and 82 was estimated in eight, randomly selected sections of the river using the Petersen single census method (Ricker 1975). Two sections were from below the confluence with the Satsop River and six were above this point; the dimensions of each sampled section were determined in the field.

Northern pikeminnow were first collected from a section using electroshocking boats. The captured fish were placed into a live well, measured for FL, tagged with an individually numbered jaw tag, opercule punched, and released after recovery back into the river near where they were captured. The fish that appeared to be injured during capture and handling were not released. Each section was then resampled 5 d after the fish had been tagged, and the numbers of tagged and untagged fish were recorded.

The population size and 95% confidence intervals (CIs) of northern pikeminnow in each section were computed using Chapman's version of the Petersen mark–recapture estimator and assuming a Poisson distribution to calculate CIs (Ricker 1975). The numbers of northern pikeminnow per section and the upper and lower bounds of the 95% CIs were standardized to fish/km because not all sections were the same length. The estimated population size of northern pikeminnow in the study area (rkm 27–82) was calculated as the mean number of northern pikeminnow/km from the sections that were sampled multiplied by 55, the number of km in the study area. The upper bound of this estimate was computed by averaging the values calculated as the upper bounds of the 95% CI and multiplying by 55. Similarly, the lower bound of this estimate was computed by averaging the lower bounds of the 95% CI and multiplying by 55.

The assumptions that must hold for the Peterson method to generate a suitable estimate of the population size are listed in Ricker (1975). We chose to mark and recapture at 5 d intervals as a compromise among the following considerations: (1) allowing the fish sufficient time to recover from the stress of marking; (2) allowing the fish sufficient time to mix in a section; and (3) reducing the chance that marked fish would emigrate from a section. Mesa and Schreck (1989) found that cutthroat trout *O. clarki* needed at least 24 h to recover from electroshocking. To our knowledge, similar studies have not been conducted with northern pikeminnow but we decided to allow at least 48 h for the fish to recover. However, we did not believe the fish would redistribute themselves in sections within 48 h between marking and recapturing events. As the time between marking and recapturing increased, the likelihood that some marked fish would emigrate increased. Thus, we concluded 5 d was a reasonable amount of time between the mark and recapture events. To provide some information on the emigration of marked fish, we sampled 100 m above and below each section on recapture days and occasionally electrofished in portions of the river not used for northern pikeminnow population estimates.

To evaluate tagging mortality and mark retention, 15 northern pikeminnow were tagged with jaw tags, opercle punched, measured, weighed, and placed in a net-pen in the lower river. All the fish had retained their tags and were healthy when examined 5 d later.

Number of meals eaten by northern pikeminnow.—The number of meals eaten by northern pikeminnow (E) was calculated using the gastric evacuation model of Beyer et al. (1988). The model was used to determine the time (h) needed by northern pikeminnow to digest 90% (ET 90%) of a meal of coho salmon (g), at which point we assumed northern pikeminnow would be ready to feed again on coho salmon smolts. The model uses meal size (g), predator size (g), and water temperature (°C) to estimate ET 90% (see Table 1). The meal size of coho salmon (g) was estimated as the mean number of coho salmon eaten by northern pikeminnow multiplied by 30 g, which was the average size of coho salmon smolts recovered from northern pikeminnow digestive tracts. Water temperatures were measured during sampling in April and May 1989 (Table 1). Northern pikeminnow fork lengths were converted to weights using the length–weight relationship reported by Parker et al. (1995).

TABLE 1.—Parameters used to estimate consumption of coho salmon smolts by northern pikeminnow in 1989 in the lower Chehalis River. Parameter values are provided separately for the upper river (rkm 27 to 42) and lower river (rkm 42 to 82) reaches.

Parameter	Value
Population size of northern pikeminnow	
Lower river	3,690
Upper river	11,800
Proportion of northern pikeminnow that had eaten coho salmon smolts[a]	
Lower river	0.170
Upper river	0.003
Number of coho salmon smolts eaten per northern pikeminnow[b]	
Lower river	1.60
Upper river	1.00
Number of days coho salmon smolts were available to northern pikeminnow[c]	
Lower river	20
Upper river	60
Time needed by northern pikeminnow to digest a meal of coho salmon smolts[d]	
Hours to 90% evacuation	30
Data used	
Predator weight (g)	650
Meal weight (g)	48
Temperature (°C)	14.1

[a] For northern pikeminnow that had eaten smolts. In the lower river, this only occurred following the release of hatchery coho salmon.

[b] In the lower river, this was only calculated for the period following the release of hatchery coho salmon.

[c] In the upper river section, wild coho salmon were considered to be available to predators for 60 d in April and May, which is the period over which smolts outmigrate from the basin (D. Seiler, Washington Department of Fish and Wildlife, unpublished data). In the lower river, we used 20 d beginning 11 May 1989 as the time period coho salmon smolts were subject to predation by northern pikeminnow. We found that predation in the lower river did not occur until after hatchery fish had been released (10–20 May 1989). A study of migration rates of wild coho salmon smolts in this basin (Moser et al. 1991) suggested the hatchery coho salmon would be available in the lower river within 1 d of their release and pass through the lower river in 1 d. Therefore, because the smolt migration is largely completed by the end of May (D. Seiler, unpublished data), we assumed predation in the lower river began 11 May 1989 and occurred for the next 20 d.

[d] Time to evacuate 90% of a meal of coho salmon was calculated using the model presented by Beyer et al. (1988). Predator weight was calculated by converting lengths to weights using Parker et al. (1995). Meal weight was a 30-g smolt multiplied by the mean number of smolts per northern pikeminnow. Temperature data was measured in situ during spring 1989.

The ET 90% (h) was divided into the estimated number of hours coho salmon were available in the study area to yield the number of meals of smolts consumed by northern pikeminnow. In the upper river section, wild coho salmon were considered to be available to predators for 60 d based upon data obtained from the migrant trap located at rkm 82 (D. Seiler, unpublished data; Table 1).

In the lower river, we assumed that wild and hatchery coho salmon smolts were available to northern pikeminnow for 20 d beginning on 11 May 1989. We selected 11 May 1989 as the point at which predation began because northern pikeminnow did not eat any coho salmon until after hatchery fish had been released. A study of the migration rates of wild coho salmon smolts in this basin using radio telemetry suggested that the hatchery coho salmon smolts reached the lower river within 1 d following their release on 10 May 1989 (Moser et al. 1991). Twenty days was used as the time period during which coho salmon smolts were eaten by northern pikeminnow in the lower river because most wild coho salmon smolts had left the basin by the end of May (D. Seiler, unpublished data). The release of hatchery fish was completed by 20 May 1989, and these fish rapidly left freshwater thereafter.

Abundance of outmigrating coho salmon smolts.—In 1989, approximately 1.3 million hatchery-produced coho salmon smolts were volitionally released from the Bingham Creek Hatchery and were only available to predators below rkm 42 (Washington Department of Fish and Wildlife, unpublished data). The wild coho salmon smolt production of the Chehalis River Basin in 1989 was 1,600,000 fish (D. Seiler, personal communication). Because coho salmon smolt production is a function of the basin area (Zillges 1977), the number of coho salmon smolts produced from any subbasin can be estimated by multiplying the number of smolts/km^2 for the entire basin by subbasin area. We calculated that 1.45 million wild coho salmon smolts migrated through the lower river study reach during April and May, of which an estimated 1.1 million wild smolts originated from above rkm 42. We estimated that about 33% of the 1.45 million wild coho salmon migrating through the lower river (0.48 million fish) were available to the northern pikeminnow based upon our results that suggested northern pikeminnow predation on smolts in the lower river only occurred for the last 20 d of the 60 d (i.e., one-third) smolt migration period.

Results

Northern Pikeminnow Diet

The contents of 667 northern pikeminnow digestive tracts were examined, of which 159 were from 1988 (mean FL = 369.6 ± 44.4 mm) and 508 (mean FL = 362.9 ± 53.5 mm) were from 1989. The percentage of northern pikeminnow digestive tracts with food was 51.6% in 1988 and 62.0% in 1989. The most frequently occurring prey items of northern pikeminnow were crayfish (Astacidae) and fish. In 1988, fish and crayfish occurred in 34.0% and 15.1% of northern pikeminnow digestive tracts, respectively; in 1989, fish and crayfish occurred in 32.7% and 22.6% of digestive tracts, respectively. In 1989, crayfish were the most prevalent food item in the upper river (39.8% of digestive tracts), while fish were the most prevalent prey in the lower river (31.5% of digestive tracts).

The fish species identified from northern pikeminnow digestive tracts included coho salmon smolts, cottids *Cottus* spp., threespine stickleback *Gasterosteus aculeatus*, speckled dace *Rhinichthys osculus*, peamouth *Mylocheilus caurinus*, and northern pikeminnow. Coho salmon smolts were the most frequently occurring fish species in northern pikeminnow digestive tracts and were found in 12.6% of northern pikeminnow in 1988 and 3.5% in 1989. Northern pikeminnow ate an average of 1.4 smolts per fish in 1988 (0.2 smolts per northern pikeminnow overall) and 1.6 smolts per fish in 1989 (0.06 smolts per northern pikeminnow overall; Table 1). In 1989, only one smolt was recovered from the 323 northern pikeminnow examined from the upper river reach, while 9.0% of the northern pikeminnow examined from the lower river had consumed smolts.

In both years, the occurrence of smolts in northern pikeminnow stomachs from the lower river increased markedly following the release of hatchery fish. In 1988, 4.5% of the northern pikeminnow had eaten coho salmon smolts prior to the release of the hatchery fish, and 38.0% of the northern pikeminnow had eaten coho salmon smolts after the hatchery fish were released. In 1989, we found no coho salmon smolts in northern pikeminnow digestive tracts prior to the release of the hatchery fish, but 17.0% of the northern pikeminnow had consumed coho salmon smolts following the release of the hatchery coho salmon.

Abundance of Northern Pikeminnow

Of the 245 northern pikeminnow tagged and released within the eight sections (range = 19–55 fish per section), 31 marked fish were recaptured out of 355 northern pikeminnow examined during recapture sampling. Most tagged fish were recaptured short distances (<100 m) from where they were released. One fish was recaptured about 10 m upstream of the section it had been released into and so was included in the estimate for that section.

TABLE 2.—Estimated numbers of coho salmon smolts eaten and percent mortality due to northern pikeminnow predation in the Chehalis River Basin in spring 1989. Consumption was computed using data provided in Table 1.

Parameter	Value
Numbers of coho salmon smolts eaten by northern pikeminnow	
Upper river	2,100
Lower river	16,100
Number of coho salmon smolts available to northern pikeminnow	
Upper river	1,100,000
Lower river	
Wild	480,000
Hatchery	1,300,000
Percent mortality of coho salmon	
Upper river	0.2%
Lower river	0.9%

However, one fish was recaptured 8 d after marking and 26 km upstream of its release location, suggesting there was some movement of fish out of sections; this would introduce some error in the population estimates. No tags were recovered in either of the two lower river sections which we believe is most likely a result of (1) marking at low tide when there was less water to sample in the sections, and (2) recapturing around high tide when the volume of water that had to be sampled increased at least threefold. Thus, population estimates were based only on data from the other six sections. The average abundance of northern pikeminnow per section (in the six with recoveries) was 304 fish (range = 190–694 fish per section) or 229 northern pikeminnow/km. In the upper river, the estimated population of northern pikeminnow was 11,800 (range = 3,000–37,900 fish); in the lower river, the estimated population of northern pikeminnow was 3,700 fish (range = 1,140–14,220 fish; Table 1).

Numbers Eaten and Percent Mortality

Few wild coho salmon smolts were eaten by northern pikeminnow in the upper river reach (Table 2). The estimated consumption of coho salmon smolts in the upper river was 2,100 fish, or about 0.2% of the coho salmon smolts migrating through this portion of the river. In the lower river, we estimated that northern pikeminnow consumed 16,100 coho salmon smolts during the 20-d period predators and prey overlapped (Table 2). The percent mortality of coho salmon smolts was about 0.9% of the combined numbers of hatchery and wild coho salmon available in this reach (Table 2).

Discussion

The results of this study suggest that predation by northern pikeminnow in the Chehalis River below rkm 82 during the April–May smolt migration period was not the primary factor responsible for the low smolt-to-adult survival rates of coho salmon in this basin. If northern pikeminnow were the major source of mortality, they should have consumed about 50% of the coho salmon originating from the Chehalis Basin since this is the difference in survival rates between the neighboring Humptulips and Chehalis rivers (Seiler 1989). In 1989, 50% of the Chehalis Basin smolt production was approximately 1.6 million fish (0.8 million hatchery fish and 0.8 million wild fish). Our study suggested that the total loss of coho salmon smolts due to northern pikeminnow predation was about two orders of magnitude less than this, or only about 18,100 smolts. This estimate can be compared with the estimated mortality of salmonid smolts due to northern pikeminnow predation in the Columbia River Basin reported by Beamesderfer et al. (1996). They determined that the annual loss of salmon and steelhead *O. mykiss* smolts was 8%, or an order of magnitude greater than our estimated loss in the Chehalis River. However, their study included multiple salmonid species and size-classes of prey, both reservior and riverine habitats, and many hundreds of kilometers of habitat, while our study included only one prey species within a narrow size range and covered 55 km of entirely riverine habitats.

The evidence suggests that many of the fish eaten were of hatchery origin. First, in the upper river where only wild smolts were present, the consumption of coho salmon smolts by northern pikeminnow was less than 1% of the wild smolts emigrating through this area. Second, the size of the smolts measured from northern pikeminnow digestive tracts was most similar to the size of the hatchery fish that were released. For example, in 1988, mean FLs of coho salmon measured from northern pikeminnow digestive tracts was 143.1 mm FL ($\pm$12.4, $N = 25$), and the mean FL of wild coho salmon measured at the migrant trap at rkm 82 was 115.5 mm FL ($\pm$10.5, $N = 81$). Third, for about 10 d following the release of the hatchery coho salmon, large numbers of coho salmon were observed jumping and breaking the surface in the lower river. This is typical behavior of hatchery fish in ponds and was never observed when only wild fish were present. Fourth, a number of coho salmon smolts captured in the lower river while electroshocking at this time had coded wire tags, all of which were from the Bingham Creek Hatchery. Fifth, the physiological condition of the coho salmon captured in the lower river (as measured by ATP-ase, thyroxine, and blood hematocrit levels) was very similar to that of the coho salmon released from the hatchery ponds (Schroder and Fresh 1992).

Our results are consistent with those of other studies which found that hatchery-produced salmonids are more vulnerable to predation by northern pikeminnow (Thompson 1959; Brown and Moyle 1981; Collis et al. 1995; Shively et al. 1996). One reason why this can occur is because hatchery-produced salmon are often less able to avoid predators than wild fish (e.g., Thompson 1966; Mesa 1994; Berejikian 1995). In addition, a rapid increase in the density of hatchery fish usually occurs immediately after they are released which, in turn, may cause northern pikeminnow or other predators to rapidly switch to a diet with more hatchery smolts (Thompson 1959; Thompson and Tufts 1967; Petersen and DeAngelis 1992; Collis et al. 1995; Shively et al. 1996). We observed such a rapid increase in density in the lower river and subsequent increase in coho salmon consumption following the release of hatchery coho salmon smolts from the Bingham Creek Hatchery.

In summary, our study suggests that northern pikeminnow predation was not responsible for the low smolt-to-adult survival rates of coho salmon in the Chehalis River Basin. However, northern pikeminnow appeared to have a more significant impact on the survival of hatchery-produced coho salmon than on the survival of wild coho salmon.

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