FINAL REPORT TO

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES
HABITAT MANAGEMENT DIVISION

WINTER PREDATION ON COHO FINGERLINGS BY BIRDS AND MAMMALS IN RELATION TO POND CHARACTERISTICS

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TABLE OF CONTENTS

List of Tables ii
List of Figures iii
Introduction 1
Study Area 2
Methods. 2
Results. 8
Animals using ponds 8
Rates of predation. 12
Predation rate and pond morphometry 12
Coho mortality and rates of predation 14
Discussion 23
Recommendations. 25
Future Study Possibilities 27
Acknowledgements 29
Literature Cited 30
Appendix A. 32

LIST OF TABLES

Number		Page
1.	Canopy cover around the two study ponds	9
2.	Number of predator species sighted at Pond 2	10
3.	Number of predator species sighted at Pond 1	11
4.	Predation rates on coho by species	13
5.	Predation rates by pond depths	15
6.	Smolt catches for Ponds 1 and 2	17
7.	Rate of predation by pond	20

LIST OF FIGURES

Number		Page
1.	Location of study area	3
2.	Morphometry of study ponds	4
3.	Distribution of pond depths and predation	16
4.	Trends in juvenile coho mortality by pond	19
5.	Coho mortality by different causes	22

INTRODUCTION

Avian predation may account for as much as 25% of the total annual salmonid mortality in coldwater streams in the northern United States (Alexander 1979). Mammalian predators, such as the river otter (Lutra canadensis) and mink (Mustela vison), occur in lower densities than birds and consume fewer (<15% of total salmonid mortality) and larger salmonids. In a restricted freshwater system, such as a pond, the impact of avian and mammalian predation may be much greater than in a stream.

In a study of the ecology of juvenile coho salmon (Oncorhynchus kisutch) in 2 riverine ponds, Peterson (1982) discovered a difference in juvenile survival rates between ponds. Peterson predicted that pond morphometry indirectly influenced survival of overwintering coho. He hypothesized that avian predators were more effective in the shallower of the 2 study ponds.

This study examined the relationship between pond morphometry and the rate of predation by avian and mammalian species on juvenile coho. Specific objectives were:

1) estimate the rate of predation on overwintering coho in Peterson's (1982) study ponds;
2) compare pond morphometry with rate of predation;
3) compare the rate of predation with the mortality of juvenile coho;
4) determine and measure factors other than pond morphometry that may influence avian and mammalian use of the ponds.

STUDY AREA

The study was conducted on 2 natural ponds (Pond 1 and Pond 2) located in the Clearwater River drainage on the west side of the Olympic Peninsula, Washington (Figs. 1, 2a,b). The ponds different morphometrically and in size. Pond 2 is larger (1.29 ha) and shallower (maximum depth 1.3 m) than Pond 1 (0.85 ha, maximum depth 3.5 m).

Both ponds were surrounded by typical riparian habitat of red alder (Alnus rubra) and Sitka spruce (Picea sitchensis). Fish cover during the overwintering period (November - April) consisted of submerged logs and branches, beds of pondweed (Potamogeton spp.), mats of Potentilla spp., and overhanging riparian vegetation. At Pond 1 a clearcut created a substantial opening approximately 30-60 m from the north and east sides of the pond. Another natural pond was located approximately 75 m to the south of Pond 2. We observed the same waterfowl species using this pond as at Pond 2.

METHODS

An elevated plywood blind was constructed at each pond in a location that provided discrete access and good visibility. The blinds were approximately 3 m above water surface elevation. Fresh spruce branches were used to disguise the structures. Direct systematic observations of the number and species of predators present, foraging success, prey type, and location of prey capture were made from December 1982 through April 1983. These observations followed a reconnaissance period in November 1982. We observed predators with the aide of 8 x 30 binoculars and a 20-60 power spotting scope.

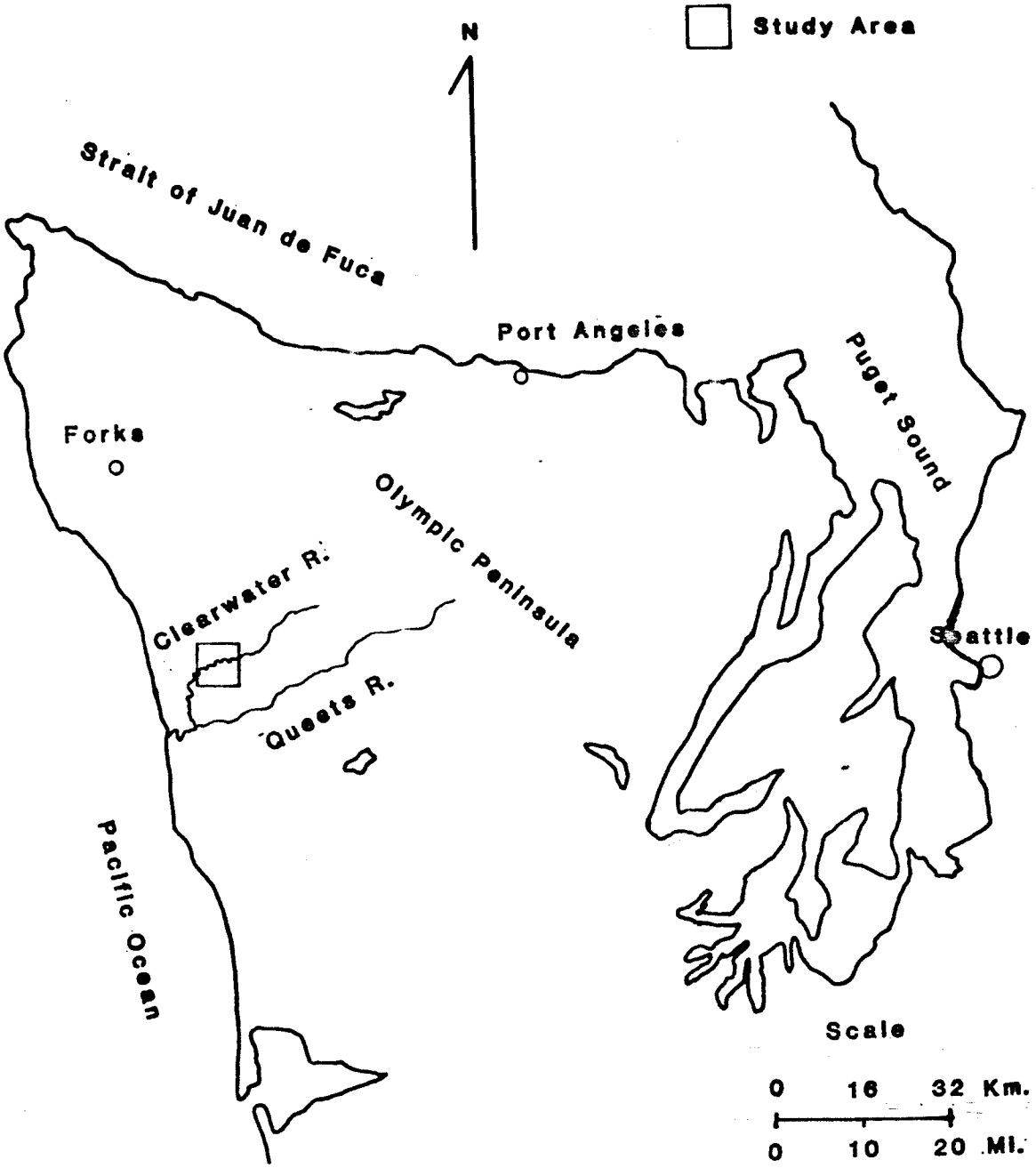
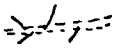


Figure 1. Location of the study area on the Olympic Peninsula, in western Washington.

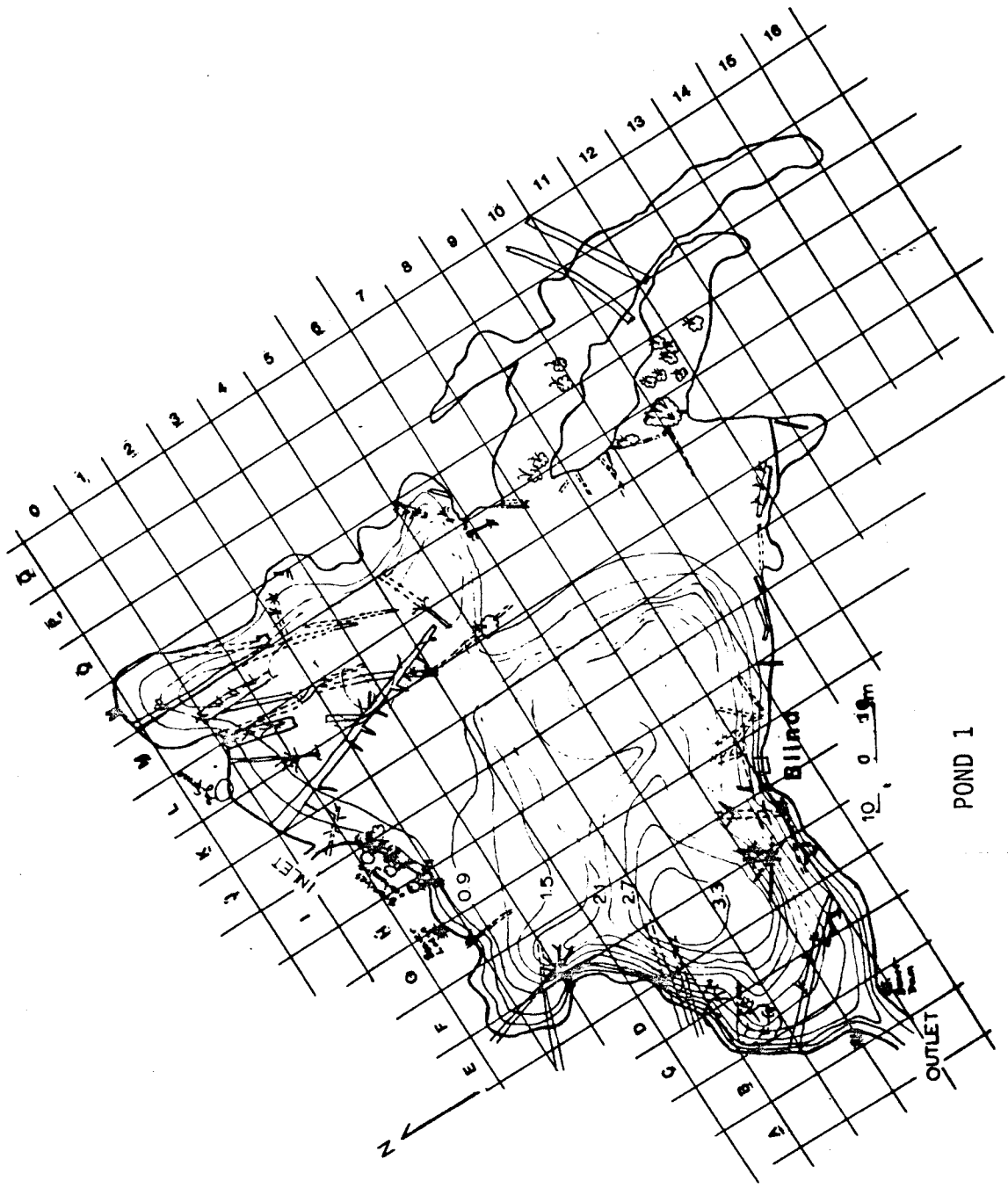
Figure 2. Morphometric depiction of the ponds with a 10 m grid system overlayed.

Key:

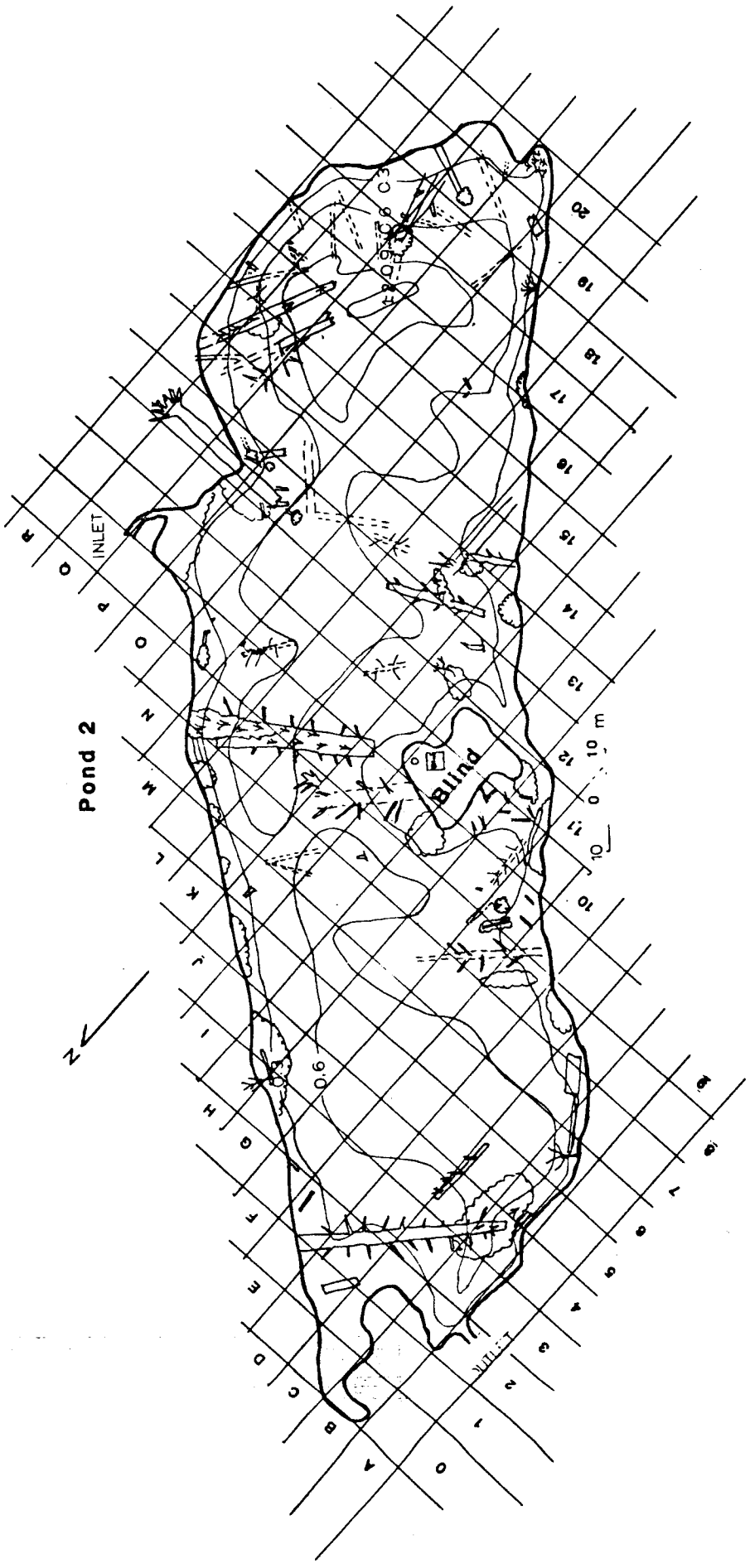


Submerged Logs

Grass/Sedge/RushVegetation



POND 1


Pond 2
INLET
Blind
N
0.6
10 0 10 m

To determine predator activity patterns, we observed each pond initially from dawn to dusk. Continuous observation periods ranged from 2 to 9.6 hours ($\bar{X}$ = 4.96, SD = 1.56, N = 32). Pond 2 was observed for a total of 77.8 hours ($\bar{X}$ = 4.86, SD = 1.78, N = 16); a total of 80.1 hours were spent at Pond 1 ($\bar{X}$ = 5.01, SD = 1.32, N = 16). In addition, we checked each pond 4 times between standard observations for presence of salmonid predators. Each pond inlet was observed twice for predator activity ($\bar{X}$ = 2.38 hours, SD = 0.92, N = 4).

One predator was observed at a time so that all prey captures could be recorded. Predator activity was noted at 2- to 5-minute intervals depending on the rapidity of their movements. A map of each pond overlain with 10 m grids was used to identify capture locations. We recorded all prey captures, noting time, grid coordinates, prey species and approximate size.

Generally several species of predators could be watched in a single day. We considered a 0.5 hour observation per predator to be the minimum for reliable analysis. Since river otters at times hunted less than 0.5 hour, we immediately began observing any otter entering the pond.

Otter scat was collected from logs in Pond 2 in December 1982 and April 1983. No otter scat was discovered in or around Pond 1. A 25% random sample was selected from each scat greater than 4 g dry weight. If the scat weighed less than 4 g all of it was analyzed. We calculated the number of coho salmon per scat, by identifying the number of complete jaw sets (using skeletonized fish from the ponds for reference), dividing by 2 and expanding for the subsample size if required. This probably is a minimum figure for the actual number of coho salmon per scat because of loss through chewing, digestion, and weathering.

We calculated the hourly rate of predation for each species per observation greater than 0.5 hour in length. For each month a predator species occurred on a pond, we obtained a mean hourly rate of predation. From this we estimated the number of coho salmon fingerlings consumed each month by:

(hourly rate) x (10 hours average day length) x (30 days/month)

Using the 10 m grid system over maps of the ponds, we calculated the percentage of each pond in 3 depth classes: (1) <0.3 m, (2) 0.3-0.6 m, and (3) >0.6 m.

RESULTS

The surrounding riparian habitat differed little between ponds (Table 1). The 3 major plant species occurred in similar quantities at both ponds ($X^2 = 1.67$, $p > 0.3$).

Animals Using Ponds

The numbers and species of animals using the ponds differed between ponds. At Pond 2 we observed 11 species of water birds (Table 2), 5 of which were potential predators on coho fingerlings. We noted 7 species using Pond 1 (Table 3), 4 of which preyed upon coho fingerlings. River otters hunted in both ponds. Generally two otters frequented Pond 2; one otter was occasionally observed at Pond 1.

Pond 2 attracted more individuals per month than Pond 1 ($X^2 = 13.31$, $p < 0.02$). More salmonid predators were sighted on each pond in November 1982, than any other month. However, at Pond 2 the greatest average number of individuals per observation occurred in January 1983. At Pond

Table 1. Absolute percent of canopy cover (>3 m) at 10 m from the edge of the ponds.

SPECIES	Percent Canopy Cover	
	Pond 1	Pond 2
Alnus rubra	62.7	67.9
Picea sitchensis	21.0	32.9
Acer circinatum	-	11.9
Acer macrophyllum	9.1	7.8
Populus trichocarpa	5.7	-
Tsuga heterophylla	-	5.3
Sambucus racemosa	2.3	1.1
Oemleria ceraciformis	-	0.6
Crataegus oxyacantha	-	0.4

Table 2. Numbers of individuals of each species sighted per month, and mean number of individuals sighted per observation period (in parentheses), Pond 2.

Species	November	January	February	March	April
*Pied-billed grebe	11 (2.2)	16 (4.0)	13 (3.3)	12 (2.4)	-
*Belted kingfisher	10 (1.1)	4 (1.0)	4 (1.0)	5 (1.5	2 (1.0)
*Great blue heron	3 (1.0)	6 (1.5)	2 (1.0)	2 (2.0)	1 (1.0)
*Hooded merganser	24 (2.7)	2 (2.0)	-	3 (1.5)	-
Bufflehead	8 (1.1)	11 (2.8)	2 (2.0)	2 (2.0)	-
Common goldeneye	14 (2.3)	10 (2.5)	10 (2.5)	1 (1.0)	-
Ring-necked duck	150(16.7)	7 (1.8)	10 (5.0)	10 (5.0)	-
Mallard	13 (2.4)	5 (1.7)	2 (2.0)	27 (5.4)	15 (5.0)
American widgeon	3 (3.0)	-	-	-	-
Wood duck	-	-	-	-	7 (3.5)
Bald eagle	1 (1.0)	-	-	-	-
*Osprey	-	1 (1.0)	-	-	-
*River otter	4 (2.0)	4 (2.0)	-	3 (3.0)	-
Totals	237 (3.2)	68 (2.0)	43 (2.4)	63 (2.6)	25 (2.6)
Species	11	10	7	9	4

* Obserserved predators on coho salmon.

Table 3. Number of individuals of each species sighted per month, and mean number of of individuals sighted per observation period (in parentheses) on Pond 1.

Species	November	December	January	February	March	April
*Pied-billed grebe	4 (1.0)	1 (1.0)	-	-	-	-
*Belted kingfisher	3 (1.0)	1 (1.0)	3 (1.0)	4 (1.0)	1 (1.0)	1 (1.0)
*Great blue heron	1 (1.0)	-	1 (1.0)	-	1 (1.0)	-
*Hooded merganser	9 (3.0)	-	6 (2.0)	8 (2.0)	3 (3.0)	-
Common goldeneye	-	-	-	1 (1.0)	-	-
Ring-necked duck	1 (1.0)	-	-	4 (2.0)	11 (3.7)	-
Mallard	6 (3.0)	-	-	4 (2.0)	17 (4.3)	9 (3.0)
*River otter	-	-	2 (1.0)	1 (1.0)	1 (1.0)	-
Beaver	-	-	1 (1.0)	-	2 (2.0)	4 (1.3)
Totals	24 (1.7)	2 (1.0)	13 (1.2)	20 (1.5)	36 (2.3)	14 (1.8)
Species	6	2	5	6	7	3

* Observed predators on coho salmon fingerlings.

1 the highest average number of individuals per observation was noted in November 1982.

Rates of Predation

The combined rate of predation for all salmonid predators in each pond varied between months (Table 4; for Pond 2, January-April, $X^2 = 11.23$, $p < 0.01$; for Pond 1, January-March, $X^2 = 27.49$, $p < 0.001$). The monthly rate of predation was significantly different between ponds (January-March; $X^2 = 13.90$, $p < 0.01$). The belted kingfisher at Pond 2 preyed upon more coho than in January or February ($X^2 = 284.47$, $p < 0.001$). We observed no coho salmon being taken during March.

At Pond 1 belted kingfisher consumption of coho salmon fingerlings decreased from January to February ($X^2 = 5.79$, $p < 0.02$). Hooded mergansers at Pond 1 preyed on more coho salmon in January than February ($X^2 = 118.15$, $p < 0.001$). Monthly rates of predation by other species were not compared because of the limited number of observations.

Nineteen river otter scat collected at Pond 2 contained an average of 15.11 coho salmon per scat (SD = 11.26, range 2-51 coho/scat). A minimum of 287 coho salmon were represented in the sample, which also contained jaws of 5 cutthroat trout and 5 steelhead fingerlings. Amphibian bones occurred in 16 scats; crayfish ectoskeleton was found in 13 scats. The observed rate of predation for river otters at Pond 2 was estimated at 11.7 per 10 hour day.

Predation Rate and Pond Morphometry

For the pied-billed grebe and belted kingfisher, the 2 most active salmonid predators, we compared capture depth with the percentage of pond

Table 4. Rate of predation by hour and month on coho salmon fingerlings in Ponds 1 and 2.

POND 1	January		February		March		April		Average	
Species	Hr	Mo	Hr	Mo	Hr	Mo	Hr	Mo	Hr	Mo
Pied-billed grebe	1.09	327	0.32	96	0.24	72	-	-	0.55	165
Belted kingfisher	0.48	144	0.40	120	-	-	1.50	450	0.79	238
River otter	1.17	351	-	-	-	-	-	-	1.17	351
Totals	2.74	822	0.72	216	0.24	72	1.50	450	0.74	222

POND 2	December		January		February		March		Average	
Species	Hr	Mo	Hr	Mo	Hr	Mo	Hr	Mo	Hr	Mo
Pied-billed grebe	1.07	321	-	-	-	-	-	-	1.07	321
Belted kingfisher	-	-	0.93	279	0.75	225	-	-	0.84	252
Great blue heron	-	-	1.24	372	-	-	2.74	822	1.99	597
Hooded merganser	-	-	0.84	252	0.20	60	-	-	0.52	156
Totals	1.07	321	3.01	903	0.95	285	2.74	822	1.11	333

in the 3 depth classes (Table 5). The pied-billed grebe was able to forage successfully at greater depths than the belted kingfisher. In both ponds the grebe foraged infrequently in the shallowest areas (<0.3 m).

Total coho salmon captures for all predator species were distributed differently in each pond (Fig. 3). Pond 2, which is relatively uniform in depth, showed no correlation between capture depth and pond depth (Spearman rank correlation coefficient $r_s = 0.24$, $p > 0.05$). At Pond 1 coho salmon were captured more often in shallow than deep areas ($r_s = 0.54$, $p < 0.05$).

When we compared total captures between ponds, more coho salmon (59%) were taken at 0.3-0.6 m in Pond 2 than Pond 1 (24%) ($X^2 = 9.99$, $p < 0.01$). Pied-billed grebes and belted kingfishers in both ponds accounted for most of this difference. However, the distribution of depth classes varied between ponds ($X^2 = 24.67$, $p < 0.001$).

Coho Mortality and Rates of Predation

Smolt yield data (Peterson in prep.) for the study ponds is summarized in Table 6. The methodology for this study is described in Peterson (in prep.). An additional 224 and 1203 juvenile coho salmon emigrated as presmolts between November and the beginning of the smolt migration (February 1 and March 1 for Pond 1 and 2, respectively). The beginning of the smolt season was arbitrarily assigned to that date when the majority of downstream migrants exhibited outward signs of smoltification. February migrants from Pond 1 were principally large "holdover" 2- to 3-year-old smolts.

Table 5. Relative amount of predation by pond depth at predation sites for Pied-billed grebe and Belted kingfisher.

	Depth (m)	A Percentage by depth	Pied-billed grebe B Predation by depth	Pied-billed grebe B/A	Pied-billed grebe B/A-1	Belted Kingfisher B Predation by depth	Belted Kingfisher B/A	Belted Kingfisher B/A-1
POND 1								
	<0.3	33	0	0.0	-1.0	63	1.9	+0.90
	0.3-0.6	9	11	1.2	+0.2	32	3.6	+2.60
	>0.6	58	89	1.5	+0.50	5	0.09	-0.91
POND 2	<0.3	22	24	1.1	+0.09	21	0.9	-0.05
	0.3-0.6	39	52	1.3	+0.33	72	1.8	+0.80
	>0.6	39	24	0.6	-0.40	7	0.2	-0.82

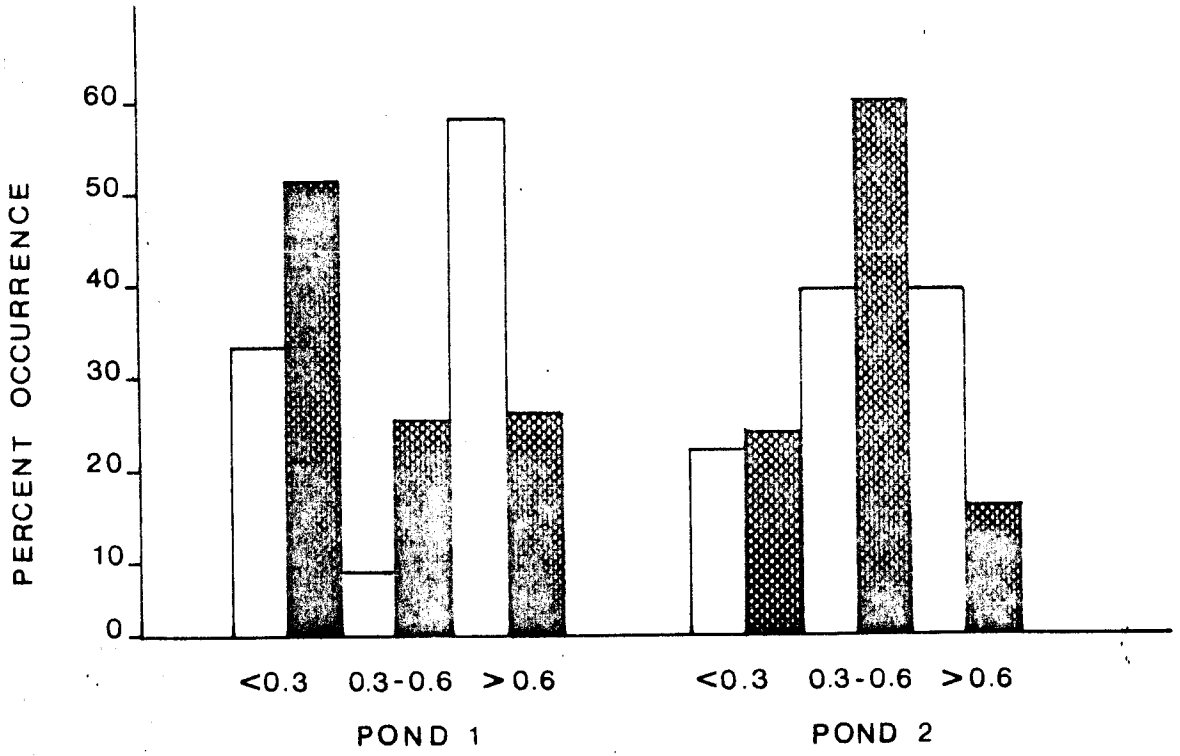


Figure 3. Relative distribution of pond depths, and predation sites on coho salmon fingerlings.

Table 6. Smolt catch data from Ponds 1 and 2 in the Clearwater River, 1983. Presmolts that emigrated from the ponds prior to the main smolt migration are excluded.

Pond	Season[a] cumulative Catch	CWT	Cumulative Prior to april 6, 1983 Catch	CWT	Release site river mile to scoop trap
Pond 1	6,487[b]	5,619	841	516	17.3
Pond 2	929[c]	874	133	114	12.6

a) Pond 1 - February 1 to June 18, 1983;
Pond 2 - March 1 to June 5, 1983

b) Includes 3,587 fish of Sol Duc hatchery origin that were planted on September 17, 1982.

c) Includes 682 fish of Sol Duc hatchery origin that were planted on September 17, 1982.

The survival of both hatchery and wild fish was substantially higher in Pond 1. Overall survival of wild fish in Pond 1 was 44% as opposed to 13% in Pond 2. Hatchery fish survival was comparably higher in Pond 1 at 36% while hatchery fish survival was approximately 5% in Pond 2. Total fish loss is difficult to determine precisely because of an undetermined number and survival of "holdover" fish from the year prior to this study. This prior rearing experience could increase their survival rate. This problem is more acute in Pond 1 where a beaver dam and low flow in the spring of 1982 probably combined to restrict smolt migration that year. Combined hatchery and wild fish losses are approximately 8,500 and 15,500 in Ponds 1 and 2, respectively. Survival rates and the estimated fish losses are probably worst case scenarios; some fish, perhaps as many as 10%-20%, may hold over and contribute to the 1982 smolt migration. Little evidence exists on this subject but available data suggests this range of values is reasonable (Cedarholm, pers. comm.).

Mortality over time was determined by expanding the marked smolt group sizes by the survival rate (determined from the ad clip groups), this was fairly constant for both Ponds 1 and 2 (Fig. 4). For Pond 1 survival from January to the medium outmigration in May was 61%. In Pond 2, however, survival was only 24% from early February to a medium outmigration date of April 1983.

We calculated the average rate of predation per month for each predatory species (Table 7). We weighted this figure by the percent of time a predator occurred on a pond each month during our observations. The months were added to estimate the number of coho fingerlings consumed during the study. Since we were unable to observe feeding by great blue herons at Pond 2, we applied the predation rate from Pond 1. Great blue

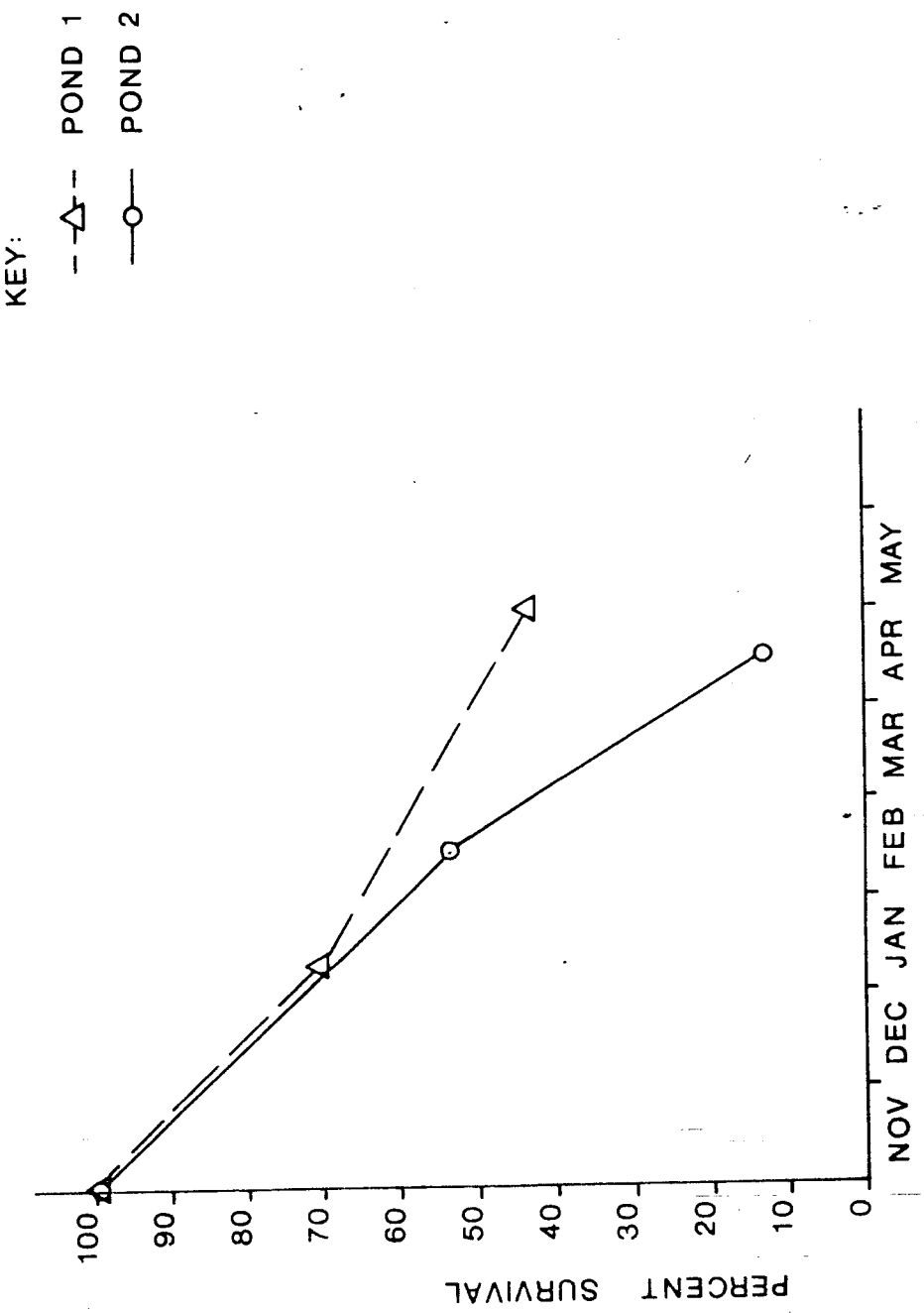


Figure 4. Trends in mortality of overwintering populations of juvenile coho salmon through time in Ponds 1 and 2 (from Peterson, in prep).

Table 7. Rate of predation on coho salmon fingerlings and estimated total mortality of coho in the study ponds.

	POND 1					POND 2				
Species	$\bar{X}$/hr	$\bar{X}$/mo	Months pres.[a]	Wt'd total[b]	% of total	$\bar{X}$/hr	$\bar{X}$/mo	Months pres.	Wt'd total	% of total
Pied-billed grebe	1.07	321	2	642.0	18.0	0.55	165	5	2286.9	34.3
Belted kingfisher	0.84	252	6	1040.8	29.2	0.79	238	6	1230.5	18.5
Great blue heron	1.99	597	4	692.5	19.5	-	597[c]	6	2005.9	30.1
Hooded merganser[d]	0.52	156	5	1185.6	33.3	-	-	4	-	-
River otter[e]	-	-	3	-	-	1.17	351	4	1137.2	17.1

a) Months present on poonds; at pond 2 presence in December is assumed if a species occurred in November and January.

b) Weighted total is achieved by: $\sum((\bar{X}/mo)(\%$ of time an individual is observed each month))

c) Rate of predation from Pond 1.

d) Hooded mergansers at Pond 2 were never observed eating coho salmon fingerlings.

e) We never determined if river otters at Pond 1 consumed coho fingerlings.

herons were more common at Pond 2 than Pond 1; thus, we feel the Pond 1 rate is a realistic estimate for Pond 2.

Total predation on coho salmon at Pond 2 was nearly double that at Pond 1. A maximum of 4 pied-billed grebes and the great blue herons at Pond 2 accounted for over 2/3 of the coho salmon eaten. At Pond 1 we estimate that hooded mergansers and belted kingfishers consumed nearly 2.3 of the coho fingerlings potentially curved.

Avian and mammalian predation accounted for 43% at Pond 2 and 42% at Pond 1 of the coho salmon mortality (Fig. 5). Overall juvenile coho salmon survival at Pond 2 was 13% for wild and 5% for hatchery fish. At Pond 1, 44% of wild and 36% of hatchery coho salmon survived overwintering. Mortality from unknown causes took a large percentage of the coho salmon fingerlings at each pond. Three factors in particular may have contributed to mortality of coho fingerlings. First, many hatchery fish probably suffered shock from transplanting. Also, fish using pond inlets may have been stranded as water fluctuated; the shallow marshy inlet may have made fish vulnerable to predation. Finally, cutthroat trout are probably a significant predator on coho salmon fingerlings.

Other animals observed on the ponds, such as the osprey and American goldeneye (Bucephala clangula), were never observed taking coho salmon fingerlings. The osprey dove twice on rising fish, but was never successful. It is uncommon for osprey to overwinter in western Washington; we feel that the osprey observed at Pond 2 in January was a rarity.

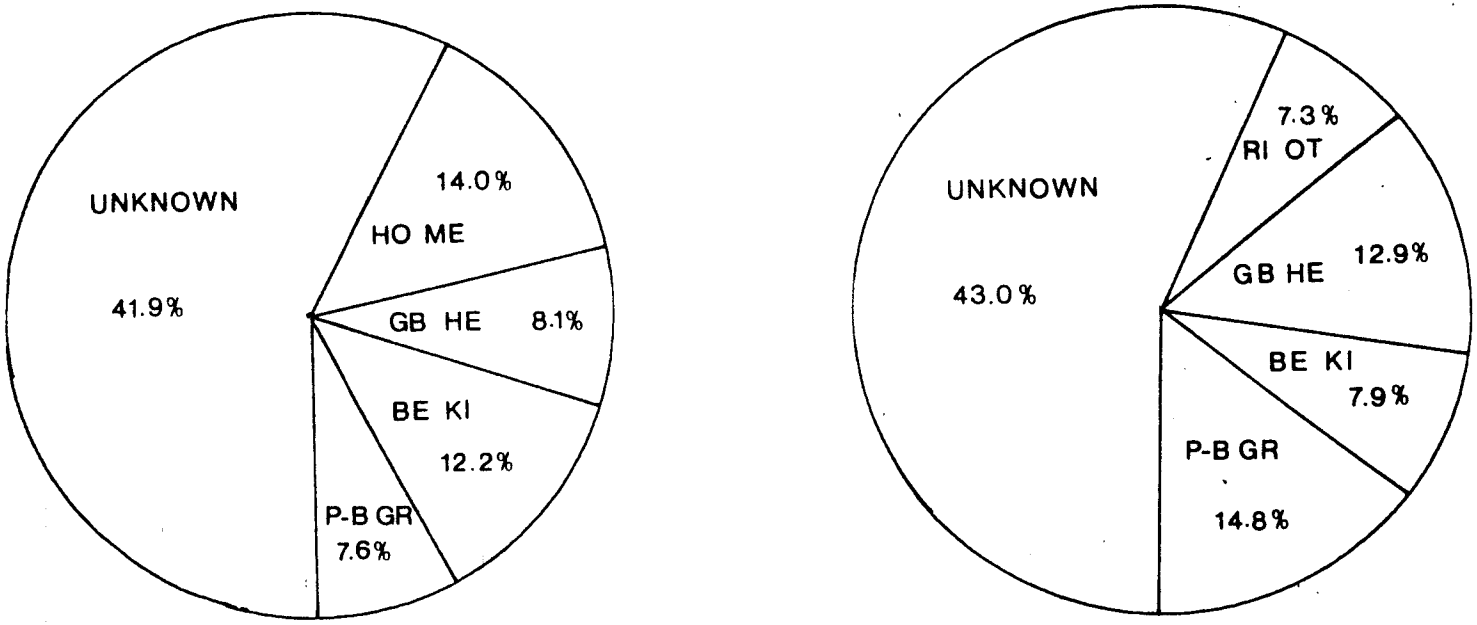


Figure 5. Percent of juvenile coho salmon mortality from different causes. P-b = Pied-billed grebe; Be Ki = Belted kingfisher; G B He = Great blue heron; Ho Me = Hooded merganser; Ri Ot = River otter; Unknown = mortality from other unknown causes.

DISCUSSION

Few studies to date have addressed the impacts of avian and mammalian predators on salmonid populations (White 1936, Elson 1962, Shetter and Alexander 1970, Peterman and Gatto 1978, Alexander 1979). Unlike our pond study, all of these studies were conducted on rivers. All but Peterman and Gatto (1978), a theoretical paper, collected predators to estimate the effects of predation on salmonid populations. None of these studies used natural live observations of the predators to document their food habits and rates of predation. Instead rates of predation on salmonids were obtained from salmonid mortality rates and stomach contents of predators. Salmonid mortality rates may result from any number of unknown causes; it is unlikely that predation is the only cause of mortality. Stomach contents can indicate the diet of an animal; however, the quantity per unit of time is unknown. Our study suggests that the rate of avian and mammalian predation on coho salmon fingerlings in the ponds is not the same as the mortality rate. The rate of predation fluctuates over days and months for any predator.

In our comparison between ponds, we generally found that more predators were present on Pond 2 than Pond 1. We feel that more pond habitat and riparian woodlands around Pond 2 may guide water birds and mammals to the pond. The clearcut and campground adjacent to Pond 1 may deter use by disturbance-sensitive species, such as great blue herons. During our observations excessive noise at the campground, which occurred infrequently, disrupted the normal feeding behavior of hooded mergansers. Noise from logging trucks was frequently audible at Pond 2; however, no disturbance was apparent. In Pond 2 the visibility and abundance of

submerged and emergent vegetation may indicate the productivity of the pond (Faaborg 1976, Palmer 1976).

Although 2.5 times as many salmonid predators occurred at Pond 2, generally more coho salmon per observation hour were captured at Pond 1. Predators at Pond 2 consumed a variety of animals (Appendix A); in contrast, at Pond 1 predation was concentrated mostly on fish species. Pond 2 supported visibly richer and more abundant amphibian and insect populations than Pond 1. The extensive shallows in Pond 2 provide a productive habitat, which are high in organic matter, such as decaying plants. Because fewer predators were present at Pond 1, the total mortality of coho salmon caused by predation was half of that at Pond 2.

Pond morphometry appeared to restrict successful captures of coho salmon by most predatory species. Only pied-billed grebes successfully captured coho at nearly any depth in either pond. Belted kingfishers appeared to favor shallow areas in both ponds. Because much of Pond 2 was shallow, kingfishers successfully captured coho over much of the pond. Steep pond sides in Pond 1 limited kingfishers to shallow areas <0.3 m in depth. A wading bird, such as the great blue heron, can hunt only where it can walk; this limits herons to water <0.6 m in depth.

Overall shallow depth, more pond habitat, greater productivity, and less disturbances appear to favor Pond 2 over Pond 1 for water bird and mammalian habitat. These influenced mortality of coho fingerlings between the two ponds. If pied-billed grebes had wintered at Pond 1, more coho salmon may have been consumed that at Pond 2. Pied-billed grebe use of the ponds appeared to be restricted by factors other than depth. Pond characteristics, such as size, amount of dense emergent vegetation, and impacts of wind, influence pied-billed use of ponds

during the breeding season (Glover 1953, Faaborg 1976). During the winter similar factors may influence pied-billed habitat use. Pond 2 was larger, contained visibly more emergent vegetation, and appeared to be more sheltered from the wind than Pond 1. Other predators, such as otters and great blue herons, may have frequented Pond 2 more often than Pond 1 because of habitat differences.

RECOMMENDATIONS

To enhance runs of coho salmon, Peterson (1982) suggested that more and better winter habitat could be created along rivers. Predation in newly created ponds could be minimized by avoiding the particular habitat features that attract salmonid predators.

The habitat qualities mentioned above could be controlled to reduce or eliminate use by the different predators. To discourage resident pied-billed grebes we recommend that pond design should:

1) keep pond size <1 ha;
2) control emergent and submerged aquatic vegetation;
3) orient the pond to maximize surface disruption by local wind conditions.

Eliminating perch sites, such as trees, brush, and limbs in and around a pond will restrict the belted kingfisher's ability to hunt. A steep-sided pond with a depth of 0.6 m along the edge may reduce effective captures by kingfishers. Intraspecific territoriality on small ponds (<1 ha) may also limit the numbers of individuals using a pond (White 1936, Bent 1940, pers. obs.). According to Elson (1962) and Alexander (1979), kingfisher predation on salmonids is generally inconsequential along river systems. However, in the restricted

environment of a shallow pond a resident kingfisher probably has a significant effect on fish populations.

Because great blue herons forage by stalking their prey, a steep-sided pond, deepening to 0.6 m, should decrease heron predation. If a productive shallow area is essential for the fish food base, dense rushes should limit visibility of fish for herons and kingfishers, although may attract pied-billed grebes. Poor inwater visibility decreases capture success by great blue herons (Krebs 1974, Bovino and Burtt 1979, Quinney and Smith 1980).

Shallow ponds are preferred habitat for hooded mergansers (Palmer 1976). However, since hooded mergansers at both ponds foraged primarily on insect larvae, sculpins, dace, and lamprey, we feel they are not significant predators of juvenile coho in riverine ponds.

Complete exclusion of river otters probably is the only way to control their predation in a pond. Otters prey predominately on fish, crayfish, and amphibians (Lauhachinda and Hill 1977). Since otters appear to prefer slow-moving and relatively large prey (Alexander 1979), they may affect juvenile coho populations minimally. Otters range over large territories (Alexander 1979, Jenkins 1980); thus, they may be infrequent hunters at any one site. Therefore, exclusion of otters from a natural pond is probably unnecessary for enhancement purposes. Our pond design for lessening avian predation may reduce otter foraging success as well.

In summary, pond design elements for optimizing juvenile coho salmon survival include:

1) a small pond, <1 ha;

2) steep sides that drop to >0.6 m depth;

3) no brush or trees within 10 m of the pond edge;

4) limbs kept <0.5 m long on logs if they stick out of the water;

5) logs placed within the pond as cover for coho;

6) control emergent vegetation within the pond except where shallow areas may be needed for insect production; these areas should be heavily vegetated with rushes or other densely clumpted perennials.

7) easy access for people to the pond to disturb potential predators.

FUTURE STUDY POSSIBILITIES

A 6-month study, such as this one, is limited in the depth of perspective that can be gained through time. We strongly recommend the continuance of this study. Little research on mortality caused by predators of salmonids has been carried out. With the exception of this study, no research to date has documented predation on salmonids in a pond habitat. With dwindling coho salmon runs and increased harvest pressure, information is needed on how to enhance natural runs. Reducing predation on juvenile coho salmon through a structured overwintering habitat appears to have potential to increase smolt yields.

When pond construction is completed the new ponds should be monitored. Any fish planted in the ponds should be marked to assess population size. A group of fish could be planted monthly to estimate monthly survival rates.

One pond could serve as a control. A barrier (wire or netting) should be placed over the control pond to keep avian predators out. If

feasible, a fence should be placed around the perimeter to prevent river otters from entering the pond.

One or two other ponds should be monitored without predator protection. Disguised elevated blinds should be built on all of the ponds. The blinds should be situated at the edge of the vegetation to supply a covered access.

The ponds should be observed for up to 4 hours per day. Longer periods are infeasible because of the long exposure of the observer to the cold. Observations on the ponds should be alternated; if 2 ponds are used, a pond should be observed every other day. Equal numbers of morning and afternoon observations should be conducted each month. These should be alternated every other day. Each pond should be observed 4 days per month.

A predator should be watched as described in this report. Activity and prey descriptions defined here should be used. Each month otter scat should be collected from within 90 m of the ponds.

On comparable but different ponds, if such exist, a periodic collection of the main predatory species would provide estimates of daily consumption and relative proportion of coho in the diet.

The data taken in this proposed future research should be analyzed to compare coho mortality in the different ponds. Where bird and mammal predators have been excluded, mortality will be from other causes. Thus we can determine better the relationship between coho salmon mortality and bird and mammal predation. Further, we will be able to observe the capture success of predators in ponds designed to deter them and so improve pond design.

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Appendix A. Average number of prey and percent of diet in each prey category consumed by each predator species, by pond.

Prey	Pied-billed grebe						Belted kingfisher					
	Pond 1			Pond 2			Pond 1			Pond 2		
	X/hr	%	n[a]	X/hr	%	n	X/hr	%	n	X/hr	%	n
Coho	1.07	56	9	0.55	58	7	0.84	70	19	0.79	64	14
Other fish	0.36	19	3	1.23	42	5	0.36	26	7	0.23	18	4
Total fish	1.43	75	12	1.30	100	12	0.88	96	26	0.72	82	18
Amphib.	-	-	-	-	-	-	-	-	-	0.26	18	4
Other[b]	0.48	25	4	-	-	-	0.17	4	1	-	-	-
Total animal	1.90	100	16	1.30	100	12	0.91	100	27	0.80	100	22

a) Number of each prey type taken

b) Crayfish and unidentifiable animal items.

Appendix A. Average number of prey and percent of diet of each prey category consumed by each predator species by pond. (Continued).

Prey	Great blue heron[c]						River otter					
	Pond 1			Pond 2			Pond 1[d]			Pond 2		
	$\bar{X}$/hr	%	n	$\bar{X}$/hr	%	n	$\bar{X}$/hr	%	n	$\bar{X}$/hr	%	n
Coho	1.99	67	8				-	-	-	1.17	16	4
Other fish	0.41	8	1				6.66	11	1	0.56	8	2
Total fish	2.40	75	9				6.66	11	1	1.45	24	6
Amphib.	-	-	-				-	-	-	1.31	20	5
Other	1.51	25	3				11.67	89	8	4.80	56	14
Total animal	3.39	100	12				15.00	100	9	6.64	100	25

c) Captures by the Great blue heron were observed only at Pond 1.

d) All river otter hunts at Pond 1 were less than 0.5 hour in langth.

Appendix. A. Average number of prey and percent of diet in each prey category consumed by each predator species by pond.

	Hooded merganser					
	Pond 1			Pond 2		
Species	X/hr	%	n	X/hr	%	n
Coho	0.52	23	6	-	-	-
Other fish	1.20	54	14	0.56	40	2
Total fish	1.65	77	20	0.56	40	2
Amphib.	-	-	-	0.84	60	3
Other	3.85	23	6	-	-	-
Total animal	2.60	100	26	1.40	100	5