Population Characteristics of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Overwintering in Riverine Ponds[1]

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Survival and growth from immigration to smolt outmigration differed substantially between pond populations of juvenile coho salmon (*Oncorhynchus kisutch*). In Pond 1 (the deeper, less-productive pond) overall survival was 78% but average fish weight increased only 49%, whereas in Pond 2 (the shallow, more-productive pond) survival was only 28% but average fish weight increased 94%. Diet of resident coho in the early spring was characterized by chironomid larvae and newly emerged adults in Ponds 1 and 2, respectively. Manipulation of pond morphometry may have potential for enhancing coho stocks.

Key words: coho, pond, winter habitat, survival, growth, diet

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La survie et la croissance entre l'immigration et l'émigration comme smolts diffèrent de façon substantielle entre populations d'étangs de jeunes saumons coho (*Oncorhynchus kisutch*). Dans l'étang 1, plus profond et moins productif, la survie générale est de 78 %, mais le poids moyen des poissons n'augmente que de 49 %. Par contre, dans l'étang 2, moins profond et plus productif, la survie n'est que de 28 %, mais le poids moyen des poissons augmente de 94 %. Le régime des saumons résidents au début du printemps est caractérisé par des larves de chironomides et d'adultes nouvellement émergés dans les étangs 1 et 2 respectivement. Il se peut que la modification de la morphométrie d'un étang offre des possibilités de mise en valeur des stocks de saumons coho.

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JUVENILE coho salmon (*Oncorhynchus kisutch*) seasonally seek out winter refuge areas throughout their range in North America. Small tributary streams (Bustard and Narver 1975) and riverine ponds (Peterson 1982) are especially preferred winter habitat. However, the ecology of juvenile salmonids in such ponds is not well documented. The purpose of this study was to compare the survival, growth, and diet of juvenile coho populations overwintering in two natural riverine ponds.

Study Area

The study ponds lie in old flood plains of the Clearwater River (Peterson 1982), originating as cutoff river meanders. Coincidentally, these sites receive near-surface groundwater flow overland from nearby terraces, and function as flow-through systems connected to the river by small outlet streams. Pond 1 is the deeper of the two ponds, and whereas Pond 2 is half again as large, it is shallow over most of its area (Table 1).

Species of fish other than coho that commonly utilize the ponds are cutthroat trout (*Salmo clarki*), prickly sculpin (*Cottus asper*), and western speckled dace (*Rhinichthys osculus*). Less frequently observed species are steelhead trout (*S. gairdneri*) and torrent sculpin (*C. rotheus*). Avian predators such as kingfishers, herons, and mergansers are commonly observed on the ponds. River otters have also been seen on both ponds, but less frequently.

Shoreline vegetation consists mainly of red alder (*Alnus rubra*), big leaf maple (*Acer macrophyllum*), Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), salmonberry (*Rubus spectabilis*), blackberries (*R. laciniatus*), sword fern (*Polystichum* sp.), sedges (*Carex* sp.), and horsetail (*Equisetum* sp.). Yellow pond lilies (*Nuphar variegatum*) grow in areas less than 1.0 m deep. Other common aquatic macrophytes include at least two species of *Potamogeton* and one bladderwort (*Utricularia* sp.). *Potamogeton* encroaches to depths of about 1.5 m, but deeper areas lack rooted plants.

Methods and Materials

Fish traps were located on the pond outlet streams that

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caught all fish migrating in either direction. All immigrant coho caught during the first and last weeks of November were marked differently with a cold brand. During these periods these same fish were also separated into two groups — those >80 mm and those <80 mm, and marked differently. This artificial separation caused the length distribution of the group of smaller fish to be skewed to the right. The group of larger fish was affected in the opposite direction, but to a lesser degree as 80 mm was considerably less than the mean of the normally distributed combined population. In addition, one group was marked in each pond after being captured by electroshocking in February, without respect to size of fish. Another such group was marked in March in Pond 2. Marked groups were designated by four-letter codes (Peterson 1982). Twenty and 15% of the population were marked in the fall in Ponds 1 and 2, respectively. Growth and survival of marked fish were assumed to be representative of the entire population. A comparison made the following spring of the lengths of marked and unmarked fish revealed no statistical difference.

Because traps were inoperable for short periods during some winter storms, an estimate of the total fall immigration was made by expanding the number of fish marked in the fall by the proportion of marked to unmarked smolts. This assumes that (1) all smolts were caught, (2) all marked smolts were identified, (3) the only recruitment to the smolt population was from fall immigrants, and (4) marking did not increase overwinter mortality of marked fish.

Assumption three is invalid as scale analysis of large fish showed some were 2 yr old and probably did not originate from the fall population. To identify the number of these smolts, the minimum length of 2-yr-old smolts from each pond was determined. The proportion of smolts greater than this size was then determined for all groups combined that were marked in the fall. This proportion was applied to the total number of outmigrants to estimate the number of smolts in the 2-yr-old size range that probably originated as fall immigrants. These fish were then subtracted from the total number of smolts in the 2-yr-old size range. The remaining large fish were assumed to be 2-yr-old smolts from the previous winter, and subtracted from the total prior to calculation of the marked-to-unmarked smolt proportion. In addition, adjustments were made in Pond 1 for a 50% contribution of the 450 fry that immigrated the previous spring. No such adjustment was made in the Pond 2 data as a blockage in the stream probably prevented fry from reaching the pond.

Growth statistics for the marked groups were determined by first calculating an average length for the group. Then correlative weights for these lengths were calculated from length–weight regressions that were developed for spring and fall populations for each pond. These weights were used to illustrate growth differences between ponds. Statistically, the difference in smolt size was measured by testing the difference in average lengths of marked groups with an unpaired *t*-test (Snedecor and Cochran 1967).

DIET

Stomach contents from 15 and 30 fish from Ponds 1 and 2, respectively, were collected by electroshocking in early afternoon on consecutive days in February. Contents of the foregut were flushed as described by Meehan and Miller (1978). Prey items from each sample were sorted, usually to family. All items from each taxon were placed on a predried and weighed filter. Unidentifiable material left after sorting was filtered onto another filter. All filters and contents were then dried at 60°C for 24 h and reweighed to the nearest 0.1 mg. Prey data were processed through a diet analysis program (Swanson and Simenstad 1978). Dry weight of stomach contents, expressed as a percent of the dry weight of the fish, which was assumed to be 0.20 wet weight, were compared between ponds with a nonparametric rank test.

TABLE 1. Physical characteristics of the study ponds.

Characteristic	Pond 1	Pond 2
Area, ha	0.85	1.29
Volume, m^3	10 300	7600
Maximum depth, m	3.5	1.3
Percent area <0.75 m deep	47	84
Percent area >1.2 m deep	38	0.3

TABLE 2. Numbers of immigrant juvenile coho in the fall and emigrant smolts for Ponds 1 and 2.

	No. of fall immigrants		
Pond	Trapped	Total estimate	No. of spring smolts
Pond 1	3297	4100	3613[a]
Pond 2	4029	5430	1534[a]
Total	7326	9530	5147[a]

[a] Includes smolts recruited from holdover and fry populations, 414 and 14 for Ponds 1 and 2, respectively.

BENTHOS

Benthos samples collected in December, February, and April were stratified by three stations selected for depth and similarity of substrate character. Three replicate samples were taken at each station on all dates. Samples were removed with a 10-cm-diameter core sampler which removed an undisturbed sample from the flocculent organic sediments of the ponds. Cores were washed through a 420-μm sieve and preserved in 70% ethanol. Animals were separated from the detritus and identified to family. Station samples were counted and placed on predried and weighed filters for drying at 60°C for 24 h and reweighed to the nearest 0.1 mg.

Benthos count and weight data were analyzed for independence of variance and distribution character (Elliott 1977). Tests indicated count data should be transformed to logarithms, but weight data were suitable for parametric testing.

Analysis of variance was used to test differences in sample dry weights and transformed ($\log_{10}$) count data between ponds. Within ponds, analysis of variance was used to test for differerences due to the effects of month and station.

PHYSICAL MEASUREMENTS

Pond temperatures at a 0.3-m depth were recorded con-

TABLE 3. Absolute survival and instantaneous mortality rates of juvenile coho in specific marked groups for Ponds 1 and 2.

Mark	Pond	Median date in	Median date out	Median residence (d)	Number in	Number out	Percent survival	Instantaneous mortality (*Z*)
RMNV	Pond 1	Nov. 7, 1977	April 25, 1978	169	578	464	80.3	0.001
	Pond 2	Nov. 10, 1977	March 21, 1978	131	408	127	31.1	0.009
RMSV	Pond 1	Nov. 8, 1977	May 12, 1978	185	39	29	74.4	0.002
	Pond 2	Nov. 10, 1977	March 30, 1978	140	26	7	26.9	0.009
RMNT	Pond 1	Nov. 29, 1977	May 3, 1978	155	49	25	51.0	0.004
	Pond 2	Nov. 29, 1977	March 26, 1978	117	101	11	10.9	0.019
RMST	Pond 1	Nov. 30, 1977	May 12, 1968	163	12	8	66.7	
	Pond 2	Nov. 29, 1977	March 30, 1978	121	11	1	9.1	
RPEV[a]	Pond 1	Feb. 25, 1978	May 4, 1978	68	64	51	79.7	0.003
	Pond 2	Feb. 26, 1978	March 26, 1978	28	112	55	49.1	0.025

[a] Captured by electroshocking and marked while in pond residence.

tinuously on chart thermographs. Water samples taken at three stations at several depths for dissolved oxygen determinations were analyzed chemically.

Results

OUTMIGRATION OF SMOLT POPULATIONS

Three thousand, six hundred and thirteen coho smolts emigrated from Pond 1, 3200 of which originated as fall immigrants, whereas Pond 2 yielded only 1534 smolts of which 1520 were fall immigrants (Table 2). In Pond 2 the peak in emigration occurred in late March, but in Pond 1 it occurred in late April and remained high until the middle of May. Larger fish migrated first from both ponds and the earlier migration observed in Pond 2 was the outcome of more rapid growth there.

SURVIVAL OF POND POPULATIONS

Overall survival of pond residents was 78 and 28% in Ponds 1 and 2, respectively. Regardless of fish size or time of pond entry juvenile coho in Pond 1 showed consistently higher survival than those in Pond 2 (Table 3). Because residence time was appreciably different between ponds, instantaneous mortality rates were compared, and they substantiated the considerably higher mortality in Pond 2.

Smaller fish in both ponds (RMSV and RMST groups) showed slightly poorer survival in both absolute and instantaneous terms. Fish which entered the ponds in late November after most of the fall population had already immigrated incurred higher mortality than did those which entered in the 1st week in November. Small sample sizes of small fish entering both ponds in late November disallowed further comparison of instantaneous mortality rates.

Based on population estimates derived by expanding the smolt populations by spring mortality, as determined by marking (RPEV groups), survival decreased in time in both ponds. Prior to late February little mortality had occurred in Pond 1, whereas nearly 50% of the population had died in Pond 2 (Fig. 1).

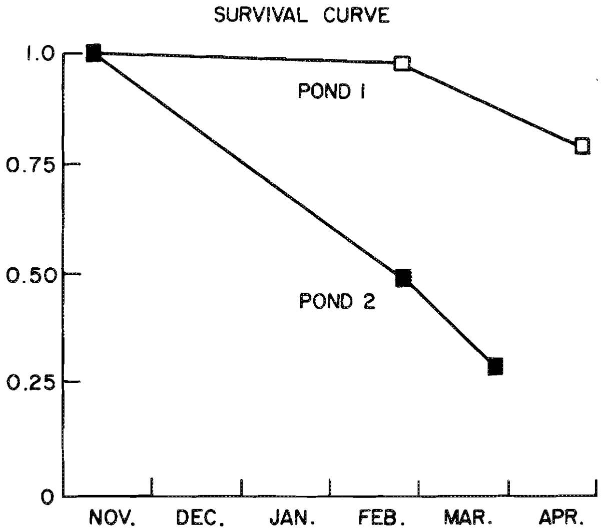

FIG. 1. Survival of pond populations through time.

GROWTH OF POND RESIDENTS

The average size of smolts in all groups in Pond 2 was significantly larger ($P < 0.01$) than that of the matching group in Pond 1 (Table 4). These apparent growth differences occurred in spite of an appreciably shorter median residence time in Pond 2.

Between fall entry and late February, average growth of fish in Pond 1 was nil. During this same period, apparent growth in Pond 2 was significant, with an average weight increase of 83%.

Smaller immigrants (RMSV groups) had caught up in size with their larger cohorts (RMNV-marked fish) by spring outmigration. However, the smaller immigrants remained in the pond an average of 16 and 9 d longer in Ponds 1 and 2, respectively, than did their cohorts in the larger size category at pond entry.

DIET

The Chironomidae were the most important prey for fish in

TABLE 4. Absolute and relative weight increases of juvenile coho overwintering in study ponds.

Mark	Pond	Median date marked	Median date recaptured	Median residence in days	Number in	Number out	Mean size in grams	Mean size out grams	Average increase Absolute grams	Average increase Relative percent
RMNV	Pond 1	Nov. 7, 1977	April 25, 1978	169	578	464	8.77	13.09	4.32	49.3
	Pond 2	Nov. 10, 1977	March 21, 1978	131	408	127	9.34	18.14	8.80	94.2
RMNV	Pond 1	Nov. 7, 1977	Feb. 25, 1978	110	578	8[a]	8.77	8.54	−0.23	−2.6
	Pond 2	Nov. 10, 1977	Feb. 26, 1978	108	408	13[a]	9.34	17.05	7.71	82.5
RMSV	Pond 1	Nov. 8, 1977	May 12, 1978	185	39	29	4.59	12.17	7.58	165.1
	Pond 2	Nov. 10, 1977	March 30, 1978	140	26	7	5.11	19.31	14.20	277.9
RMNT	Pond 1	Nov. 29, 1977	May 3, 1978	155	49	25	7.87	12.33	4.46	56.7
	Pond 2	Nov. 29, 1977	March 26, 1978	117	101	11	8.72	16.40	7.68	88.1
RMST	Pond 1	Nov. 30, 1977	May 12, 1978	163	12	8	5.04	13.50	8.46	167.9
	Pond 2	Nov. 29, 1977	March 30, 1978	121	11	1	4.97	17.60	12.63	254.1
RPEV[b]	Pond 1	Feb. 25, 1978	May 4, 1978	68	64	51	9.49	13.89	4.40	46.4
	Pond 2	Feb. 26, 1978	March 26, 1978	28	112	55	16.89	19.95	3.06	18.1

[a] Recaptured by electroshocking.

[b] Captured by electroshocking and marked while in pond residence.

both ponds, occurring in all stomachs. In Pond 1, chironomid larvae comprised 72% of the diet numerically, and 40% gravimetrically (Table 5). In Pond 2, adult chironomids were more important than were the larvae. Qualitative observations of insect emergence indicated there was a protracted emergence of chironomids in Pond 2 during late winter and early spring, and that coho fed heavily on this emergence. Adults occurred in 87% of the stomachs and accounted for 56% of the Pond 2 diet gravemetrically (Table 6). Limnephilid caddis fly larvae and baetid mayfly nymphs were next in order of importance in Ponds 1 and 2, respectively.

Tested with a nonparametric rank test, total dry weight of stomach contents (expressed as a percentage of the calculated dry weight of the fish) showed no statistical difference between ponds. However, when plant and unidentifiable weight fractions were subtracted from all data, fish from Pond 2 (scant plant material in their guts) had higher dry weights ($P < 0.05$). Pond 1 fish ingested a higher proportion of plant material apparently incidentally with encased chironomid and limnephilid larvae.

BENTHOS

Taxonomic composition of the benthos from both ponds was typical of other pond environments. Diptera larvae, principally Chironomidae, predominated.

An analysis of variance on sample dry weights that tested the effects of pond, month, and station showed the only significant main effect was due to pond ($P < 0.01$). A duplicate analysis of transformed ($\log_{10}$) count data indicated a similar effect ($P < 0.01$).

Sample dry weights compared by station between ponds showed that all stations in Pond 2 had greater mean dry weights than those in Pond 1; however, only station one was statistically different ($P < 0.05$) (Fig. 2). This station is the most important to compare between ponds because it represents habitat typical of $\sim$ 50 and 80% of Ponds 1 and 2, respectively.

TABLE 5. Frequency of occurrence, numerical and gravimetric composition of major invertebrate taxa in the diet of juvenile coho in Pond 1.

Prey taxa	Frequency of occurrence	Composition Numerical	Composition Gravimetric
Chironomidae	100.00	71.9	39.6
Chironomidae[a]	60.00	4.1	7.6
Limnephilidae	53.3	14.6	7.8
Ceratopogonidae	46.7	4.6	0.5
Copepoda	20.0	1.3	0.4
Sialidae	20.0	.8	36.2

[a] Adults all other taxa consumed as larvae.

POND TEMPERATURE AND DISSOLVED OXYGEN

Pond temperatures from December through May, at 0.3 m of depth, ranged from 4.0 to 15.0°C and in both ponds during December and January moderated between 4.0 and 7.0°C. Inlet water in both ponds was a constant 8.3°C through the winter; however, this warmer water influenced only limited areas in each pond.

Dissolved oxygen measurements ranged from 11.0 to 9.5 mg/L in Pond 1 and from 10.6 to 7.7 mg/L in Pond 2. In both ponds the lower readings came from the deepest areas.

Discussion

Morphometry indirectly affected survival and growth of overwintering juvenile coho, being the singular most apparent difference in the limnology of the study ponds.

General observations revealed that herons and kingfishers frequented both ponds daily and mergansers have occasionally been observed on both ponds. Avian predation is probably the main cause of mortality to pond residents, although mammalian predators have been observed as well. The elongated shape and extensive shallows of Pond 2 allowed

TABLE 6. Frequency of occurrence, numerical and gravimetric composition of major invertebrate taxa in the diet of juvenile coho in Pond 2.

Prey taxa	Frequency of occurrence	Composition	
		Numerical	Gravimetric
Chironomidae	93.3	12.5	1.4
Chironomidae[a]	86.7	55.4	56.0
Baetidae	66.7	20.5	20.8
Dytiscidae	30.0	1.4	8.6
Coenagrionidae	27.7	1.0	1.4

[a] Adults all other taxa consumed as larvae.

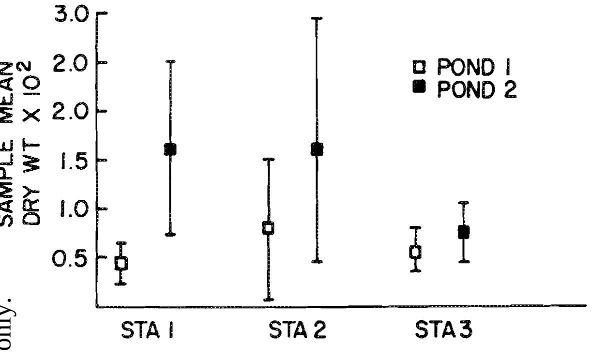

FIG. 2. Benthos sample dry weight (g) compared by station between ponds.

easier hunting for herons and mergansers. Fish in Pond 2 concentrated in a single school beginning in January, perhaps in response to heavy predation, whereas no such behavior was observed in Pond 1.

Lower survival of later immigrants into both ponds might have been associated with successively poorer fish condition as winter progressed. Late arrivals had experienced several severe freshets and a period of low temperatures. Mason (1976) found lipid reserves of underyearling coho of all sizes declining progressively through winter but a more pronounced reduction in the smaller fish. This may in part explain the better survival of the early arrivals as they would have been able to conserve lipid reserves to a greater degree in the benign pond environment.

Because temperatures were nearly identical, superior growth of fish in Pond 2 (nearly twice as great as in Pond 1) appears to be the outcome of greater prey abundance and its exploitation rate.

Abundance of food in these two ponds is, in part, determined by morphometry. Depth restricts the growth of attached aquatic macrophytes in Pond 1, whereas in Pond 2 these plants grow throughout the pond. Aside from providing a high-quality detrital base for insect production (Hodkinson 1975), there is a rich invertebrate fauna directly associated with such aquatic macrophytes (Berg 1950).

Although coho in Pond 2 had eaten larger meals, the more-abundant food base may also have been of higher quality than that in Pond 1 where the fish fed largely from the benthos on encased limnephilid and chironomid larvae. Additionally, if the coho in Pond 1 avoided predators during the winter by staying in the deep part of the pond, this would also have influenced their growth as that area of the pond had the lowest benthos densities.

Implications for Habitat Enhancement

This study demonstrates that survival and growth of juvenile coho overwintering in riverine ponds can be strongly influenced by pond morphometry. These findings suggest that enhancement of winter habitat, such as constructing pond environments or providing access to such areas, should be evaluated more extensively. It may be possible to maximize both survival and growth benefits to overwintering fish by combining the productivity of a shallow pond and the cover aspects of a deeper one in riverine environments.

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