Effects of Introduced Fishes on Wild Juvenile Coho Salmon Using Three Shallow Western Washington Lakes

by

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Abstract

Pacific salmon declines have been blamed on hydropower, overfishing, ocean conditions, and land-use practices; however, less is known about introduced fish impacts. Most of the hundreds of lakes and ponds in the Pacific Northwest contain introduced fish and many of these water bodies are also important for salmon production, especially coho salmon. Over two years, we examined predation impacts of ten common introduced fishes (brown bullhead catfish *Ameiurus nebulosus*, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, golden shiner *Notemigonus crysoleucas*, green sunfish *Lepomis cyanellus*, largemouth bass *Micropterus salmoides*, pumpkinseed *Lepomis gibbosus*, rainbow trout *Oncorhynchus mykiss*, warmouth *Lepomis gulosus*, and yellow perch *Perca flavescens*) and two native fishes (cutthroat trout *Oncorhynchus clarki,* and prickly sculpin *Cottus asper*) on wild juvenile coho salmon *Oncorhynchus kisutch* in three shallow western Washington lakes, all located in different watersheds. Of these species, largemouth bass were responsible for an average of 98% of the predation on coho salmon in all lakes, but total impact to each run varied among lakes and years. Very few coho salmon were eaten by black crappie, brown bullhead catfish, cutthroat trout, prickly sculpin, and yellow perch, while other species were not observed to eat coho salmon. Juvenile coho salmon growth in all lakes was higher than in nearby streams. Therefore, food competition between coho salmon and introduced fishes in lakes was probably not limiting coho salmon populations. Largemouth bass are widespread, present in 85% of lowland warmwater public-access lakes of Washington (n=421). Future research would help identify impact of largemouth bass predation across the region, and prioritize lakes where impacts are most severe. Nevertheless, attempts to transplant or increase largemouth bass numbers in lakes important to coho salmon would be counterproductive to coho salmon enhancement efforts.

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Introduction

Pacific salmon are integral to the aquatic ecosystems, the economy, and both Native American and European culture of the Pacific Northwest. Five species of Pacific salmon have declined in abundance, especially along the southern half of their native range in California, Oregon and Washington. These declines have been drastic, and many salmon stocks are now protected under the U.S. Endangered Species Act.

Salmon declines have been blamed on a combination of overharvest, habitat destruction, presence of dams, climate change, and interactions with hatchery fish (National Research Council 1996; Finney et al. 2000; Kareiva et al. 2000; Finney et al. 2002). While numerous studies have examined the effects of these factors, few have examined the role of introduced fishes in the decline of salmon stocks. Lakes and rivers in the western United States were stocked en-mass with nonnative fishes, including centrarchids, ictalurids, percids and salmonids, during the late 19th and early 20th century, by European settlers and the U.S. Fish Commission (Lampman 1946; Wydoski and Whitney 1979). The introductions and subsequent movement of these fishes were widespread and virtually all lowland lakes and many river systems in the Pacific Northwestern region of the United States now contain some introduced fish. Few were stocked into lakes on the Pacific Coast of Canada; however, there is increasing interest by angling groups to introduce many of these species. Although popular with anglers (Zook 1999), introduced fishes have contributed to declines of native fishes in many regions of the American West (Minckley and Deacon 1991; Gunckel et al. 2002).

Most studies of interactions among introduced fishes and Pacific salmon have been conducted in large deep lakes, reservoirs, or large river systems (Poe et al. 1991; Tabor et al. 1993; Fayram and Sibley 2000; Nowak et al. 2004). However, the most common introduced fishes found in the freshwaters of the Pacific Northwest evolved in warm, shallow waters of the eastern United States and prefer the littoral areas of lakes and ponds. Few of these species develop large populations in deep, cold lakes or reservoirs, or fast-flowing Pacific Northwest streams. Shallow, off-channel sites such as ponds, sloughs, marshes, and the littoral zones of lakes are more suitable habitat for these species. These areas are also important for salmon; these habitats are reported to contribute 15-62% of the total production of juvenile salmon in various watersheds (Bustard 1983; Brown and Hartman 1988; Beechie et al. 1994). In western Washington State alone, over 450 lakes and ponds are accessible to anadromous salmon, providing rearing habitat and migration corridors for their journey to the sea (Washington Department of Fish and Wildlife unpublished data). The vast majority of these lakes and ponds are small and shallow, yet almost no information is available regarding the impacts of introduced fishes on the numerous small salmon runs that use the hundreds of shallow lakes throughout the Pacific Northwest.

The goal of our study was to (1) evaluate the degree to which the most common introduced fishes prey on juvenile salmon in three small shallow western Washington lakes; (2) evaluate effects by season, and size group of predators; (3) calculate number of juvenile salmon removed by predation in each lake; and (4) compare juvenile salmon growth among lakes and nearby streams to investigate the potential for competition for food to limit juvenile salmon growth. We focused our study on the effects on coho salmon because of their long freshwater residence time as juveniles (usually > 1 year), and their propensity to use lakes and other off-channel habitats to rear.

Methods

Our study was conducted over a 2-year period in three shallow (< 8 m deep), lowland (< 125 m above mean sea level in elevation) western Washington lakes, all located in different watersheds (Table 1). We used a standard combination of gear types to sample the diets, population sizes and growth of introduced and native fishes in each of the lakes once or twice per month, throughout the year. Each sampling year started the first of April and continued to the first of April the following year. During April 1998 to April 1999 (first year) we sampled each lake twice each month during salmon smolt migration and once per month the rest of the year. From April 1999 to April 2000 (second year), we sampled each lake once per month throughout the year. Water temperatures were taken on each sampling date using a Scout II hydrolab. In both the littoral zone and the deepest portion of the lake, we took temperature readings every 0.5 m from the surface to the bottom. For sampling fish, each lake was divided into eight sections. Half of the sections were randomly chosen and sampled during the day and half were sampled at night to provide diel information on diet. By the end of each sampling trip, the entire lake was sampled. Fish were captured in the littoral zones using minnow traps and gill nets set for two hours to minimize mortality, and boat electrofishing to sample the entire shoreline of each section. Deeper areas of the lakes were sampled using vertical and horizontal gill nets, slat traps and minnow traps. In deep areas in the summer, when no fish were captured, hydroacoustic surveys were used to confirm the absence of fish. Additionally, we snorkeled portions of Big Beef Creek approximately 1.6 km below and 0.5 mi km above Lake Symington in midsummer 1999 to identify the distribution of introduced predators in streams adjacent to the lake.

All captured fish were anesthetized and total length was measured to the nearest mm. Weights (g) were taken on the first 100 fish of each species to develop relationships between length and weight. At the start of the study, all fish were either fin-clipped or tagged for population estimates, but after three sampling periods we tagged only largemouth bass using individually numbered anchor tags. The stomachs of up to 30 individuals of each age cohort of each species were pumped during both day sampling and night sampling using gastric lavage to obtain contents. Minimum size of the fish pumped was 75 mm TL. Contents were then stored in a 10% formalin solution buffered with borax and transported to the laboratory, where they were separated into the following 11 groups: insects, zooplankton or other non-crayfish invertebrates; crayfish; salmon fry; salmon smolts; unidentified salmonids; other fish; unidentified fish; amphibians; birds; rodents; detritus, plants or other materials. We captured hundreds of juvenile coho salmon in the three lakes. The only other salmon captured were eight juvenile chum salmon from Long Lake. Therefore, we assumed all salmon in the gut contents were coho. Digested fish material was identified to species using diagnostic bones (Hansel et al. 1988) when present. Salmon fry and smolts represented two distinct length groups in each lake. Regressions of cleithrum (shoulder), dentiary (lower jaw) or standard length to total length were used to identify salmon juveniles as either smolts or fry. The sorted stomach contents were blotted on absorbent paper and weighed on an analytical balance to the nearest 0.001 g.

Predation was evaluated using the Wisconsin bioenergetics model (Hanson 1997) to estimate the weight of salmon consumed by each predator group over a one-year period. The Wisconsin bioenergetics model is an energy balance equation that relates consumption rate to growth, metabolism, water temperatures, and excretion in an individual fish. Population and survival estimates are used to expand the consumption of an individual fish to the population as a whole. Using this model, we calculated consumption rates of salmon by type of introduced species.

Data needed for the model included the thermal experience of predators in each lake; introduced fish diet, growth, survival, gonad growth, population estimates, and energy density; and energy density of the prey. Water temperatures used were those measured at the depth fish were captured. We assumed species captured by boat electrofishing were feeding at the water temperature measured at a depth of 1.0 m in the littoral zone. For those captured by other techniques such as nets or traps, we used the temperature at the depth where the device was set. Diet was the proportion of each diet item by weight for each month. If less than ten fish were caught in a particular month, adjacent months would be combined to obtain a sample size that would be greater than ten. Growth was estimated by examining the movement of cohorts throughout the year from length-frequency histograms and confirmed by monitoring the change in length of tagged fish between sampling periods. Because growth is calculated by changes in fish weight by the model, length data were transformed into weight data using weight-length relationships developed for each species at each lake. Predator population and survival estimates were used to expand the rate of consumption of coho salmon by individual predators to the population as a whole. Survival was calculated using an age-length key and regressing numbers of fish against age (Ricker 1975). Energy is expended for gonadal growth in fishes, and consumption is required to supply this energy. Average growth of gonads of introduced predators and time of spawning was estimated from field observations and the literature (Timmons et al. 1980).

Population sizes of largemouth bass greater than 150 mm total length (TL) were obtained over six sampling events from April 7 to June 18, 1998 using a Schnabel mark-recapture estimate (Ricker 1975). Mark-recapture estimates assume that there is no mortality or recruitment during the sampling period. Therefore, we calculated population sizes before most spawning activity, because we did not want recruitment to seriously affect our estimates. Assumptions of the mark-recapture method also include the marked fish become randomly mixed with the unmarked, tags are not lost, tags are visible to surveyors, there is no difference in mortality between tagged and untagged fish, and that tagged and untagged fish are equally vulnerable to capture. We replaced tagged fish to the sections of each lake where they were captured and allowed at least one week before recapture to ensure they were randomly mixed. The floy tags we used were highly visible to the surveyors, and at the beginning of the study we both fin-clipped and floy-tagged each largemouth bass, and examined each untagged captured fish for evidence of fin clips and wounds under the dorsal to ensure tags loss was minimal. We carefully inserted anchor tags in the dorsal musculature to reduce wounding and associated mortality.

Largemouth bass recruitment in small maritime-influenced shallow western Washington lakes is more stable from year-to-year than largemouth bass in cold inland reservoirs where year class strength can be affected severely by water drawdown, winter mortality of young, and wave action. Therefore, population estimates calculated in 1998 were used to approximate those in 1999.

Consumption rates were calculated by season and then summed to obtain the estimate for the entire year. We subdivided consumption rate by spring (the period of smolt migration), summer, and late fall/early winter because growth rates and available food among these three periods was different. Model default values for predator energy densities were used. Energy densities of prey were either reported in literature provided by the model or were that of a closely related surrogate species provided by the model. We used the following energy densities for prey, expressed as Joules per gram of prey body mass: invertebrates = 3000; other fish = 4186; amphibians = 4000; coho salmon fry = 5765; crayfish = 3000; coho salmon smolts = 5774; birds = 4000; rats = 4000.

Consumption rates calculated the mass of salmon fry or salmon smolts in g per day per individual predator of each cohort. We separated fry and smolts in the diet by using a cutoff of 100 mm TL, which was determined through examination of length frequencies. Numbers of smolts consumed were calculated by dividing total weight of smolts eaten by the average weight of a smolt determined from a length-weight regression equation. To calculate numbers of fry eaten, we first calculated the total length of fry on that particular sampling date. We then converted total length to weight using length-weight regressions and divided total grams of fry consumed by the weight of an individual fry on that date. We transformed numbers of fry consumed into smolt equivalents by multiplying fry numbers by 0.12, a survival rate from fry to smolt estimated for the Big Beef Creek watershed (D. Seiler, Washington Department of Fish and Wildlife unpublished data.). Smolt equivalents (Rand et al. 1993; Ford et al. 2001; Bartron and Scribner 2004) are a common method of expressing numbers of fry in a form that can be compared to smolt numbers. Adding the number of smolts consumed to the number of smolt equivalents consumed provided an estimate of the number of smolts eaten over one year.

We calculated three estimates of the number of coho salmon eaten by each predator species for each lake, for each year. The *low* and *nominal estimates* included only fish that could be positively identified as salmon in the diet and were based on the lower 95% confidence level and the nominal estimate of the largemouth bass population estimate respectively. The *high estimate* was based on the upper 95% confidence level of the largemouth bass population estimate and included both fishes that could positively be identified as salmon, and unidentified salmonid fishes in the diet.

Comparison of the number of juvenile coho salmon eaten by largemouth bass with a measure of juvenile salmon abundance gave an approximation of the impact to the run. We obtained estimates of the juvenile coho salmon smolt outmigration in the Lake Symington (Big Beef Creek) watershed, and the Wildcat Lake (Wildcat Creek) watershed from traps managed by the Washington Department of Fish and Wildlife (Unpublished Data). Lake Symington was located midway between the headwaters of Big Beef Creek and its outlet to Puget Sound, so only a portion of the entire run would have been exposed to the largemouth bass predation in Lake Symington. The trap measuring the number of salmon smolts produced above Wildcat Lake was in place on Wildcat Creek, immediately at the outlet of Wildcat Lake. Trapping data from the Salmonberry Creek watershed, which contained Long Lake, were unavailable. Habitat/smolt production relationships produced for Washington streams (Zillges 1977; Baranski 1989) were used to calculate potential smolt production in Salmonberry and Curley Creeks, which entered and exited the lake respectively. Available habitat was calculated using a combination of air photos, and ground surveys using standard methods (Zillges 1977; Baranski 1989) for an estimate of low-flow wetted perimeter. All smolts produced in Salmonberry Creek were exposed to competition or predation from introduced fishes and possibly some from Curley Creek were as well. Because estimates of smolt production potential do not actually measure the numbers of juvenile salmon exiting a watershed, but the potential of a watershed to produce salmon smolts, they are prone to more error than trap counts.

Results

Juvenile coho salmon rearing in all three lakes grew much faster than those in nearby streams draining into Puget Sound (Figure 1), suggesting coho salmon populations were not food-limited in the lakes. However, growth was recorded only in the spring because few juvenile salmon were found in the lakes in late summer.

Fish predation was a significant source of mortality of coho salmon juveniles. Over the two-year study, 30,622 fish were sampled and the contents of 10,262 stomachs were pumped and analyzed. Percent of salmon in the diet was highest for largemouth bass (Table 2). Other species primarily targeted insects and zooplankton. Some salmon were found in the diet of black crappie, brown bullhead, cutthroat trout, prickly sculpin, and yellow perch. Although in three instances salmon constituted 5-10% of the total weight of the stomach contents for these fishes, this usually represented one salmon in the diet the entire year for the species. We found no evidence of rainbow trout, bluegill, or pumpkinseed sunfish feeding on any salmon.

While some salmon were eaten by other species, the vast majority of total salmon was eaten by largemouth bass in all three lakes. Percentage of the total catch consisting of largemouth bass in each lake for each year was as follows: Wildcat 1998-99, 81; Wildcat 1999-00, 88; Symington 1998-99, 35; Symington 1999-00, 42; Long 1998-99, 27; Long 1999-00, 35. Therefore, largemouth bass averaged 51% by number of the total catch of fishes over all three lakes during both years. Among the three lakes, an average of 94% of the salmon found in diets each year were in largemouth bass stomachs (Figure 2). When diet was standardized by catch (mean weight of salmon per individual fish of each species *x* number of fish of that species in total catch), an average of 98% of the salmon prey from each lake were found in largemouth bass stomachs (Figure 2).

Our bioenergetics analyses concentrated on largemouth bass predation, because the amount of coho salmon eaten by all other species was minimal. Lake Symington contained the smallest largemouth bass population, while Long Lake contained the largest population (Table 1). Density of largemouth bass was highest in Lake Symington but lowest in Long Lake. Most largemouth bass were captured in shallow water of the littoral zones at average depths of approximately one meter, experiencing the thermal regime of this region (Figure 3). Annual survival of largemouth bass did not vary substantially in Long Lake or Lake Symington between years (Table 3). In Wildcat Lake, survival declined by about 26% between years. Examining movement of modal size of largemouth bass cohorts and corroborating this with data from tagged fish provided estimates of largemouth bass growth for the model (Figure 4). Largemouth bass growth was rapid compared to previously reported Washington state averages (Wydoski and Whitney 1979).

The bioenergetic analysis revealed that both the largemouth bass populations in Symington and Long Lakes ate the most coho salmon smolt equivalents. The largemouth bass population in Wildcat Lake ate the fewest (Table 4). Largemouth bass predation varied by season ($P < 0.025$, $F = 9.216$, Table 5). Most occurred in spring when coho salmon smolts were migrating through lakes to the sea, or coho salmon fry were moving from creeks into lakes. We captured few coho salmon in any of the lakes in summer or early fall (Figure 5). Consequently, predation was usually low at this time of year.

No salmon were found in the diet of age-0 largemouth bass. Of those largemouth bass age-1 and older, we found no evidence that a particular size group or age class of largemouth bass was responsible for more predation on coho salmon than others. Total numbers of smolt equivalents eaten did not differ by age class ($P > 0.25$, F=0.747), nor did grams of smolt equivalents eaten per gram of largemouth bass differ among various age classes of largemouth bass ($P > 0.25$, F = 0.660).

Almost all of the predation by largemouth bass on coho salmon was likely confined to the lakes. During the mid-summer 1999 snorkel surveys of Big Beef Creek adjacent to the Lake Symington, we saw only a few age-0 largemouth bass, part of the cohort that did not eat any coho salmon in the lakes. Additionally, even though it was mid-July, water temperatures in the Creek were considerably lower than those in the lake, and were much below that needed for optimal feeding of largemouth bass.

Juvenile coho salmon outmigrations were largest in the Big Beef Creek (Lake Symington) watershed, and lowest from the outlet of Wildcat Lake (Table 4). The amount of coho salmon smolt production eaten by largemouth bass also varied considerably among watersheds, from about 5% of the number exiting the system to over twice the number exiting the system. Lake Symington contained the smallest largemouth bass population (Table 1), and was located in the watershed that produced the largest number of coho salmon smolts of the three systems studied. Furthermore, Lake Symington was located midway in the Big Beef Creek watershed, and a substantial portion of the smolts passing through the Big Beef Creek trap were produced below the lake and never exposed to the largemouth bass predation in Lake Symington. Not surprisingly, the amount of smolt equivalents eaten by largemouth bass in Lake Symington compared to the number exiting the Big Beef Creek Trap was lowest in this system.

Long Lake contained the largest population of largemouth bass, and was fed by Salmonberry Creek and drained by Curley Creek. Number of juvenile salmon eaten in this lake, compared to the juvenile coho salmon production potential in the watershed was much greater (Table 4). Wildcat Lake supported the smallest run of smolts because a screen was present at the outlet of the lake to prevent stocked trout from leaving the system. Even though the screen was in place, a few salmon were able to pass around the screen, and both fry and smolts were found above the barrier. The small smolt run exiting the lake was severely impacted by largemouth bass predation (Table 4). For example in 1998-99, the number of juvenile coho salmon smolts passing over the trap at the exit to the lake was only half as many as those that were eaten by largemouth bass in the lake. Because the screen partially blocked salmon migration through the lake and upstream, it was removed in 1999.

Discussion

Juvenile coho salmon growth was higher in the lakes than in several nearby streams and higher than an average for south Puget Sound streams that was recorded in the literature (Rounsefell and Kelez 1938; Kahler et al. 2001; Figure 1). This suggests juvenile salmon were not growth-limited in the lakes we studied, and that food competition with introduced fishes, while possibly occurring, was likely unimportant in contributing to mortality of juvenile coho salmon. This is consistent with data from others (Swales and Levings 1989; Irvine and Johnston 1992; Bryant et al. 1996; Quinn and Peterson 1996) who found that coho salmon rearing in lakes grew faster than those in nearby streams.

We studied the effects of the most widely distributed introduced fishes in Washington's shallow lakes (Zook 1978; Fletcher 1982; Fletcher 1983; Washington Department of Fish and Wildlife 2003). Of these fishes, largemouth bass were the most important predators of coho salmon. Predation on salmon was important in all systems studied. The percent impact to the run was smallest in Lake Symington; however, only a portion of the run that exited the trap passed through the lake. Lake Symington was located midway in the watershed. If only half the salmon production was upstream of the lake, 10-20% of the salmon exposed to predation would have been removed, not 5-10%.

Future research to prioritize where largemouth bass predation is most severe would allow for the maintenance of valuable non-threatening largemouth bass populations for anglers while identifying those largemouth bass populations for potential control that would have a substantial effect on salmon runs. Predation impacts to salmon in our three lakes seemed greatest when there was a small coho salmon run passing through a lake containing a large littoral zone supporting many largemouth bass versus a large run passing through a small lake.

No specific largemouth bass size group (Age-1 and over) was responsible for more salmon predation than other size groups. While rapidly growing young largemouth bass typically require higher food rations, salmon were a small component of their diet. Because consumption of salmon was sporadic, there were no discernable differences in predation on salmon among largemouth bass size classes, even though smaller individuals may have eaten more food per gram body weight overall.

The results of our studies of three shallow lakes were different from those from studies of some large Pacific Northwest rivers and deep lakes where largemouth bass, and a related species, smallmouth bass *M. dolomieui* were less important predators on juvenile salmon. Northern pikeminnow, a native species, were the most important predators in the John Day Reservoir of the Columbia River, responsible for 78% of the total loss of juvenile salmonids (Poe et al. 1991). In large (8966 ha), deep (85 m) Lake Washington, smallmouth bass did not have a large impact on sockeye salmon populations (Fayram and Sibley 2000) in contrast to the significant effects of native cutthroat trout (Nowak et al. 2004). However, our results agree with others who have studied impacts of black basses in shallow systems. Impacts of smallmouth bass in the Hanford Reach of the Columbia River were greater, presumably because of greater habitat overlap among juvenile salmonids and smallmouth bass (Tabor et al. 1993). In the shallow Tenmile Lake system of Oregon, Reimers (1989) stated that time association between the introduction of largemouth bass (1971) and reduced levels of coho salmon for the next 15 years was dramatic. He further stated that natural production of wild coho smolts was limited to the tributary streams because of high levels of predation in the lakes. Smallmouth bass introductions have been shown to drastically alter littoral zone native fish communities in central Ontario (Vander Zanden et al. 1999; MacRae and Jackson 2001), and removal of smallmouth bass from a New York lake resulted in a significant increase in the abundance of five species of native fishes (Weidel et al. in review). In years past, piscicide was regularly used to clear small and medium-sized Washington lakes of introduced warmwater predators and competitors so stocked trout fry, many of similar size to coho salmon juveniles, could survive. Decreased piscicide use in Pacific Northwest lakes, especially in western Washington, has made it difficult to clear them of introduced fishes, and survival of trout fry stocked into these systems is usually too low to support a viable fishery (Bradbury 1986). Currently most trout fisheries in western Washington are maintained by stocking large catchable trout (>150 mm) because mortality of smaller fry is too large to be cost-effective. In deeper systems, such as Columbia River reservoirs or Lake Washington, there may be more of a spatial separation of largemouth bass and salmon than in shallow lakes, allowing the salmon to avoid largemouth bass predation. In addition the small amount of littoral zone available for establishment of largemouth bass in deep lakes or riverine systems may limit their populations.

Largemouth bass are widespread, present in 85%, of the lowland warmwater public-access lakes of Washington (n=421)(Washington Department of Fish and Wildlife 2003). Because hundreds of these lakes are accessible to anadromous salmonids and are often used as rearing areas and migration corridors, future examination of the effects of largemouth bass predation on juvenile salmon on a landscape scale could help identify the overall impacts of this introduced species.

Whether a decrease in predation on coho salmon juveniles in lakes would translate into larger adult populations is unclear at this time. Kareiva et al. (2000) estimated that modest reductions in first-year or estuarine mortality would reduce population declines in Chinook salmon *O. tshawytscha*. In addition, coho smolt size is positively correlated with subsequent survival (Mathews and Ishida 1989; Holtby et al. 1990; Irvine and Johnston 1992) and those rearing in lakes are consistently larger than those in nearby streams. However, other important mortality factors such as climate conditions affecting ocean survival and the availability of summer low-flow habitat may dampen the benefits of attempting to improve lake survival by removing largemouth bass. Nevertheless, attempts to increase largemouth bass numbers in important coho rearing sites, or transplanting largemouth bass to lakes important to coho salmon would be counterproductive to coho salmon enhancement efforts.

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Table 1. Descriptions of study lakes for introduced fish/salmon interactions project. Fish species are BBH = brown bullhead catfish, BC = black crappie, CH = chum salmon, CT = cutthroat trout, GDS = golden shiner, GS = green sunfish, LMB = largemouth bass, PKS = prickly sculpin, PS = pumpkinseed sunfish, RB = rainbow trout/ steelhead, WM = warmouth sunfish, YP = yellow perch. Population estimate is number of largemouth bass > 150 mm TL.

Lake	Size (ha)	Watershed	Fish Species	Elevation (m)	LMB			
					Population Estimate	Low 95% C.I.	High 95% C.I.	Density (fish/ha)
Symington	24	Big Beef Creek	BBH, BG, CO, YP, LMB, RB, CT, GS, PS, WM	120	338	218	549	14.08
Long	127	Salmonberry/Curley Creeks	YP, BC, BG, LMB, CT, CO, CH, GDS, PKS, BBH	36	922	705	1205	7.26
Wildcat	44	Wildcat Creek	CO, PKS, CT, RB, LMB	116	438	361	533	9.95

Table 2. Percent by weight of stomach contents of fishes captured from three western Washington lakes. Data were separated into two one-year periods, March 1998-March 1999, and April 1999-March 2000.

		Prey Item									
Predator	***N***	**Invertebrates (Not Crayfish)**	**Non-Salmon Fish**	**Amphibians**	**Salmon**	**Crayfish**	**Unidentified Fish**	**Unidentified Salmonid**	**Birds**	**Rodents**	**Aquatic Plants, Detritus, And Other**
					Wildcat Lake 1998-99						
Coho salmon	15	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Prickly sculpin	162	89.62	2.72	0.00	4.64	0.00	0.19	0.00	0.00	0.00	2.84
Cutthroat trout	102	99.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
Largemouth bass	1240	16.58	67.27	2.27	1.57	4.09	1.02	4.91	0.00	0.00	2.29
Rainbow trout (Incl. Steelhead)	121	86.77	5.79	0.00	0.00	0.00	1.82	3.36	0.00	0.00	2.27
					Wildcat Lake 1999-00						
Coho salmon	32	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly sculpin	82	99.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44
Cutthroat trout	58	99.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
Largemouth bass	971	25.29	57.77	8.76	5.96	1.01	0.97	0.01	0.00	0.01	0.24
Rainbow trout (Incl. Steelhead)	66	99.02	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.93
					Long Lake 1998-1999						
Brown bullhead	227	95.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.09
Black crappie	210	88.61	5.29	0.00	2.31	0.00	0.45	0.03	0.00	0.00	3.31
Bluegill	329	97.53	0.26	0.00	0.00	0.00	0.03	0.00	0.00	0.00	2.18
Coho salmon	70	98.87	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Prickly sculpin	96	83.12	3.91	0.00	0.00	11.62	0.77	0.00	0.00	0.00	0.57
Cutthroat trout	332	96.58	3.14	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.24
Golden shiner	1	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Largemouth bass	1008	6.34	74.62	2.75	3.09	6.67	1.43	1.42	1.23	0.26	2.18
Pumpkinseed	162	99.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51
Rainbow trout (incl. Steelhead)	12	89.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.22
Yellow perch	108	91.59	6.90	0.00	0.00	0.00	1.49	0.02	0.00	0.00	0.00
					Long Lake 1999-2000						
Brown bullhead	115	79.38	2.32	0.00	9.34	0.00	0.00	0.00	0.00	0.00	8.95
Black crappie	136	69.90	27.49	0.00	0.00	0.00	2.05	0.00	0.00	0.00	0.56
Bluegill	372	95.68	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	4.24
Coho salmon	149	99.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23
Prickly sculpin	159	73.44	22.07	0.00	0.00	0.00	0.12	3.63	0.00	0.00	0.74

Predator	*N*	Prey Item									
		Invertebrates (Not Crayfish)	Non-Salmon Fish	Amphibians	Salmon	Crayfish	Unidentified Fish	Unidentified Salmonid	Birds	Rodents	Aquatic Plants, Detritus, And Other
Cutthroat trout	333	86.63	12.38	0.29	0.00	0.00	0.07	0.00	0.00	0.00	0.64
Golden shiner	7	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00
Largemouth bass	518	17.93	52.95	11.35	4.87	5.33	1.27	3.45	0.00	0.00	2.86
Pumpkinseed	130	98.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05
Rainbow trout (incl. Steelhead)	15	88.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.23
Yellow perch	447	89.39	6.39	0.15	0.00	0.00	0.04	0.00	0.00	0.00	4.03
Lake Symington 1998-1999											
Brown Bullhead	186	90.01	2.22	0.00	0.00	0.00	0.26	0.00	0.00	0.00	7.51
Bluegill	48	99.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82
Coho Salmon	55	99.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Cutthroat Trout	136	95.38	2.07	0.00	0.11	0.00	0.35	0.00	0.00	0.00	2.09
Green Sunfish	54	81.74	0.00	17.40	0.00	0.00	0.00	0.00	0.00	0.00	0.85
Largemouth Bass	432	8.28	27.00	24.37	19.82	11.80	2.56	3.80	0.00	0.00	2.38
Pumpkinseed	212	93.46	0.28	0.41	0.00	0.00	0.05	0.00	0.00	0.00	5.79
Rainbow Trout	12	99.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Yellow Perch	165	92.29	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	7.07
Lake Symington 1999-2000											
Brown Bullhead	191	96.41	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.18
Bluegill	26	77.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.12
Coho Salmon	233	98.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06
Cutthroat Trout	58	88.30	4.94	0.00	6.31	0.00	0.00	0.00	0.00	0.00	0.45
Green Sunfish	93	99.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
Largemouth Bass	281	18.39	25.01	19.72	12.59	9.12	0.42	6.93	0.00	0.00	7.82
Pumpkinseed	187	98.76	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	1.23
Rainbow Trout	4	99.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
Yellow Perch	103	94.15	0.28	0.00	1.28	0.00	0.00	0.46	0.00	0.00	3.84

Table 3. Survival of largemouth bass in three western Washington lakes. Numbers under age columns indicate number of fish in each age group captured.

Lake	Year	Age 1	2	3	Annual Survival Rate (*S*)
Wildcat	1998-99	802	233	213	0.52
	1999-00	1061	114	71	0.26
Long	1998-99	894	147	312	0.59
	1999-00	266	116	79	0.54
Symington	1998-99	188	129	31	0.41
	1999-00	235	12	25	0.33

Table 4. Number of coho salmon smolt equivalents eaten by largemouth bass in the three study lakes. The *low* and *nominal estimates* included only fish that could be positively identified as salmon in the diet and were based on the lower 95% confidence level and the nominal estimate of the largemouth bass population estimate respectively. The *high estimate* was based on the upper 95% confidence level of the largemouth bass population estimate and included both fishes that could positively be identified as salmon, and unidentified salmonid fishes in the diet. Smolt abundance for Lake Symington was the number of smolts that passed through the Big Beef Creek Trap close to the outlet of Puget Sound in 1998 and 1999, respectively. Smolt abundance for Wildcat Lake was the number of smolts that passed through the trap at the outlet of the lake in 1998 and 1999, respectively. Smolt abundance for Long Lake is the range of smolt production potential for Salmonberry Creek only (low number) that flows into Long Lake to smolt production potential for Salmonberry and Curley Creeks combined (high number). Curley Creek exits Long Lake and flows into Puget Sound.

		Number of Smolt Equivalents Eaten by Largemouth Bass			
Lake	**Year**	**Low**	**Nominal**	**High**	**Smolt Abundance**
Symington	98-99	1131	1754	3311	22,222 – 20,967
Symington	99-00	603	908	2356	
Long	98-99	1082	1414	2108	3,478-8,404
Long	99-00	2090	2728	4632	
Wildcat	98-99	73	88	461	30-55
Wildcat	99-00	0	0	109	

Table 5. Salmon consumption (numbers) by entire largemouth bass population each day during each season as estimated by the Wisconsin bioenergetics model. Spring–early summer was defined as April 1 – mid-July (14th-20th depending on lake and year). Late summer–early fall was defined as mid-July (14th-20th) – Late October (13th-28th). Late fall–winter was defined as Late October (13th-28th) – end of March (31st). In Lake Symington, 1999, season change between LS/EF and LF/W was September 15.

Lake	Year	Spring-Early Summer	Late Summer-Early Fall	Late Fall-Winter
Symington	98-99	16.047	0.522	0.036
Symington	99-00	7.505	0.000	0.773
Long	98-99	11.252	0.913	0.747
Long	99-00	7.217	5.443	8.858
Wildcat	98-99	0.838	0.000	0.000
Wildcat	99-00	0.000	0.000	0.000

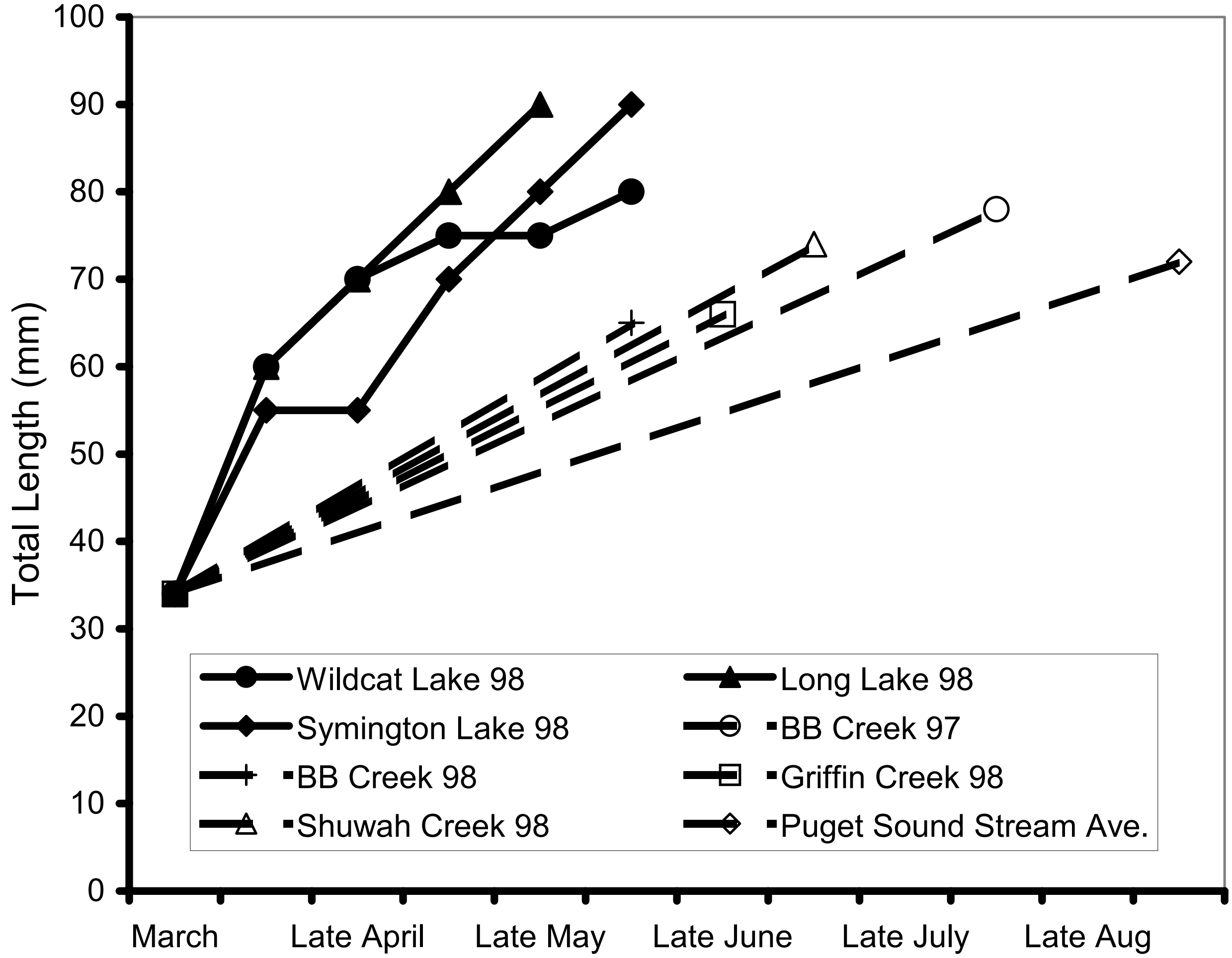

Figure 1. Growth of coho salmon juveniles in the three study lakes and in Puget Sound streams. Coho salmon emerge from the gravel in nearby creeks in March at an average size of approximately 34 mm TL (Sandercock 1991).

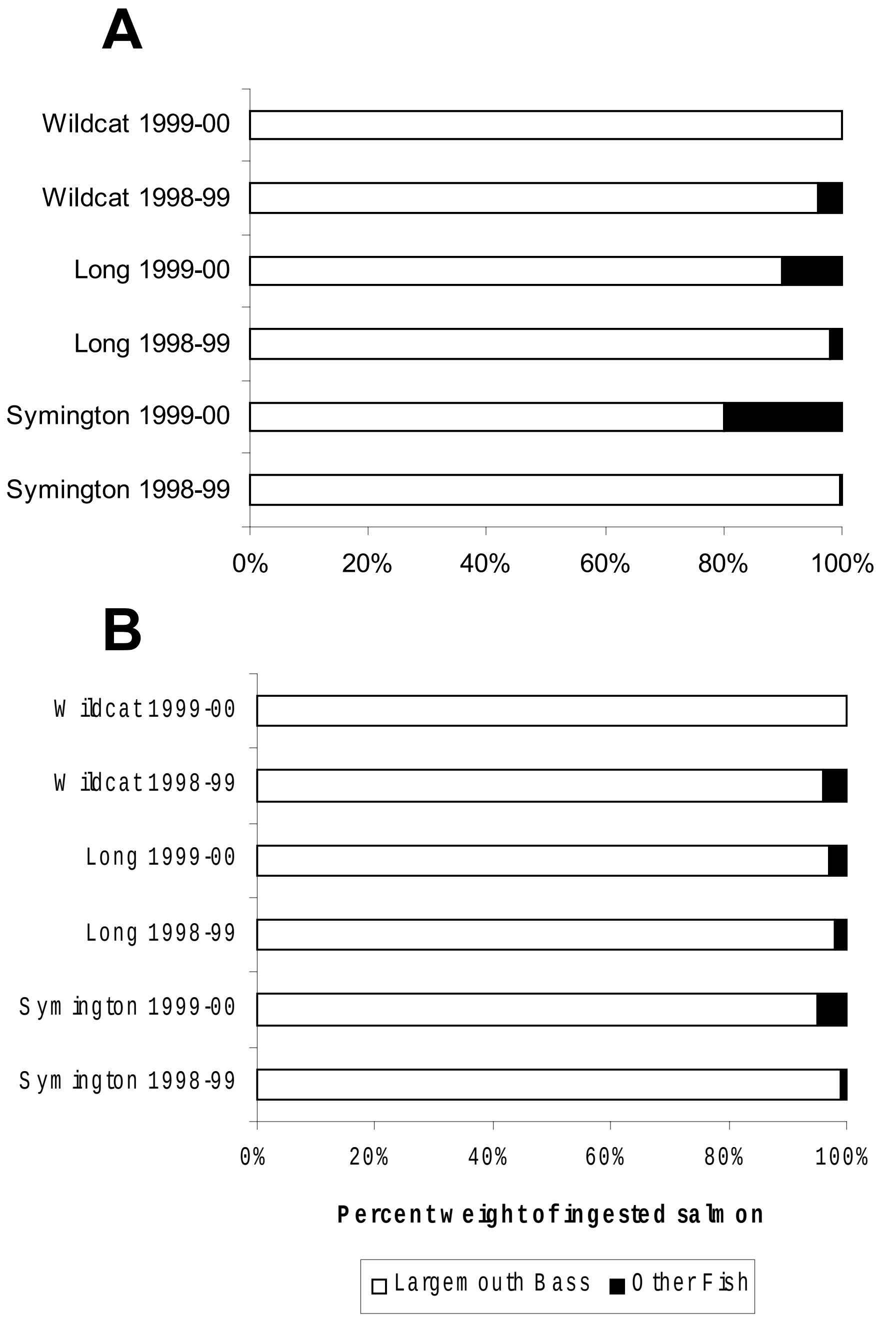

Figure 2. Percent distribution of total salmon ingested recovered from fish diets of various predators (A). Same data standardized by catch (B, mean number of salmon per individual fish of each species x number of fish of that species in total catch). Wildcat 1999-2000 data based on fish identified as salmonids.

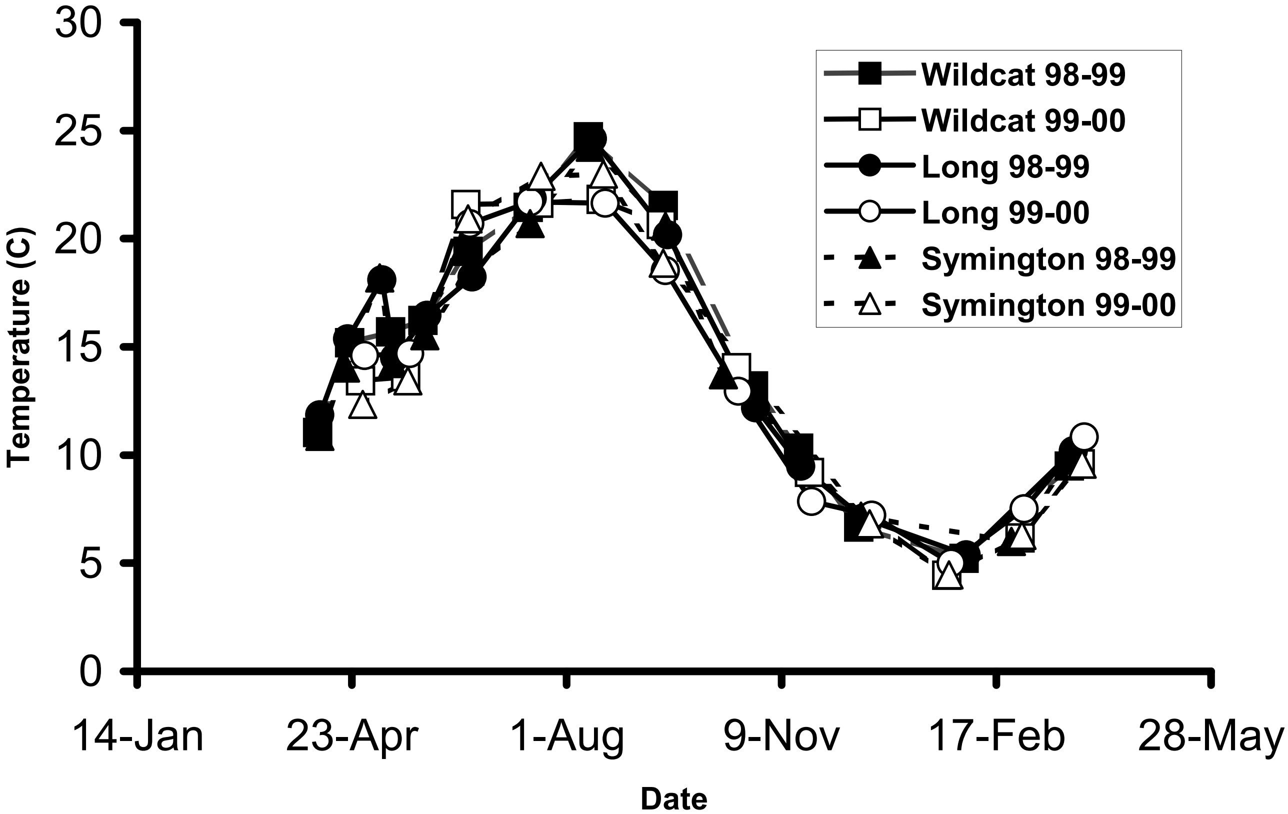

Figure 3. Thermal experience of largemouth bass in three western Washington lakes, April 1998-April 2000.

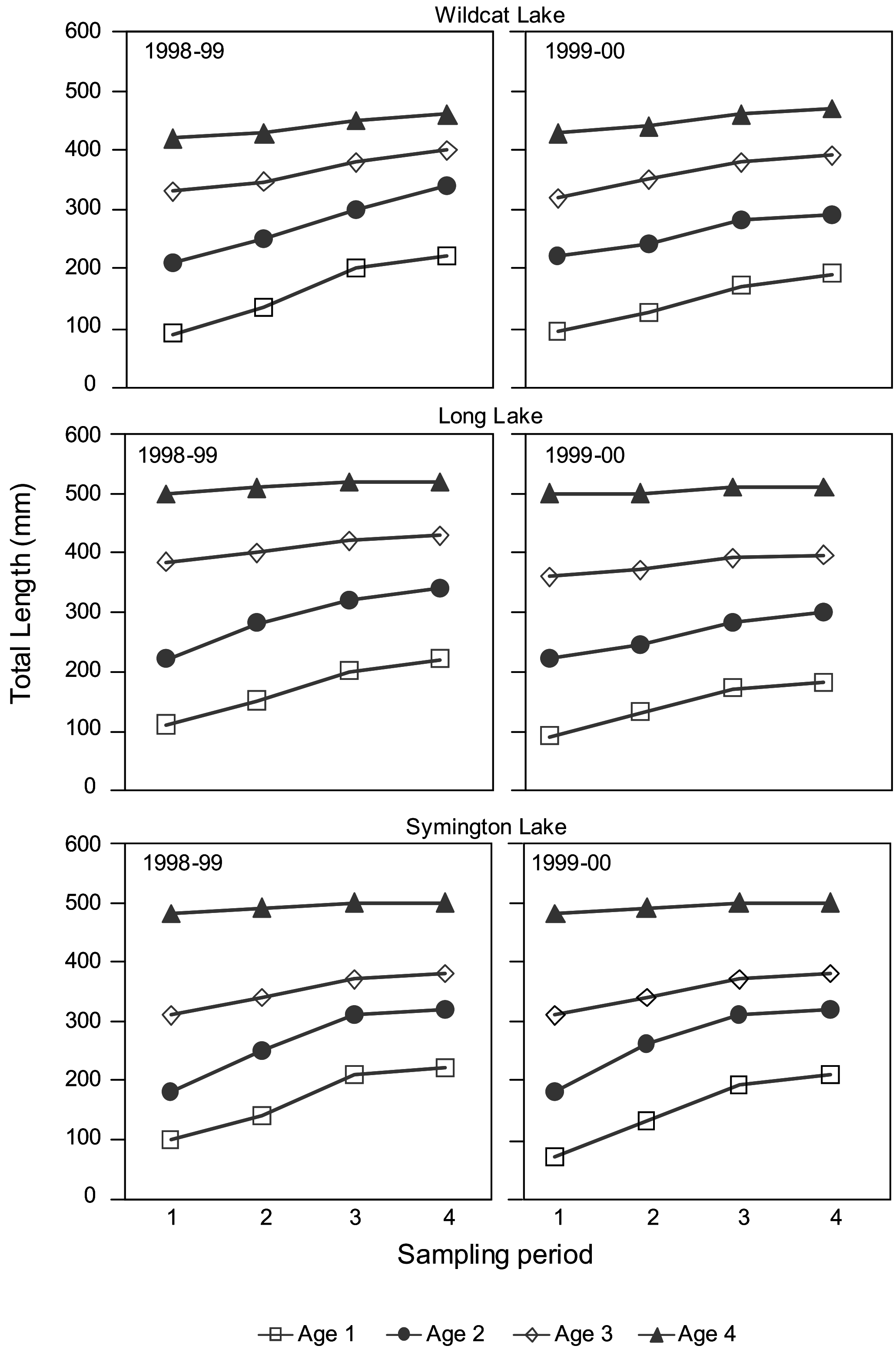

Figure 4. Modal total length of largemouth bass at sampling period 1 (April 7-9, 1998; April 27-29, 1999), period 2 (July 14-17, 1998; July 15-20, 1999); period 3 (October 13-28, 1998; Symington September 15, 1999, Wildcat and Long, October 19-20 1999) and period 4 (March 23-25, 1998; March 28-30, 1999). Age-4 bass include age-4 and older.

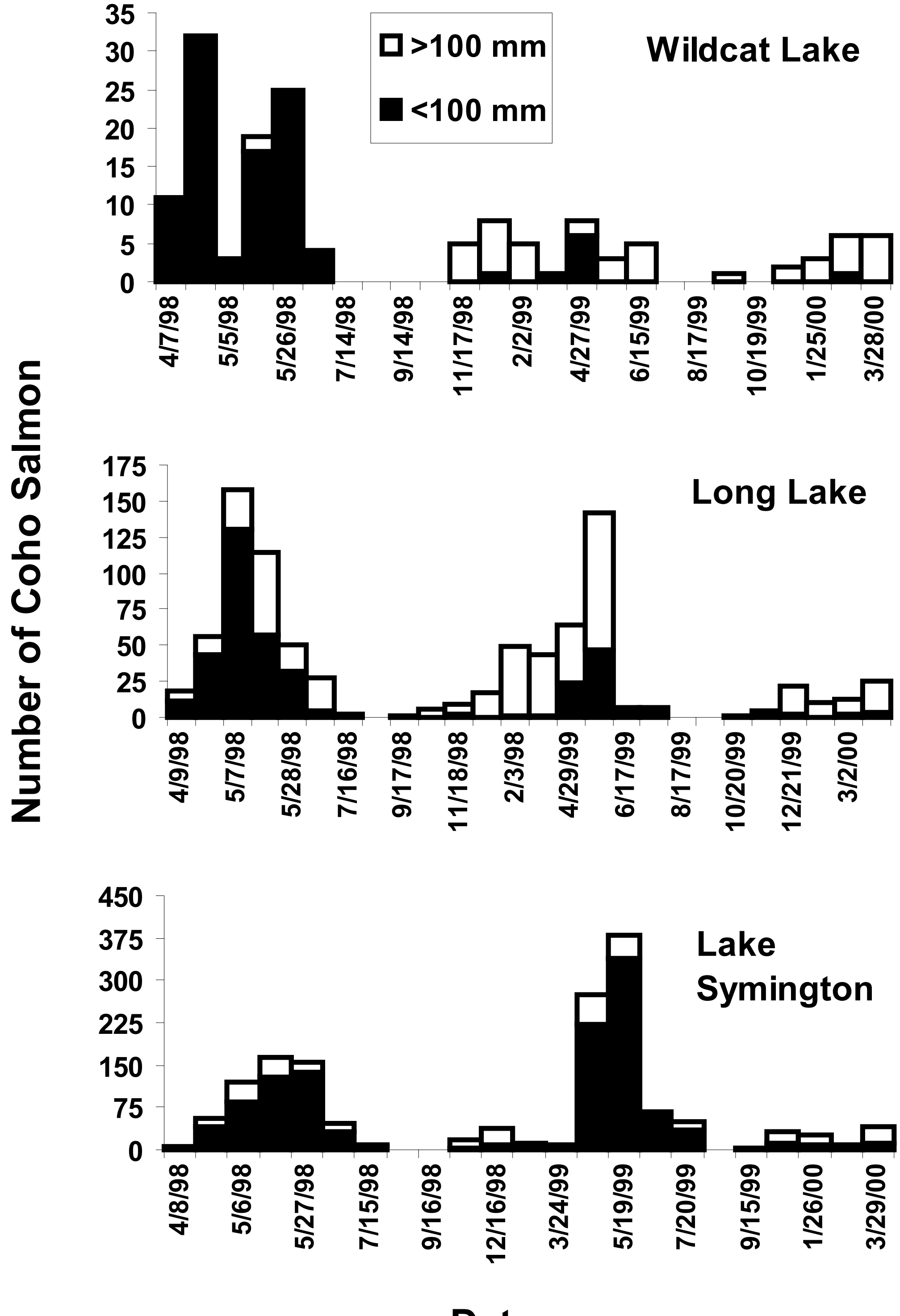

Figure 5. Number of coho salmon captured in each lake by time of year. Effort was similar for all surveys. Coho salmon catch per unit effort was underestimated for the spring, 1998 in Lake Symington. Not all coho salmon electrofished were brought onto the boat for counting and weighing.