2001 Spencer Lake Survey: Biological Characteristics of a Minimally Exploited, Isolated Fish Community Consisting of Smallmouth Bass, Largemouth Bass, and Prickly Sculpin

by

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Abstract

Spencer Lake, a remote, isolated body of water located on Blakely Island (San Juan County), was surveyed by members of the Washington Department of Fish and Wildlife Warmwater Fish Enhancement Program and students and faculty from Seattle Pacific University's Department of Biology during April, August, and November 2001. Smallmouth bass *Micropterus dolomieu* dominated the catch, followed by largemouth bass *M. salmoides* and, to a much lesser extent, prickly sculpin *Cottus asper*. Size structures and catch rates varied with season, and fish were of primarily moderate size relative to those in other Washington lakes. Relative weights of smallmouth bass were low by regional and national standards (75^{th} percentile) and decreased with length. Largemouth bass displayed relative weights that were consistent with the national standard but also decreased with length. The oldest fishes captured were a 13 year-old smallmouth bass and a 10 year-old largemouth bass. The median age of all fish captured was five years for smallmouth bass and four years for largemouth bass. Smallmouth bass growth, expressed as length at age, was lower than in other western Washington lakes available for comparison with this study. Largemouth bass growth was similar to other western Washington lakes for the first five years, then declined markedly. A reduced forage base, low water temperatures, and a lack of fishing pressure may all contribute to the observed bass population characteristics, though their effects are apparently stronger in shaping the smallmouth bass population.

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Introduction and Background

Spencer Lake is a small (28 hectares), oligotrophic lake located in the central portion of Blakely Island in Puget Sound, Washington (Figure 1). The shoreline of Blakely Island is composed almost entirely of steep, rocky cliffs, which rise to a maximum elevation of 320 m at Blakely Peak in the northeast part of the island (Wolcott 1973). Spencer Lake is fed by precipitation, groundwater, and intermittently by Horseshoe Lake, which is located upstream and to the north at an elevation of ~ 120 m. The mean and maximum depths of Spencer Lake are 13.3 and 22.7 m, respectively. The shoreline length is 3.7 km. Surface water exits Spencer Lake (elevation = 63 m) to the west, where it is dammed, but eventually discharges to Thatcher Bay and Lopez Sound.

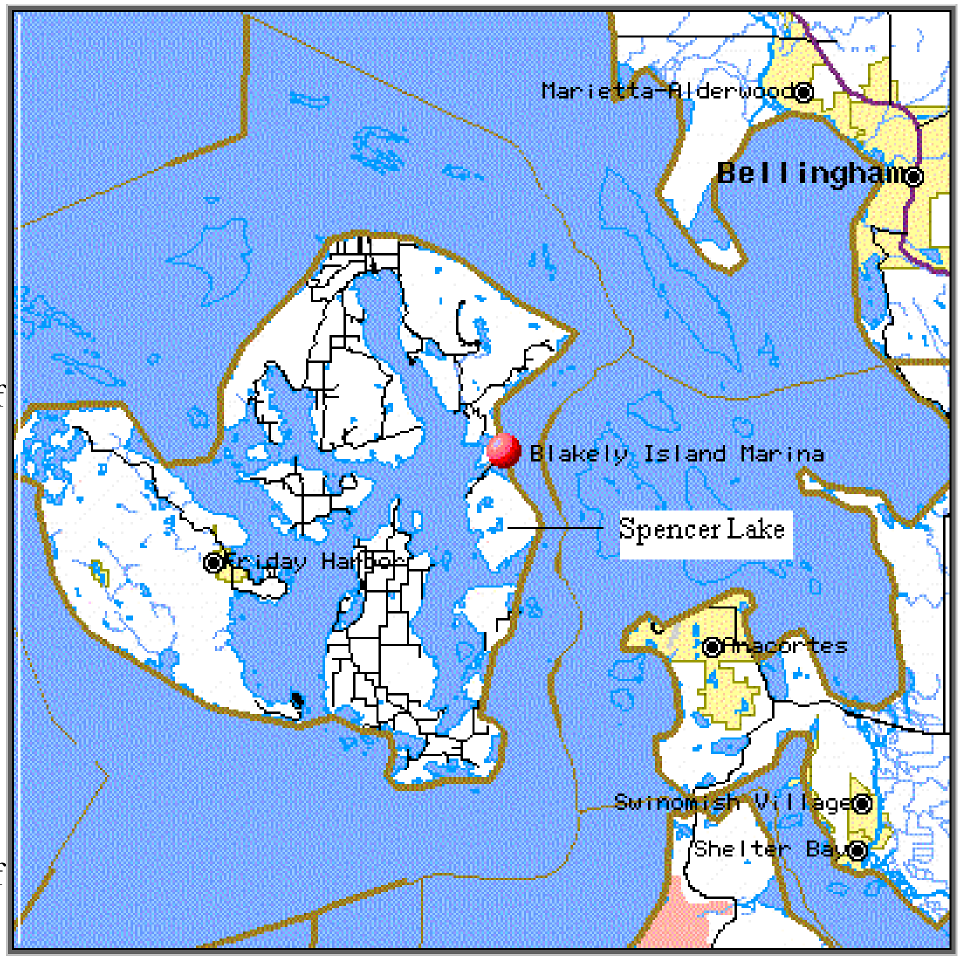


Figure 1. Map of San Juan County showing location of Spencer Lake on Blakely Island.

Public access to Blakely Island is limited to the Blakely Island Marina (Figure 1) and the nearby airstrip. Except for the private residential area around the marina, the island is largely natural and pristine. The interior of the island is heavily timbered, which is selectively harvested. The island supports a typical northwest second growth forest of Douglas fir *Pseudotsuga menziesii*, western hemlock *Tsuga heterophylla*, and western red cedar *Thuja plicata*. There are also isolated pockets of coastal species like Sitka spruce *Picea sitchensis* and others adapted to drier climates such as juniper *Juniperus scopulorum*, pine *Pinus* spp., madrone *Arbutus menziesii*, and oak *Quercus garryana*. Seattle Pacific University (SPU) maintains the Blakely Island Field Station along the shores of Spencer Lake. Shoreline development is limited to two houses. Prior to this study, the only information available on the Spencer Lake fish community was a June 1980 SPU study that captured 19 largemouth bass *Micropterus salmoides* (Appendix A) and anecdotal information from occasional anglers. Both sources indicated that Spencer Lake contained only largemouth bass, the native prickly sculpin *Cottus asper*, and smallmouth bass *M. dolomieu*. In fact, Spencer Lake contains the oldest known smallmouth bass population in the state, introduced approximately 80 years ago (Fletcher 1991). The origin of the other species in Spencer Lake is unknown; however, intermittent emigration from upstream Horseshoe Lake cannot be ruled out. According to the 1980 SPU study, most of the largemouth bass captured exceeded 200 mm total length, age classes from 1 + to 7 + were evenly represented, the sex ratio of the population was heavily skewed towards males, and much of the diet of largemouth bass consisted of insects (Appendix A). In recent years, the only management activity undertaken by Washington Department of Fish and Wildlife (WDFW) and its predecessor, the Washington Department of Game, at Blakely Island has been permitting the stocking of hatchery rainbow trout *Oncorhychus mykiss* into Horseshoe Lake. To date, these fish have not shown up in the creels of anglers at Spencer Lake.

Since there is no public access, Spencer Lake has received minimal fishing pressure for at least the last decade and little other human disturbance – both rare circumstances for any mainland lake in northwest Washington. Thus, the system could provide the opportunity to investigate the effects of little or no fishing pressure and a reduced forage base on a fish community primarily consisting of two of Washington's most popular freshwater gamefish species. In order to take advantage of this opportunity, staff from WDFW's Warmwater Fish Enhancement Program collaborated with students and faculty from SPU's Department of Biology to conduct standardized seasonal stock assessments of Spencer Lake throughout 2001. We assessed species composition, relative abundance, size structure, growth, and condition of fish in the lake. A companion study examining smallmouth and largemouth bass diets, in particular whether significant cannibalism occurs in the system, will be published under separate cover (Appendix B).

Materials and Methods

Spencer Lake was surveyed during the spring (April 18-20), summer (August 3-5), and fall (November 14-16) of 2001 using methods adapted from Bonar et al. (2000), who recommended using an electrofishing boat, gill nets, and fyke nets to capture the widest variety and greatest number of fish possible. However, access to Blakely Island is limited to private or charter air and boat service, which precluded transporting an electrofishing boat to the island. We therefore substituted angling and diving methods for electrofishing in order to sample the lake. Previous studies have shown that angling and diving compare favorably to electrofishing when sampling bass (Downen and Mueller 2000a; Mueller *in press*).

Sampling locations were selected by dividing the shoreline into 11 consecutively numbered sections of about 400 m each (determined visually from a map). Because of the modest size of the lake, sections were systematically sampled to maximize dispersion of gear types. Each section was assigned at least one of four sampling techniques: angling, scuba diving/snorkeling, gill netting, and fyke netting. Gill nets were assigned to moderately deep sections, fyke nets to shallow sections, and angling and visual surveys were assigned to deep sections or those not assigned a net type.

Angling sessions were conducted during daylight hours (0800 – 1800). Only one angler fished during April, but two anglers fished simultaneously in August and November. Anglers positioned their boat at one end of a 400-m section of shoreline, traveled parallel to shore, and fished continuously until reaching the other end of the shoreline section. The duration of each session was 50 min. Anglers primarily used light tackle and artificial lures (e.g., plastic grubs).

Scuba diving and snorkeling operations were also conducted during daylight hours (1000 – 1600). Modified strip transects, similar to those described by Mueller et al. (2001) and Mueller (*in press*), were used by divers to observe and count fish in up to seven 400-m sections of shoreline during each sampling period. The width of each strip transect was determined by the divers' lateral visibility. Visibility was estimated at the beginning of each dive by counting the number of kick-strokes (1 kick-stroke = 1 m swam by second author) taken to reach an arbitrarily selected submerged object (e.g., rock or piling) at the limit of the lead diver's visibility. The visibility estimate for all three sampling periods was ~ 8 m. Doubling this number resulted in the strip transect width for each sampling period, based on the lateral visibility to either side of the dive team. Divers swam strip transects parallel to shore at the surface and along the 6 and 1.5 m isobaths as determined by submersible depth gauges. In areas where the bottom was low grade or flat, an underwater compass bearing was used in conjunction with the depth bounds to ensure that the divers stayed generally parallel to shore. In this way, divers sampled depths (< 5 m) preferred by north temperate bass during summer and fall (Winter 1977; Savitz et al. 1993). Divers swam side-by-side near the bottom and maintained a relatively constant rate of forward motion to easily cover the 400-m shoreline distance of each sample section in 20 min. All fish observed within the limits of the divers' visibility within the depth bounds were approached, identified to species, counted, and TL estimated visually (± 10 mm) by comparing the animals to reference marks spaced 5 mm apart along one edge of a hand-held underwater slate. The nearshore diver counted and measured only those fish directly in front and toward shore of his position, while the offshore diver counted and measured only those fish directly in front and away from shore of his position (i.e., the mirror-opposite of the nearshore diver). To ensure independence of fish counts within each transect, divers recognized individual fish and groups of fish by size, scars or fin anomalies, and relative position within the transect. Divers conferred with each other using hand signals to make sure fish were counted only once (Eberhardt 1978). The accuracy of underwater length estimates was confirmed by comparing the markings on the slate with structural relief that black bass rested on or passed by (Mueller 1995; Thurow and Schill 1996). Accuracy was enhanced by the divers' prior knowledge of bass size structure as determined from previous angling samples (*sensu* Griffith 1981; Jones 1984). Divers recorded their observations separately on underwater slates and combined the data upon returning to the surface.

Experimental gill nets (45.7 m long × 2.4 m deep) were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size (13, 19, 25, and 51 mm stretched) monofilament mesh. Fyke nets were constructed of 1.2 m diameter hoops with funnels attached to a 2.5 m cod end (6.4 mm nylon mesh). Attached to the mouth of the net were two 15.2 m wings and a 31 m lead. Gill nets and fyke nets were set overnight (sunset to sunrise, or ~ 12 hours) at four locations each (= 4 net nights for each gear type) during a sampling period. Gill nets were set perpendicular to the shoreline. The small-mesh end was attached onshore while the large-mesh end was anchored offshore. The fyke nets were set in water less than 3 m deep with wings extended at 45 to 90E angles from the lead.

Some sampling sites were sampled a second time using a different gear type when time allowed and to compensate for low success in the nets. Three of the 11 sites were sampled twice in April, seven in August, and eight in November.

Except young-of-year, all fish captured angling or in nets were stored in live wells, brought to shore, and anesthetized using an ~3 ml/L solution of a 1:10 mixture of clove oil:ethanol (Anderson et al. 1997). Fish were identified to species, measured to the nearest 1 mm, and assigned to a 10-mm size class based on total length (TL). For example, a fish measuring 156 mm TL was assigned to the 150-mm size class for that species, a fish measuring 113 mm TL was assigned to the 110-mm size class, and so on. When possible, up to10 fish from each size class were weighed to the nearest 0.5 g. However, if a sample included several hundred individuals of a given species, then a sub-sample (n ' 100 fish) was measured and weighed while the remainder was counted overboard. The length frequency distribution of the sub-sample was then applied to the total number collected. Weights were estimated for fish not individually weighed using a linear regression of $\log_{10}$-length on $\log_{10}$-weight of fish from the sub-sample. Scales were removed from up to five fish from each size class for aging. Scale samples were mounted, pressed, and the fish aged according to Carlander (1982), Jearld (1983), and Fletcher et al. (1993). Otoliths were removed from some bass and prickly sculpin for aging purposes as well. These data are summarized in Appendix C.

Water quality data was collected near the deepest part of the lake at 1-m intervals during midday on April 19, August 2, and November 15, 2001. Using a Hydrolab® probe and digital recorder, information was gathered on dissolved oxygen, temperature, turbidity, pH, specific conductance and total dissolved solids.

Data Analysis

Balancing predator and prey fish populations is the hallmark of warmwater fisheries management. According to Bennett (1962), the term 'balance' is used loosely to describe a system in which omnivorous forage fishes maximize food resources to grow to harvestable-sizes and to become abundant enough to feed predators. Predators must reproduce and grow to control overproduction of prey and predator species, as well as provide adequate fishing. To maintain balance, predator and prey fish must be able to forage effectively. Evaluations of species composition, catch rates, size structure, growth, and condition (plumpness or robustness) of fish provide useful information on the adequacy of the food supply (Kohler and Kelly 1991), as well as the balance and productivity of the community (Swingle 1950; Bennett 1962).

Species Composition

We determined species composition by weight (kg) of fish captured during each sampling period using procedures adapted from Swingle (1950). The species composition by number of fish captured during each sampling period was determined using procedures outlined in Fletcher et al. (1993) with one exception. While young-of-year or small juveniles are often not considered because large fluctuations in their numbers may lead to misinterpretation of results (Fletcher et al. 1993), we chose to include them since their relative contribution to total species biomass was small. Moreover, the overall length frequency distribution of fish species may suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes. Many of these fish would be subject to natural attrition during their first winter (Chew 1974), resulting in a different length frequency distribution by the following year. However, the presence of these fish in the system relates directly to fecundity, forage base for larger fish, and interspecific and intraspecific competition at lower trophic levels (Olson et al. 1995). We therefore rely on species composition as an ecological indicator and catch per unit effort (CPUE) and proportional stock density (PSD) as stock indicators.

The percent species composition by weight was calculated as the weight of fish captured of a given species divided by the total weight of all fish captured × 100. The species composition by number was calculated as the number of fish captured of a given species divided by the total number of all fish captured × 100.

Catch Per Unit Effort

Catch per unit effort by gear type was determined for all species (number of fish/hour angling or scuba diving/snorkeling, and number of fish/net night). Only stock-length fish and larger were used to determine CPUE for smallmouth and largemouth bass, whereas CPUE for prickly sculpin were calculated for all sizes. Stock length, which varies by species (Table 2), refers to the minimum size of fish having recreational value. Since sample locations were randomly selected, which might introduce high variability due to habitat differences within the lake, 80% confidence intervals (CI) were determined for each mean CPUE by species and gear type. CI was calculated as the mean ± $t_{(\text{"}, N\text{-}1)}$ × *SE*, where t = Student's t for " confidence level with N-1 degrees of freedom (two-tailed) and *SE* = standard error of the mean. Because it is standardized, CPUE is a useful way to compare relative abundance of stocks between lakes. Furthermore, the confidence intervals reflect the relative uniformity of species distributions throughout a given lake. CPUE values for Spencer Lake can be compared to western Washington averages from up to 22 lakes (first author, unpublished data) sampled during the same time of year (Table 1).

Table 1. Mean catch per unit effort (number of fish/hr electrofishing and number fish/net night) for stock-length smallmouth bass and largemouth bass, and sculpin (Cottidae) collected from several western Washington State lakes while electrofishing, gill netting, and fyke netting from 1997 through 2000 (first author, unpublished data).

	Gear Type					
Sample Period and Species	**Electrofishing (# Fish/Hr)**	**# Lakes**	**Gill Netting (# Fish/Net Night)**	**# Lakes**	**Fyke Netting (# Fish/Net Night)**	**# Lakes**
Spring						
Smallmouth bass	---	---	---	---	---	---
Largemouth bass	29.7	8	0.7	6	---	---
Sculpin	23.7	3	0.3	1	---	---
Summer						
Smallmouth bass	---	---	---	---	---	---
Largemouth bass	19.4	3	2.0	2	---	---
Sculpin	4.9	3	0.3	1	---	---
Fall						
Smallmouth bass	3.8	8	2.3	7	0.5	1
Largemouth bass	29.0	22	1.4	16	0.3	2
Sculpin	20.7	15	0.4	5	0.4	5

Stock Density Indices

The proportional stock density of each fish species was determined following procedures outlined in Anderson and Neumann (1996). PSD was calculated as the number of fish $ quality length/number of fish $ stock length × 100, is an index of length frequency data that gives the percentage of fish in a population that are of recreational value to anglers. Stock and quality lengths, which vary by species, are based on percentages of world-record lengths. Again, stock length (20-26% of world-record length) refers to the minimum size fish with recreational value, whereas quality length (36-41% of world-record length) refers to the minimum size fish most anglers like to catch.

The relative stock density (RSD) of each fish species was examined using the five-cell model proposed by Gabelhouse (1984). In addition to stock and quality length, Gabelhouse (1984) introduced preferred, memorable, and trophy length categories (Table 2). Preferred length (45-55% of world-record length) refers to the minimum size fish anglers would prefer to catch when given a choice. Memorable length (59-64% of world-record length) refers to the minimum size fish most anglers remember catching, whereas trophy length (74-80% of world-record length) refers to the minimum size fish considered worthy of acknowledgment. Like PSD, RSD provides useful information regarding population dynamics, but is more sensitive to changes in year-class strength. RSD was calculated as the number of fish $ specified length/number of fish $ stock length × 100. For example, RSD P was the percentage of stock length fish that also were longer than preferred length, RSD M, the percentage of stock length fish that also were longer than memorable length, and so on. Eighty percent confidence intervals for PSD and RSD were calculated as described above for CPUE.

Table 2. Length categories for smallmouth bass and largemouth bass used to calculate stock density indices (PSD and RSD) of fish captured at Spencer Lake (San Juan County) during 2001.

Measurements are minimum total lengths, TL (mm), for each category (Anderson and Neumann 1996).

	Minimum size (mm TL)				
Species	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
Smallmouth bass	180	280	350	430	510
Largemouth bass	200	300	380	510	630

PSD and RSD have become important tools for assessing size structures of warmwater fish populations and determining management options for warmwater fish communities (Willis et al. 1993). PSD values from this study can be compared to the mean PSD values from up to 15 western Washington lakes (first author, unpublished data) which are summarized in Table 3.

Table 3. Mean proportional stock density (PSD) indices for smallmouth and largemouth bass by gear typed and season from up to 15 western Washington lakes sampled during 1997 to 2000 (first author, unpublished data).

Values in parentheses are number of lakes. EB = electrofishing boat, GN = gill net, FN = fyke net.

	Smallmouth bass			Largemouth bass		
Season	**EB PSD**	**GN PSD**	**FN PSD**	**EB PSD**	**GN PSD**	**FN PSD**
Spring	---	---	---	55 (8)	87 (4)	---
Summer	---	---	---	27 (3)	60 (1)	---
Fall	33 (2)	85 (5)	---	31 (15)	57 (7)	---

Three major management options commonly implemented for warmwater fish communities include the panfish option, balanced predator-prey option, and big bass option and each of these has associated ranges of PSD and RSD values (Table 4).

Table 4. Stock density index ranges for largemouth bass and bluegill under three commonly implemented management strategies (from Willis et al. 1993).

PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), and memorable length fish (RSD-M).

	Largemouth bass			Bluegill	
Option	**PSD**	**RSD-P**	**RSD-M**	**PSD**	**RSD-P**
Panfish	20 – 40	0 – 10		50 - 80	10 - 30
Balanced	40 – 70	10 – 40	0 – 10	20 - 60	5 - 20
Big bass	50 – 80	30 – 60	10 – 25	10 - 50	0 - 10

Age and Growth

Scale samples from fish collected sampled at Spencer Lake were evaluated to determine length at age (L_n) and growth characteristics using Lee's modification of the direct proportion method (Carlander 1982). Using Lee's modification, L_n was back-calculated as $L_n = a + A \times (TL - a)/S$, where A is the radius of the fish scale at age n, TL is the total length of the fish captured, S is the total radius of the scale at capture, and a is the species-specific standard intercept from a scale radius-fish length regression. Mean back-calculated lengths at age n for each species were presented in tabular form for easy comparison of growth between year classes, as well as between Spencer Lake fish and the western Washington average from up to 32 lakes (first author, unpublished data)

Length Frequency

The size structure of each species captured was evaluated by constructing a stacked length frequency histogram (percent frequency of fish in a given size class captured by each gear type). Although length frequencies are generally reported by gear type, we report the length frequency of our catch with combined gear types which is then broken down by the relative contribution each gear type makes to each size class. Selectivity of gear types not only biases species catch based on body form, and behavior, but also based on size classes and subsequent habitat use within species (Willis et al. 1993). Therefore, an unbiased assessment of length frequency is unlikely under any circumstance. Our standardized 1:1:1 gear type ratio adjusts for differences in sampling effort between sampling times and locations. Furthermore, differences in size selectivity of gear types may in some circumstances result in offsetting biases (Anderson and Neumann 1996). Length frequency proportions for each gear type are divided by the total numbers of fish caught by all gear types for each size class. This changes the scale but not the shape of the length frequency percentages by gear type. If concern arises that pooled gear does not represent the least biased assessment of length frequency for a given species, then the shape of the gear type-specific distributions is still represented on the graphs, and these may be interpreted independently.

Relative Weight

Plotting relative weights of individual fish provides a snapshot of how their "plumpness" compares to the national 75th percentile and western Washington state averages. Plotting relative weights of individual fish provides a snapshot of how their "plumpness" compares to the national 75th percentile and western Washington state averages. A relative weight (W_r) index was used to evaluate the condition of all species except prickly sculpin. A W_r value of 100 generally indicates that a fish is in good condition when compared to the national standard (75th percentile) for that species. Furthermore, W_r is useful for comparing the condition of different size groups within a single population to determine if all sizes are finding adequate forage or food (ODFW 1997). Following Murphy and Willis (1991), the index was calculated as $W_r = W/W_s \times 100$, where W is the weight (g) of an individual fish and W_s is the standard weight of a fish of the same total length (mm). W_s is calculated from a standard $\log_{10}$weight-$\log_{10}$length relationship defined for the species of interest. The parameters of the W_s equations for many warmwater fish species, including the minimum length recommendations for their application, have been compiled by Anderson and Neumann (1996). With the exception of prickly sculpin, the W_r values from this study were compared to the national standard (W_r = 100) and, where available, the mean W_r values from up to 25 western Washington lakes sampled during 1997 and 1998 (Steve Caromile, WDFW, unpublished data).

Results and Discussion

In general, the smallmouth bass population from Spencer Lake exhibited a high proportion of old, medium-sized fish exhibiting slow growth and low relative weight. The largemouth bass sampled were comprised of relatively younger, medium-sized individuals that displayed growth for at least the first few years comparable to other western Washington lakes. After four years, largemouth bass growth rates appear to decline. Largemouth bass relative weights were generally below western Washington averages but still within the range normally considered indicative of a healthy population. Consideration of these population characteristics indicates that there may be significant differences between the Spencer Lake fish community and those in other western Washington lakes. Possible reasons for these differences include the lack of fishing pressure or other harvest, a short growing season due to water temperature, and high levels of competition and lack of a sufficient forage base for all sizes classes, including young-of-year. There is also indication that these conditions have shaped the smallmouth and largemouth bass populations differently. Following is a more detailed discussion of these characteristics and consideration of factors that are potentially contributing to them.

Species Composition

As expected, the only fish species captured or observed during our surveys were smallmouth bass, largemouth bass and prickly sculpin (Table 5); this was supported by the diet study as well (Appendix B). In April, smallmouth bass dominated our catch by weight (72%) and number (62%). Largemouth bass comprised less than 30% of our catch by weight and number, whereas prickly sculpin made up about 10% of the species composition by number but less than 0.5% by weight. In August, smallmouth bass dominated our catch by weight (68%), while largemouth bass were dominant by number (60%). This was due to a large influx of young-of-year largemouth bass during summer. Only one prickly sculpin was observed in August comprising a very small percentage of the species composition by weight and number. In November, largemouth bass dominated our catch by weight (53%) and number (54%), while smallmouth bass comprised less than 47% of our catch by weight and number. Again, prickly sculpin were the least abundant in terms of weight (0.8%) and number (6%).

Table 5. Species composition by weight (kg) and number of fish captured at Spencer Lake (San Juan County) during 2001.

Sample period and species	Species composition by weight (kg)	by weight (%)	by number (#)	by number (%)	Size range (mm TL)
April					
Smallmouth bass (*Micropterus dolomieu*)	12.09	72.33	53	61.63	189 – 332
Largemouth bass (*M. salmoides*)	4.57	27.32	24	27.91	125 – 390
Prickly sculpin (*Cottus asper*)	0.06	0.34	9	10.46	20 – 156
Total	16.72		86		
August					
Smallmouth bass	22.86	68.31	195	39.16	50 – 396
Largemouth bass	10.60	31.68	302	60.64	41 – 403
Prickly sculpin	< 0.01	0.01	1	0.20	69
Total	33.47		498		
November					
Smallmouth bass	5.46	46.35	20	40.00	235 – 325
Largemouth bass	6.22	52.81	27	54.00	53 – 426
Prickly sculpin	0.10	0.83	3	6.00	35 – 162
Total	11.78		50		

CPUE

Catch rates for Spencer Lake fish varied by season, gear type, and species (Table 6), which is fairly typical of lentic fishery investigations (Pope and Willis 1996). Angling CPUE for stock-length smallmouth bass was similar between April and August, but decreased in November. Angling CPUE for stock-length largemouth bass peaked in August; however, no prickly sculpin were captured while angling. Diving CPUE for stock-length smallmouth and largemouth bass peaked in August, while the highest CPUE for prickly sculpin occurred in April. Gill netting CPUE for stock-length smallmouth bass was highest in August, but gill netting CPUE for stock-length largemouth bass peaked in November. No stock-length smallmouth and largemouth bass were captured using fyke nets, although several young-of-year were captured during August. The only prickly sculpin captured fyke netting occurred in August.

In April, angling was the most effective method for sampling stock-length smallmouth bass, whereas diving was the most effective method for sampling stock-length largemouth bass and prickly sculpin (Table 6). Angling CPUE for stock-length smallmouth bass was higher than the western Washington average electrofishing CPUE for smallmouth bass (Table 1), possibly suggesting a relatively higher density population. Angling and diving CPUEs for stock-length largemouth bass and prickly sculpin were considerably lower than the western Washington average electrofishing CPUEs for the species, suggesting low-density populations. However, gill netting CPUEs for stock-length largemouth bass and prickly sculpin (both 0.25) were consistent with western Washington averages (<1 fish/net night).

Table 6. Mean catch per unit effort (number of fish/hr angling or scuba diving/snorkeling, and number fish/net night), including 80% confidence intervals for stock-length smallmouth bass and largemouth bass (SMB & LMB, respectively) and prickly sculpin (COT = Cottidae) collected from Spencer Lake (San Juan County) during 2001.

	Gear type							
Sample period and species	**Angling (# fish/hour)**	**# sites**	**Diving (# fish/hour)**	**# sites**	**Gill netting (# fish/net night)**	**# net nights**	**Fyke netting (# fish/net night)**	**# net nights**
April								
SMB	9.80 " 2.00	6	0.60 [a]	5	0.75 " 0.61	4	0	4
LMB	0.80 " 0.51	6	7.20 [a]	5	0.25 [a]	4	0	4
COT	0	6	4.80 " 3.35	5	0.25 [a]	4	0	4
August								
SMB	9.93 " 2.68	11	60 [a]	1	2.75 " 1.69	4	0	4
LMB	2.18 " 1.03	11	15 [a]	1	0.75 " 0.32	4	0	4
COT	0	11	0	1	0	4	0.25 [a]	4
November								
SMB	2.00 " 1.42	12	0	7	0	4	0	4
LMB	0.40 " 0.22	12	0	7	1.75 [a]	4	0	4
COT	0	12	0.86 " 0.71	7	0.25 [a]	4	0	4

[a] Sample size too small or catch rates too variable to permit calculation of reliable confidence intervals

In August, diving was the most effective method for sampling stock-length smallmouth and largemouth bass (Table 6), but this finding should be viewed with caution since the result is based on one pass through a single shoreline section. Again, angling CPUE for stock-length smallmouth bass was higher than the western Washington average electrofishing CPUE for smallmouth bass (Table 1), and angling and diving CPUEs for stock-length largemouth bass and prickly sculpin were considerably lower than the western Washington average electrofishing CPUEs for those species. Furthermore, gill netting CPUEs for both species were lower than western Washington averages.

In November, angling was the most effective method for sampling stock-length smallmouth bass, but the CPUE (Table 6) was lower than the western Washington average electrofishing CPUE for the species (Table 1). Gill netting was the most effective method for sampling stock-length largemouth bass with a slightly higher CPUE than the western Washington average.

Stock Density Indices

Like CPUE, PSD values for Spencer Lake fish varied by season, gear type, and species (Table 7). The size structures of the smallmouth and largemouth bass populations at Spencer Lake, as indicated by PSD values, are generally smaller than those found in western Washington (Table 3). The smallmouth bass population appears to be out of balance with respect to its prey base, whereas the largemouth bass population appears to be in balance with its prey base (Table 4). In April and November, angling PSDs for smallmouth bass were higher than the mean electrofishing PSD for the species, which supports the findings of Ross et al. (1995). In August, the highest PSD values for smallmouth and largemouth bass occurred while gill netting, which is common in western Washington.

Table 7. Traditional stock density indices including 80% confidence intervals for smallmouth bass and largemouth bass collected from Spencer Lake (San Juan County) while angling, scuba diving/snorkeling, gill netting and fyke netting during 2001.
PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T). AN = angling, SK = scuba diving/snorkeling, GN = gill netting and FN = fyke netting.

Sample period and species	Gear type	# stock length fish	PSD	RSD-P	RSD-M	RSD-T
April						
Smallmouth bass	AN	49	37 " 9	0	0	0
	SK	1	0	0	0	0
	GN	3	0	0	0	0
	FN	0				
Largemouth bass	AN	4	25 [a]	25 [a]	0	0
	SK	12	8 [a]	0	0	0
	GN	1	0	0	0	0
	FN	0				
August						
Smallmouth bass	AN	91	9 " 4	0	0	0
	SK	20	10 " 9	0	0	0
	GN	11	18 " 15	9 [a]	0	0
	FN	0				
Largemouth bass	AN	20	15 " 10	0	0	0
	SK	5	40 " 28	0	0	0
	GN	3	67 " 35	33 [a]	0	0
	FN	0				
November						
Smallmouth bass	AN	20	65 " 14	0	0	0
	SK	0				
	GN	0				
	FN	0				
Largemouth bass	AN	4	0	0	0	0
	SK	0				
	GN	7	86 " 17	14 [a]	0	0
	FN	0				

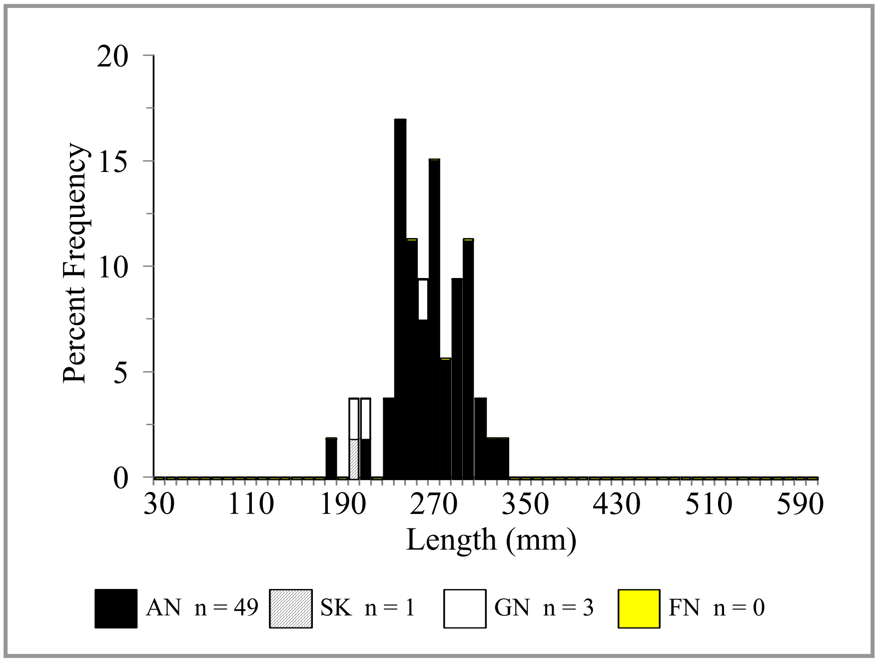
[a] Sample size too small or catch rates too variable to permit the calculation of reliable confidence intervals.

Smallmouth Bass

Among all sample periods, smallmouth bass total lengths ranged from 86 to 396 mm, excluding young-of-year. Length frequency distributions from April, August, and November indicate a preponderance of modest-size fish (Figures 2, 4, and 6). The most frequently captured size classes exceeded 200 mm TL. A large influx of young-of-year occurred by August, but these fish did not appear in our November sample.

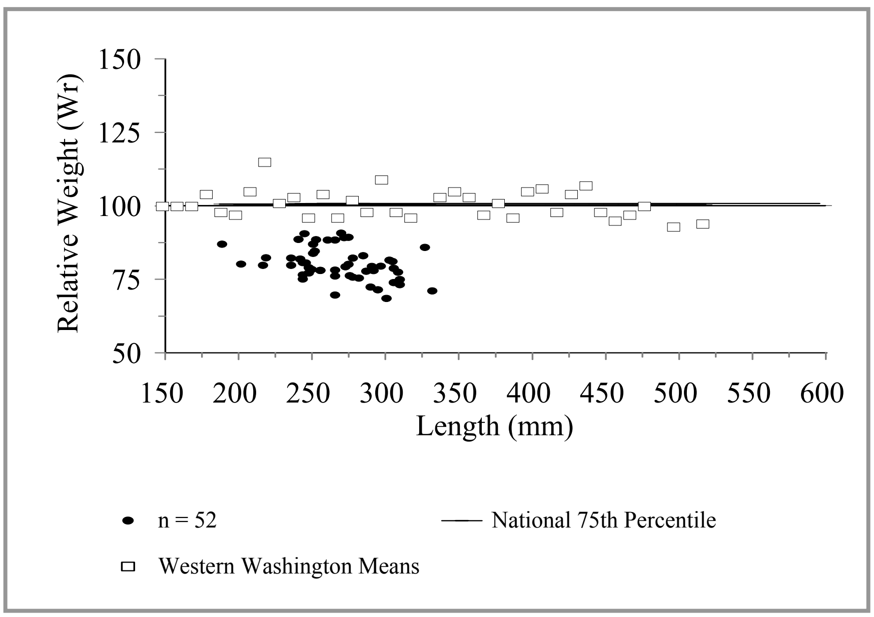
Relative weight values for smallmouth bass were generally below the national 75th percentile (W_r = 100) and the western Washington average for the species (Figures 3, 5, and 7). Relative weights decreased as length increased, indicating that larger fish were having more difficulty meeting their dietary needs than smaller fish. Seasonal changes were evident as well. Mean W_r values for April, August, and November were 80, 91, and 79, respectively. The below-average relative weights of smallmouth bass in April and November may be indicative of inefficient foraging, competition, the reduced forage base, or some combination of these factors (Anderson and Neumann 1996; Blackwell et al. 1999). Our companion diet study indicated a high degree of overlap in the diets of both bass species and among all size classes (Appendix B). The peak in August probably reflects increased metabolic activity and improved foraging during the growing season.

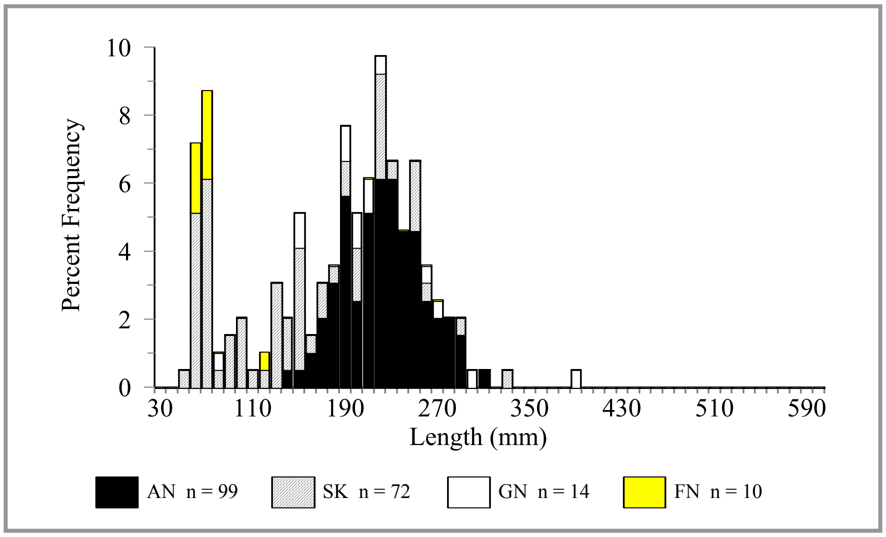
Smallmouth bass ranged in age from one to thirteen years old (Table 8). The median age was five years. The population had a high frequency of older fish; only ~ 10% of the fish sampled were aged between one and three years old. Of the other studies of western Washington lakes containing smallmouth bass available for comparison, none captured fish as old as the oldest fish captured in our study (13 years), although in one lake a 10-year-old smallmouth bass was captured (Downen and Mueller 2000b). Half of the lakes available for comparison did not have a smallmouth bass older than six years. Thus, the median age of Spencer Lake smallmouth bass was almost as old as the oldest fish captured in most western Washington Lakes. The lack of exploitation or harvest is the likely reason for the age structure observed at Spencer Lake, since anglers or other predators are not removing older, larger fish. Length at age back-calculations indicated slow growth in Spencer Lake smallmouth bass when compared to the western Washington average for the species. In fact, Spencer Lake smallmouth bass exhibited the slowest growth of any western Washington smallmouth bass population studied to date (first author, unpublished data).



AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 2. Length frequency histogram of smallmouth bass sampled from Spencer Lake (San Juan County) during April 2001.





AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 5. Length frequency histogram of smallmouth bass sampled from Spencer Lake (San Juan County) during August 2001.

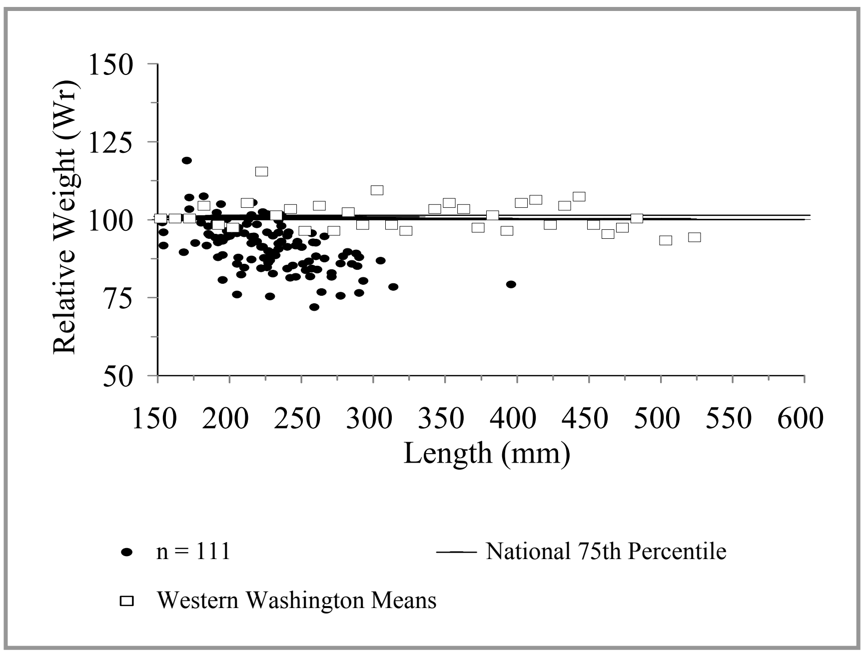
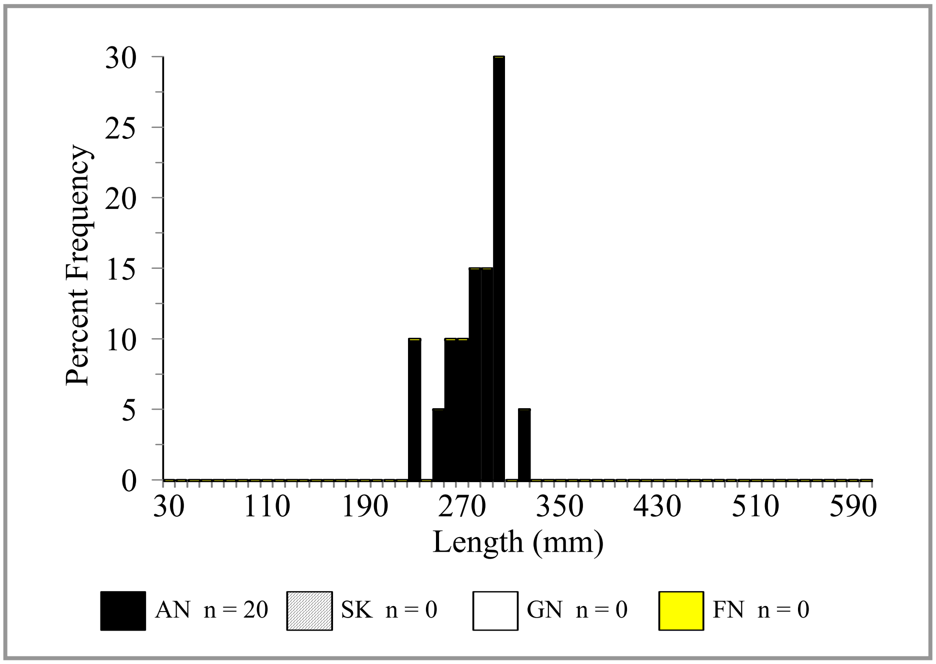


Figure 4. Relationship between total length and relative weight (*Wr*) of smallmouth bass from Spencer Lake (San Juan County) during August 2001 compared with means from up to three western Washington lakes and the national 75th percentile.



AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 7. Length frequency histogram of smallmouth bass sampled from Spencer Lake (San Juan County) during November 2001**.**

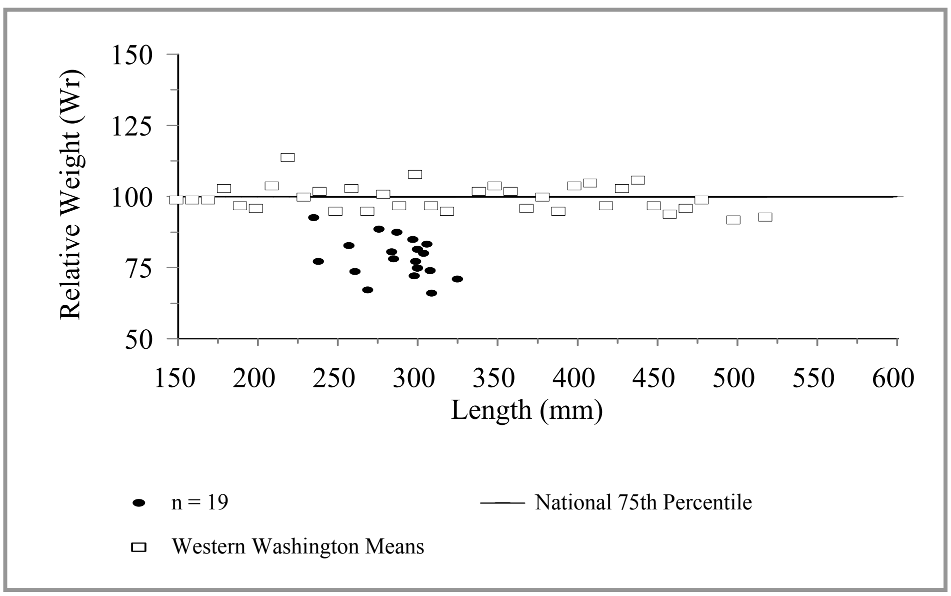


Figure 6. Relationship between total length and relative weight (Wr) of smallmouth bass from Spencer Lake (San Juan County) during November 2001 compared with means from up to three western Washington lakes and the national 75th percentile**.**

Table 8. Age and growth of smallmouth bass (*Micropterus dolomieu*) captured at Spencer Lake (San Juan County) during 2001.

Values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982) compared to averages from up to eight western Washington lakes (first author, unpublished data).

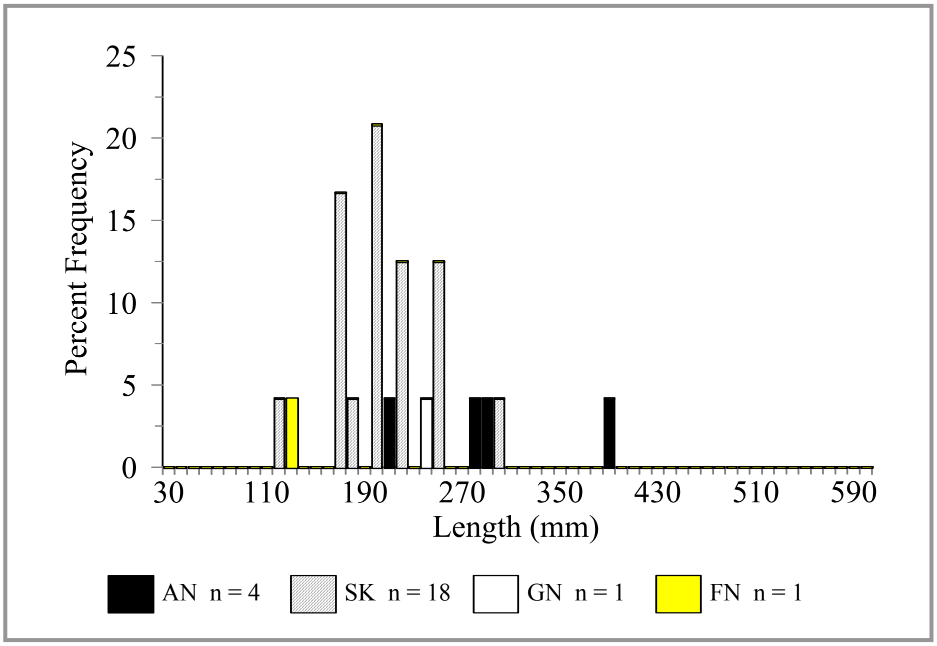
Year class	# fish	Mean total length (mm) at age												
		1	2	3	4	5	6	7	8	9	10	11	12	13
2000	2	68.2												
1999	1	70.2	114.6											
1998	10	96.6	139.5	129.6										
1997	18	78.6	124.3	154.4	180.3									
1996	23	75.4	121.6	163.0	192.6	214.5								
1995	20	74.9	119.5	163.1	194.6	218.5	239.9							
1994	15	76.1	121.8	166.2	201.5	229.2	249.6	268.3						
1993	23	73.4	119.7	161.8	194.1	222.2	246.2	264.2	280.0					
1992	7	68.2	102.1	140.7	176.3	203.6	231.7	250.9	268.2	281.1				
1991	5	73.5	110.3	142.7	175.4	210.2	240.3	271.9	293.6	307.1	317.0			
1990	0													
1989	0													
1988	1	73.6	133.4	179.8	218.4	251.2	272.4	299.5	320.7	338.1	353.5	369.0	378.6	388.3
Weighted mean		76.6	121.3	157.2	190.9	218.9	243.7	265.0	280.7	295.5	323.1	369.0	378.6	388.3
Western WA average		86.2	167.3	234.8	298.7	346.8	393.1	413.0	452.1	461.4	485.6	---	---	---

Largemouth Bass

Among all sample periods largemouth bass total lengths ranged from 109 to 422 mm, excluding young-of-year. Length frequency distributions from April, August, and November indicate a mix of small and modest-size fish (Figures 8, 10, and 12). Like smallmouth bass, the most frequently captured size classes (excluding young-of-year) exceeded 200 mm TL. A large influx of young-of-year occurred by August, but unlike smallmouth bass, these fish were also sampled in November.

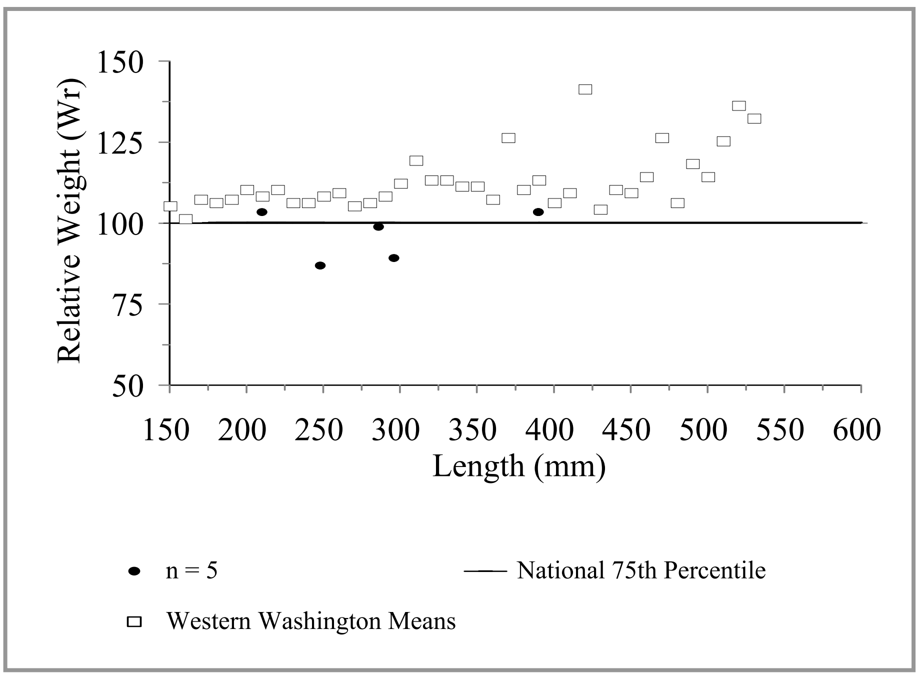
Relative weights for largemouth bass were generally below the western Washington average, but consistent with or above the national 75th percentile (Figures 9, 11, and 13). No largemouth bass captured had a W_r value < 82. Like smallmouth bass, seasonal changes in largemouth bass W_r were evident. Mean W_r values for April, August, and November were 96, 104, and 100, respectively. Again, the peak in August reflects improved foraging and increased metabolic activity during the growing season. However, in August, relative weight decreased as fish size increased. Still, largemouth bass are clearly not trophically challenged like their congeners. If low W_r in smallmouth bass was due to forage or competition factors, the latter were not affecting largemouth bass to the same degree.

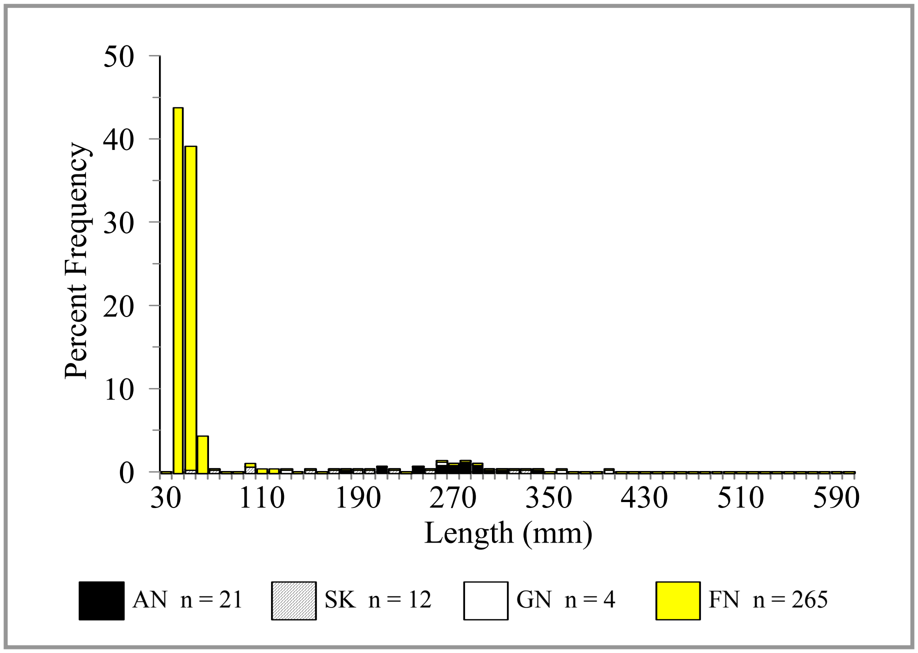
Largemouth bass ranged in age from one to ten years (Table 9). The median age was four years. Forty-percent of fish sampled were aged between one and three years old. Of the other western Washington lakes containing largemouth bass available for comparison, 24% had fish older than 10 years (first author, unpublished data), the age of the oldest fish caught in Spencer Lake. Unlike smallmouth bass, length at age back-calculations indicated that growth was similar to that of largemouth bass from other western Washington lakes; however, after age 4, growth decreased (Table 9). Thus, the two bass populations in Spencer Lake appear to be responding differently to the growth-limiting factors that occur in the lake.



AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

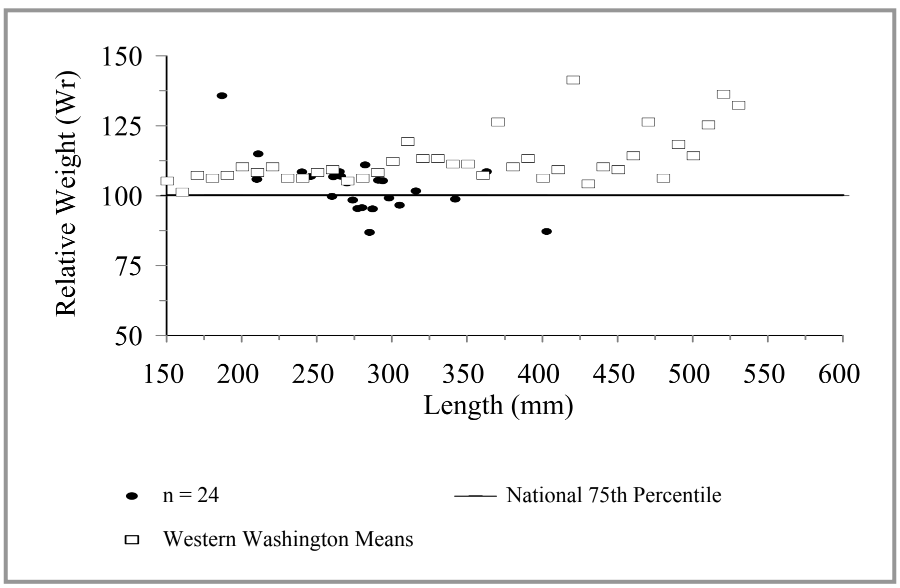
Figure 9. Length frequency histogram of largemouth bass sampled from Spencer Lake (San Juan County) during April 2001.

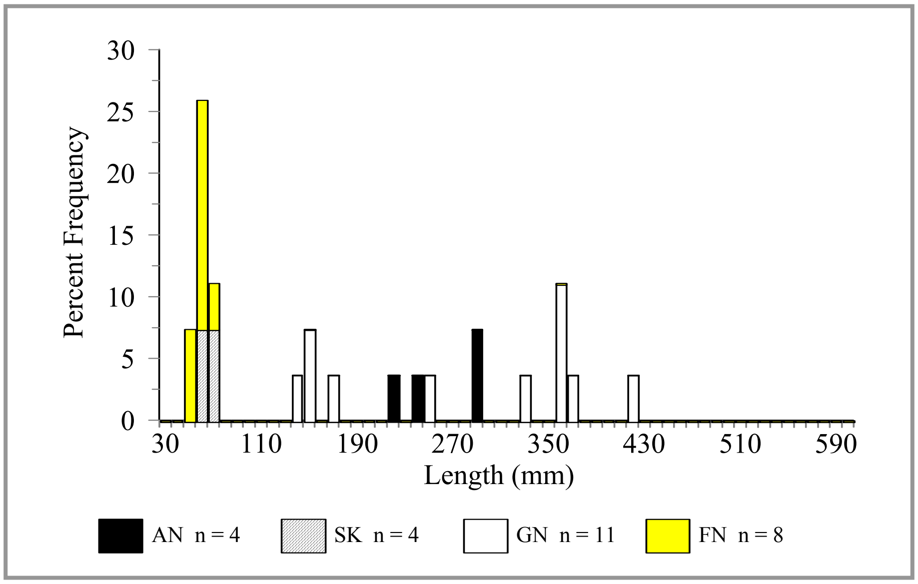




AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 10. Length frequency histogram of largemouth bass sampled from Spencer Lake (San Juan County) during August 2001.





AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 12. Length frequency histogram of largemouth bass sampled from Spencer Lake (San Juan County) during November 2001.

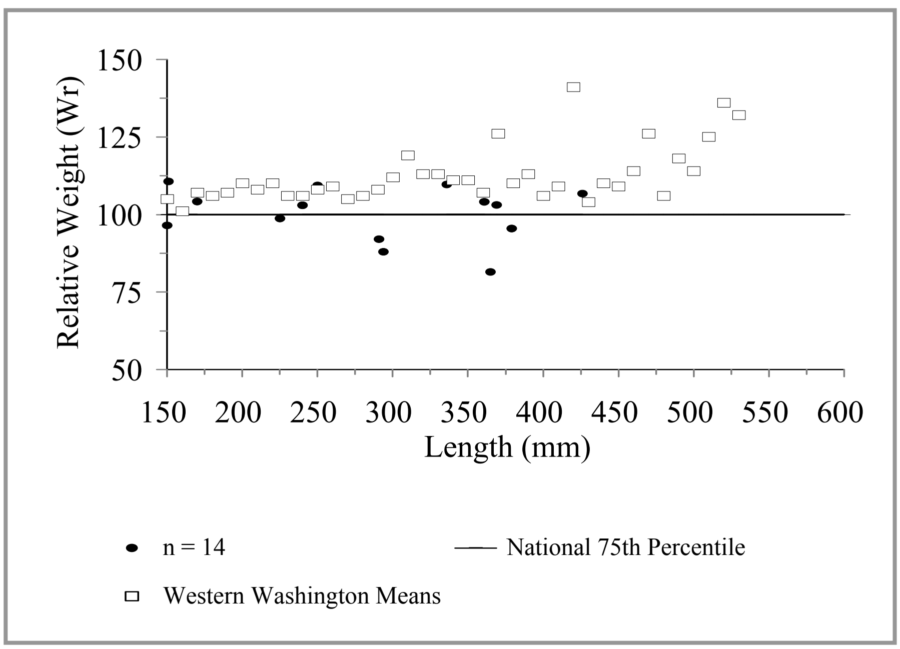


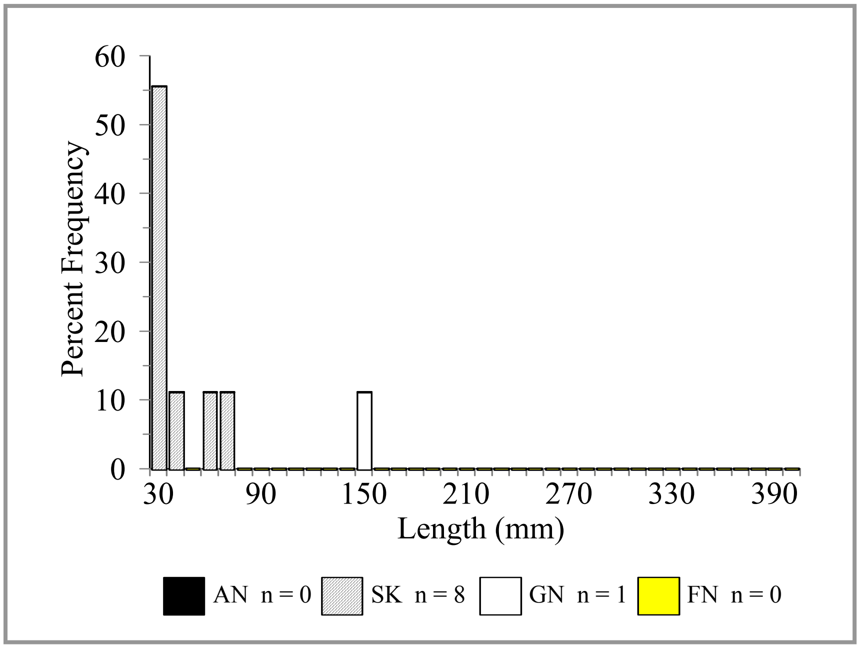
Figure 13. Relationship between total length and relative weight (Wr) of largemouth bass from Spencer Lake (King County) during November 2001 compared with means from up to 25 western Washington lakes and the national 75th percentile.

Table 9. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Spencer Lake (San Juan County) during 2001.
Values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982) compared to averages from up to 32 western Washington lakes (first author, unpublished data).

Year class	# fish	Mean total length (mm) at age									
		1	2	3	4	5	6	7	8	9	10
2000	8	64.7									
1999	5	67.8	143.8								
1998	6	76.9	159.5	231.8							
1997	15	74.8	159.3	221.0	265.0						
1996	4	75.4	169.0	249.3	298.0	324.3					
1995	5	65.7	126.1	186.4	231.3	260.0	275.7				
1994	1	77.4	161.4	225.8	290.2	325.2	343.4	360.2			
1993	3	70.6	135.6	208.3	271.1	300.9	330.9	358.2	369.0		
1992	1	70.0	131.7	182.9	238.7	280.6	324.8	359.7	378.4	390.0	
1991	1	64.4	118.3	153.2	206.0	246.2	261.0	294.8	305.4	317.0	325.4
Weighted mean		71.3	151.0	217.3	262.4	290.1	300.0	348.2	358.1	353.5	325.4
Western WA average		82.1	153.7	207.7	262.0	309.9	356.7	383.9	397.4	424.8	442.8

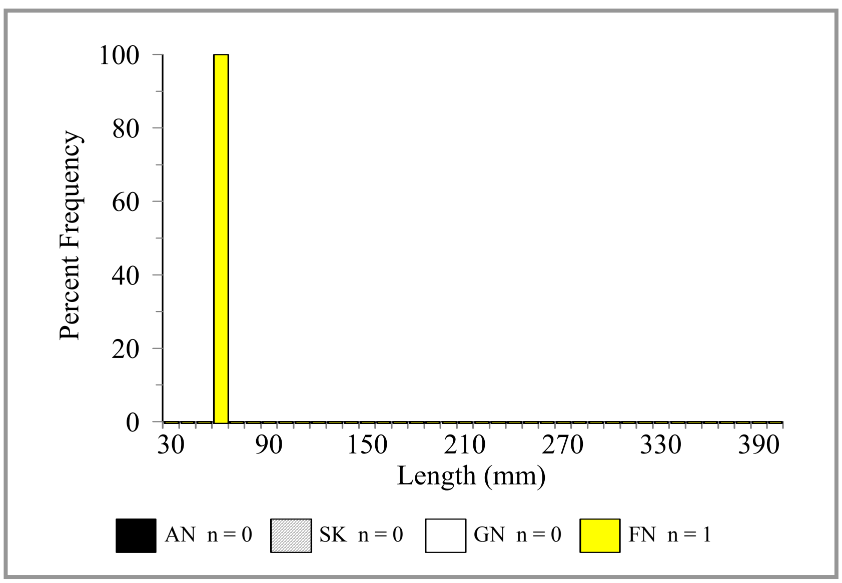
Prickly Sculpin

A total of 12 prickly sculpin, ranging in size from 20 to 162 mm TL, were observed or collected while scuba diving/snorkeling and gillnetting (Figures 14, 15, and 16). Fish were aged up to five years, with most year classes being represented (Appendix C).



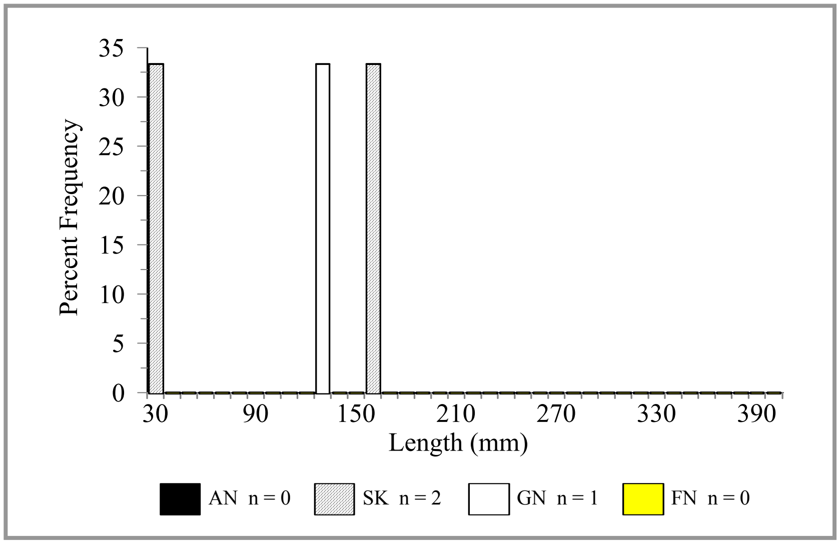
AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 14. Length frequency histogram of prickly sculpin sampled from Spencer Lake (San Juan County) during April 2001.



AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 15. Length frequency histogram of prickly sculpin sampled from Spencer Lake (San Juan County) during August 2001.



AN = angling, SK = scuba diving/snorkeling, GN = gill netting, and FN = fyke netting.

Figure 16. Length frequency histogram of prickly sculpin sampled from Spencer Lake (San Juan County) during November 2001.

Exploitation

Few studies have been conducted on unexploited fish populations. However, several trends have been noted in a variety of species, including largemouth and smallmouth bass (Goedde and Coble 1981, Reed and Rabeni 1989, Kocovsky and Carline 2001). For example, a smallmouth bass population that had been unexploited for over 20 years exhibited slow growth (Reed and Rabeni 1989). Furthermore, a walleye population that had been unexploited for 64 years exhibited slow adult growth while the juveniles exhibited excellent growth (Kocovsky and Carline 2001). Unexploited or underfished populations typically have a high density of stunted, middle-aged fish that experience slow growth (Bennett 1962). We observed this pattern in both bass species at Spencer Lake, although growth of largemouth bass did not appear to decline until after age 4, which was similar to the findings of Kocovsky and Carline (2001) who found that walleye displayed slow growth only as adults. The lack of exploitation in Spencer Lake is undoubtedly shaping the bass populations, but appears not to be the sole factor affecting them. It should be noted that harvest is not entirely absent – kingfishers, blue herons, osprey, and eagles have all been observed around the lake and could be predators on certain size classes. Eagles have been directly observed eating bass from the lake (personal observations; Tim Nelson, SPU, personal communication).

Water Quality

Water quality data from all three sampling periods is summarized in Table 10. April water temperatures ranged from 11.9° C at the surface to 4.3° C near the bottom of the lake. During spring, the thermocline appeared at ~ 6 m. However, the lake was only slightly stratified with respect to dissolved oxygen (range = 7.3 – 9.4 mg/L), and pH levels (~ 8.0) were uniform throughout the water column. August water temperatures ranged from 20.4° C at the surface to 4.6° C near the bottom of the lake. The summer thermocline was also at ~ 6 m. Again, the lake was only slightly stratified with respect to dissolved oxygen (range = 6.1 – 7.7 mg/L), and pH levels (~ 8.0) were uniform throughout the water column. Water temperatures in November ranged from 9.9° C at the surface to 5.0° C near the bottom. During fall, the thermocline was 'pushed down' to 10 m. Dissolved oxygen levels fell, ranging from 3.7 to 4.9 mg/L, while pH held steady at ~ 8.0.

Smallmouth and largemouth bass in Spencer Lake are subjected to a short growing season due to slow warming of the lake. The optimal temperature for smallmouth bass is between approximately 21° C and approximately 26.7° C (Wydoski and Whitney 1979) and between 26.5 and 30.9° C for largemouth bass (Cincotta and Stauffer 1984). Below 10° C, largemouth bass become fairly inactive (Wydoski and Whitney 1979). In Spencer Lake, water temperatures above 10° C have been recorded within the first two weeks of April in 1996, 1997, and 1998 (third author, unpublished data). By the end of April, water temperature is usually above 12° C. However, in 1999, water temperature was only 8.9° C by mid-April, but warmed to 12.9° C by the end of the month. Between 1996 and 1999, surface temperatures above 15° C were never recorded before the beginning of May. In 1996 and 1999, surface temperatures were not recorded above 15° C until the last week of May. Data beyond May is only partially available, though in 1996 surface temperature as of the last week in June was only 18.6° C. While these temperatures are below the preferred temperatures favored by both species, they are comparable to temperatures observed in other western Washington Lakes (Mueller 1998 a, b; Mueller 1999; Downen and Mueller 2000b). Although the preferred temperature range of smallmouth bass is closer to the temperatures observed in Spencer Lake, smallmouth bass growth and relative weights appear to be more detrimentally affected than the largemouth bass.

Table 10. Water quality at Spencer Lake (San Juan County) during 2001. Samples were collected mid-afternoon from over the deepest part of the lake. TDS = total dissolved solids, DO = dissolved oxygen.

Date	Secchi depth (m)	Depth (m)	Temperature (EC)	pH	TDS (g/L)	Turbidity	DO (mg/L)	Conductance (µS/cm)
April 19	5.7	Surface	11.87	7.96	0.1303	0	8.44	203.6
		1	11.45	8.08	0.1301	0	8.78	203.6
		3	10.29	8.17	0.1301	0	9.17	203.1
		6	7.47	8.18	0.1306	0	9.37	204.3
		9	5.50	8.08	0.1298	0	8.87	202.4
		12	4.61	8.03	0.1302	0	8.93	203.2
		15	4.41	7.94	0.1301	0	8.66	203.1
		18	4.29	7.83	0.1299	0	8.29	202.5
		20	4.30	7.87	0.1298	0	7.28	204.0
August 2	6.4	Surface	20.37	8.10	0.1436	0.5	6.13	224.1
		1	20.28	8.30	0.1434	0	6.13	229.1
		3	20.37	8.43	0.1431	0	6.21	223.7
		6	15.91	8.40	0.1382	0	7.71	217.3
		9	7.56	8.19	0.1379	0	7.43	216.2
		12	5.24	8.05	0.1376	0.1	6.73	214.9
		15	4.64	8.00	0.1371	0	6.59	214.0
November 15	9.3	Surface	9.87	8.22	0.1322	0	4.79	206.3
		1	9.86	8.17	0.1323	0	4.62	206.3
		3	9.75	8.13	0.1326	0	4.65	206.7
		6	9.67	8.10	0.1324	0	4.74	207.1
		9	9.58	8.08	0.1325	0	4.86	207.0
		12	5.75	7.87	0.1305	0	4.19	204.0
		15	5.03	7.79	0.1308	0	3.86	204.1

Young-of-Year and Cannibalism

Largemouth bass normally undergo a niche shift in their first summer, switching from feeding on invertebrates to feeding on other small fishes (Olson 1996), though cannibalism has also been observed (Johnson and Post 1996). Marked increases in growth have been observed in largemouth bass young-of-year that switch to piscivory versus those that do not (Aggus and Elliot 1975). Largemouth bass young-of-year survival and over-winter survival is also linked to size (Gutreuter and Anderson 1985; Olson 1996). The lack of other fish species in Spencer Lake limits piscivory and therefore may delay or preclude any niche shifts.

It was originally hypothesized that cannibalism might be a principle force shaping the bass populations in Spencer Lake. Cannibalism is well-documented in smallmouth bass and the lack of forage fish in the lake could shift piscivory towards this feeding mode (Dong and DeAngelis 1998). Consumption of young-of-year bass by young-of-year congeners could be occurring, though this would require separate early and late-spawning cohorts. Smallmouth bass normally spawn in water about 2° C cooler than largemouth bass, which might allow smallmouth bass to prey on later-emerging largemouth bass. The significant decrease in catch rates of young-of-year between August and November ostensibly supports this hypothesis, if it were not for the fact that confirmed bass tissue was found in < 2% of all stomachs sampled in our diet study (Appendix B). Though sampling error could account for the difference in catch rates of young-of-year bass between August and November, forage shortages and cool temperatures are more likely responsible for young-of-year mortality.

Lack of Forage Due to Competition and a Reduced Forage Base

Three forage-related conditions may be affecting growth and relative weight in Spencer Lake bass. First, diet analysis revealed a high degree of overlap between both species and all size classes (Appendix B). Second, except for prickly sculpin, there are no large prey items such as panfish or crayfish for the bass to feed on. Third, cannibalism does not appear to be a common behavior in either species. Large fish therefore lack access to their preferred forage base of panfish and crayfish and are instead consuming items that are normally utilized only by smaller size classes (Olson et al. 1995). Slow adult growth of smallmouth bass might be attributed to the lack of a sufficiently large forage base *sensu* Emery (1975). As noted above, young-of-year may also be facing a lack of forage. Bass in Spencer Lake may therefore be facing forage shortages throughout the course of their life. Largemouth bass growth in the first four years, however, appears to be normal and growth may not slow until later in life. Young fish would therefore be foraging effectively while older, large fish are having more difficulty meeting their caloric needs. This is supported by the trend of W_r decreasing as fish length increases.

Conclusion

The Spencer Lake smallmouth bass population appears to resemble other unexploited populations. The Spencer Lake largemouth bass population also resembles other unexploited populations, with slow adult growth and the presence of old individuals. There is, however, a deficiency in the older size classes and 24% of western Washington lakes available for comparison had largemouth bass older than the oldest fish captured in Spencer Lake. The Spencer Lake largemouth bass age structure therefore bears similarities to both unexploited and exploited populations. The lack of large fish in both populations may be attributed to slow growth or sampling error. Other factors, such as disease, heavy parasite loads, or high levels of bird predation may be shaping the populations.

The two bass populations appear to be responding to the harvest, temperature, forage, or other population structuring conditions of Spencer Lake quite differently. These differences are enigmatic, since temperatures in Spencer Lake though not ideal, favor smallmouth bass and whatever harvest does occur should be biased toward smallmouth bass. Young-of-year of both populations should also experience food shortages their first year because of the lack of other fish species to prey on. Given the differences in W_r and growth in the young size classes between the two populations, we propose that the population difference may be due to differences in foraging behaviors, energetic expenses, or temperature tolerance. In predator-crowded systems, largemouth bass exhibit more of an opportunistic feeding style (Bonar et al. 1994) and may be more suited to the forage conditions of Spencer Lake. The length of time these populations have been isolated and undisturbed may have also led to inbreeding suppression, genetic drift, or adaptation, contributing to the observed differences between the two populations.

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Appendix A.

Appendix A. Biological data and gut content analysis of largemouth bass *Micropterus salmoides* sampled from Spencer Lake, Blakely Island in June 1980 (source: Seattle Pacific University, Department of Biology, Blakely Island Field Station files).					
Gear type	**Length (mm)**	**Weight (g)**	**Sex**	**Age**	**Gut contents (%)**
Trap (2 hr)	83	7.4	Unknown	1 +	Insect larvae (100)
Trap (2 hr)	114	24.0	Unknown	2 +	Broken down food (95); detritus (5)
Angling	195	119.0	Male	1 +	Miscellaneous aquatic insects (50); detritus (50)
Angling	205	128.8	Male	2 +	Miscellaneous aquatic insects (100)
Angling	224	163.0	Male	3 +	Trichoptera larvae (50); detritus (50)
Angling	226	168.5	Male	4 +	Miscellaneous insects (100)
Angling	233	176.6	Male	3 +	Detritus (75); Trichoptera larvae (15); Damselflies (10)
Angling	238	180.6	Female	1 +	Miscellaneous insects (50); detritus (50)
Angling	243	178.6	Male	3 +	Carpenter ants (100)
Angling	258	232.7	Male	3 +	Prickly sculpin (100)
Angling	269	263.8	Male	5 +	Trichoptera cases (80); Trichoptera larvae (20)
Angling	288	360.5	Male	5 +	Trichoptera cases (90); Trichoptera larvae (5); damselfly nymph (5)
Angling	290	318.2	Male	6 +	Carpenter ants (100)
Angling	296	395.0	Female	6 +	Trichoptera cases (80); Trichoptera larvae (15); damselfly nymphs (5); tapeworms
Angling	303	445.6	Female	7 +	Tapeworms (100)
Angling	313	436.0	Female	7 +	Tapeworms (90); Trichoptera larvae (5); detritus (5)
Angling	314	336.1	Male	6 +	Carpenter ants (100)
Angling	318	473.4	Female	5 +	Prickly sculpin (100)
Angling	332	472.0	Male	7 +	Carpenter ants (100)

Appendix B

2001 companion study examining smallmouth and largemouth bass diets from Spencer Lake, Blakely Island.

Diet Analysis of Smallmouth Bass (*Micropterus dolomieu*) and Largemouth Bass (*Micropterus salmoides*) from Spencer Lake, Blakely Island, Washington

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ABSTRACT

Diet and age studies were performed on smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*) captured in Spencer Lake, Washington. The lake was sampled in April, August, and November 2001 to observe any seasonal variation. Spencer Lake is known to lack common forage items like bluegill and crayfish, thus limiting the possible forage base for the bass. We hypothesized that this could result in cannibalism, stunted growth rates and utilization of unique food sources for the bass. Instances of cannibalism were extremely rare and occurred in only 2 of the 183 fish sampled. The primary prey choices of both species were a wide variety of insects and prickly sculpin (*Cottus asper*). There was no correlation found between size of the bass and prey choice. The growth rates of the bass were slower than state averages for both species, but more pronounced in the smallmouth bass.

INTRODUCTION

Spencer Lake is a small 29.2-hectare oligo-mesotrophic, monomictic lake located on Blakely Island in the San Juan Archipelago in northern Puget Sound. The lake is separated into a large deep basin (23 m max depth) and a small shallow basin (4 m max depth). The bottom substrate in the deeper basin generally consists of rock and woody debris, while the shallow basin has a significantly softer bottom and has a higher density of macrophytes. Surface temperatures in the summer range from about 15-20 °C. Spencer Lake is fed mostly by runoff from its steep, glacier-carved watershed. Human impact on the lake is very low and over 95% of the shoreline remains undeveloped.

The lake has historical significance because it was stocked with smallmouth bass (*Micropterus dolomieu*) in 1922, the first ever plant of that species on record in Washington State. Largemouth bass (*Micropterus salmoides*) were stocked at a later unknown date. The only other species currently present in the lake is the native prickly sculpin (*Cottus asper*). Spencer Lake is different from many lakes in Washington because crayfish and forage fish such as bluegill, a common prey base for bass, are not present.

Dong and DeAngelis (1998) demonstrated that juvenile bass occasionally resort to cannibalism when food is scarce. We hypothesized that there would be a good chance of detecting cannibalism in Spencer Lake bass because of the limited forage base. We also hypothesized that the bass would display slower than average growth due to the limited forage base.

METHODS

The Spencer Lake survey was conducted collaboratively between Seattle Pacific University and the Washington State Department of Fish Wildlife (WDFW). Sampling took place over three four-day sessions in April, August, and November 2001. Three gear types were used to capture fish: standard gill nets, standard fyke nets, and angling. The shoreline of the lake was divided into 11 400-m sections as determined from a map. When possible, multiple gear types were used at each location. Both types of nets were set during the late evening and retrieved the following morning. When angling was used, angling pressure was applied evenly over a fifty-minute period to an entire 400-m section.

Captured fish were anesthetized in a 3ml/L, 10% clove oil: 90% ethanol solution. The fish were identified to species, weighed to the nearest 0.5 grams, and measured to the nearest millimeter. Scale samples were taken from the fish for aging purposes. Stomach contents were removed using a gastric lavage system (Light et al. 1983). Fish were released into the same section in which they were captured.

The contents of the stomach were filtered with a wire screen and then separated and weighted (wet weight) with respect to the following categories: fish (to species level), insect[1], mollusk, amphibian, plant, and other. Analysis of the diet was performed with respect to differences in both length and species of bass.

Scales were analyzed by the WDFW warmwater aging unit using standard annulus measurement and back calculation techniques. Age data gathered from the scales were compared to state averages to examine overall growth as indicated by length at age.

[1] The category "insect" also includes some small crustaceans such as *Daphnia*.

RESULTS

Gut contents from 135 smallmouth bass and 48 largemouth bass were analyzed over the course of the study. The largemouth bass ranged from 109 to 426 mm and had a mean total length (TL) of 262.7 mm. The smallmouth bass ranged from 86 to 332 mm and had a mean total length of 227.8 mm. Hundreds of small young of year (YOY) bass were also captured in the fyke nets in August and in November, but they are not included in this study because of the difficulty to examine their stomach contents. Olson (1996) observed that these fish feed almost exclusively on small crustaceans.

In each of the sampling periods, insects were the most common prey item for both largemouth and smallmouth bass. Prickly sculpin was the second most common prey for both species, however it was much more common in largemouth bass. In November, there was a significant increase in the number of fish with empty stomachs for both species of bass. Table 1 shows the seasonal variation in the presence of the various food categories. Figures 1-6 show the most common food item found (by weight per individual fish) for each of the different periods. Cannibalism occurred in only 2 instances and both were in August (one 260-mm largemouth bass and one 184-mm smallmouth bass each had a YOY largemouth bass in their gut). We found no significant variation of prey choice in relation to the size of the predator. This analysis was difficult because of small sample sizes (especially during April and November). Figure 7 shows the similarity in prey choices for smallmouth bass less than 250 mm TL and those greater or equal to 250 mm TL during August.

As expected, we found that the bass in Spencer Lake exhibited slower than average growth when compared to other western Washington lakes (Figures 8 and 9). The largemouth bass were very close to the state average until about 4 years of age. The smallmouth bass were significantly behind the state averages in every age class. It should be noted that the averages for smallmouth bass are gathered from only a few lakes and might not represent a fair average for the area.

DISCUSSION

In lakes with numerous and abundant prey choices, the diets of largemouth and smallmouth bass have been shown to shift from aquatic insects, small fish and crayfish to predominately larger fish and crayfish as the bass get larger (Pflug and Pauley 1984). We found no major variation in the diet composition of bass of different sizes in Spencer Lake. The typical dominant prey items of bass in lakes with high bass growth are not present in Spencer Lake. In some crowded lakes, smaller bass have been shown to cannibalize regularly (Quan et al. 1998). This study found cannibalism among young bass to be rare in Spencer Lake, for it occurred in only 2 out of the 183 stomachs examined.

Predator-crowded systems, such as Spencer Lake, commonly support fish with below average growth rates (Bonar et al. 1994). The growth rates of the smallmouth bass that we found in Spencer Lake were lower than those found in many other lakes in western Washington. Interestingly, largemouth bass growth was average for younger and middle aged fish, but slowed as the bass aged. We propose that the slow growth rates found in this study are a direct result of a limited forage base.

ACKNOWLEDGMENTS

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TABLE 1. Gut content analysis (% presence) of largemouth and smallmouth bass *Micropterus* spp. sampled from Spencer Lake, Blakely Island in 2001.

Species	Date	Fish	Insect	Mollusk	Plant	Amphibian	Other	Empty
Largemouth bass	April (n=6)	0.50	0.67	0.17	0.33	0.17	0.17	0.17
	August (n=27)	0.56	0.48	0.26	0.11	0.00	0.00	0.26
	November (n=15)	0.27	0.47	0.07	0.13	0.07	0.00	0.40
Smallmouth bass	April (n=42)	0.33	0.71	0.10	0.05	0.07	0.07	0.05
	August (n=74)	0.31	0.68	0.09	0.12	0.00	0.05	0.24
	November (n=19)	0.11	0.42	0.05	0.05	0.00	0.05	0.47

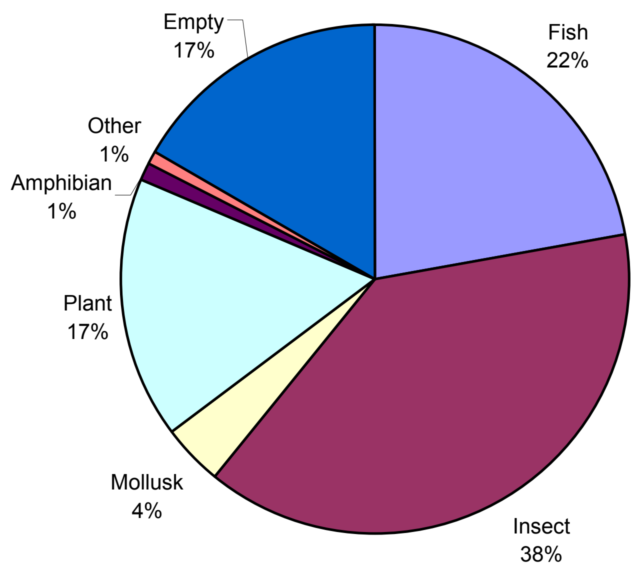

FIGURE 1. Summary of largemouth bass stomach contents by mass from Spencer Lake, Blakely Island, April 2001 (n=6).

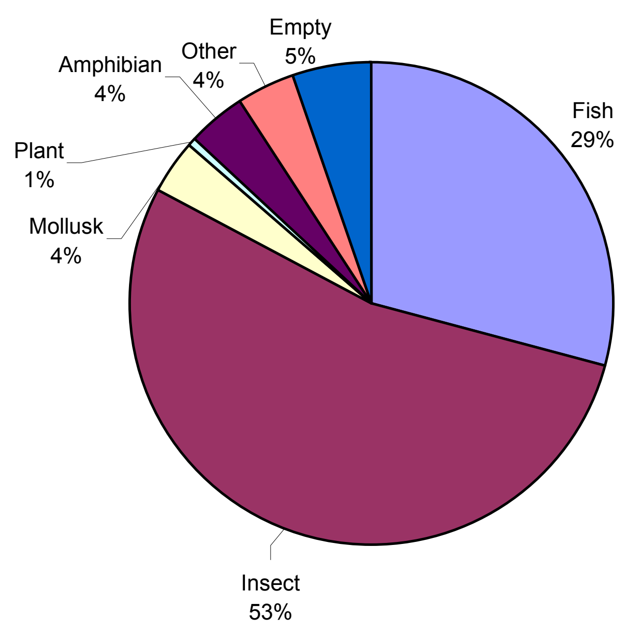

FIGURE 2. Summary of smallmouth bass stomach contents by mass from Spencer Lake, Blakely Island, April 2001 (n=42).

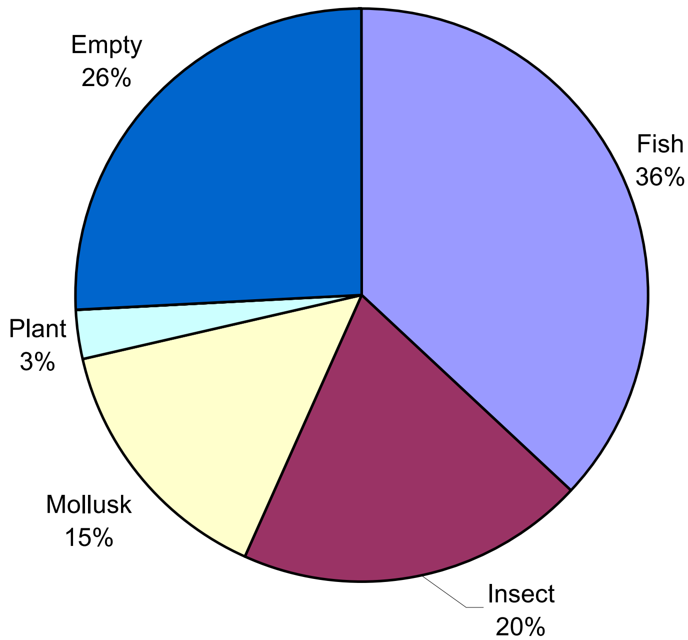

FIGURE 3. Summary of largemouth bass stomach contents by mass from Spencer Lake, Blakely Island, August 2001 (n=27).

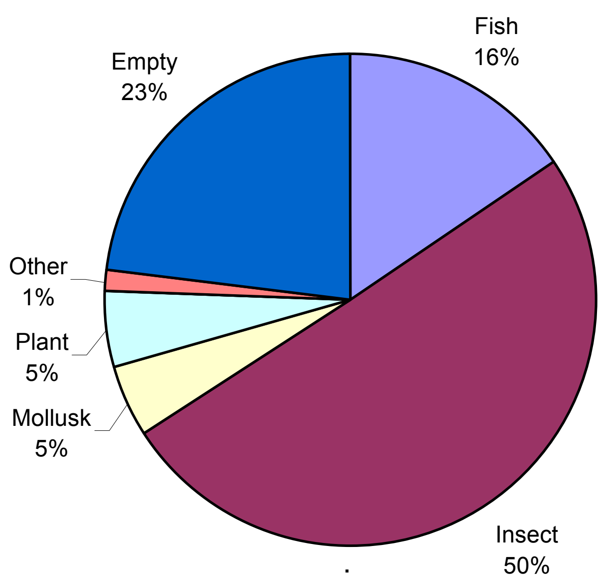

FIGURE 4. Summary of smallmouth bass stomach contents by mass from Spencer Lake, Blakely Island, August 2001 (n=74).

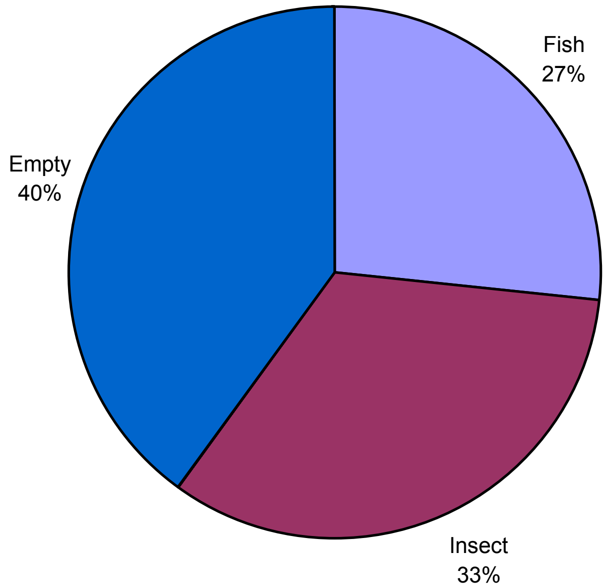

FIGURE 5. Summary of largemouth bass stomach contents by mass from Spencer Lake, Blakely Island, November 2001 (n=15).

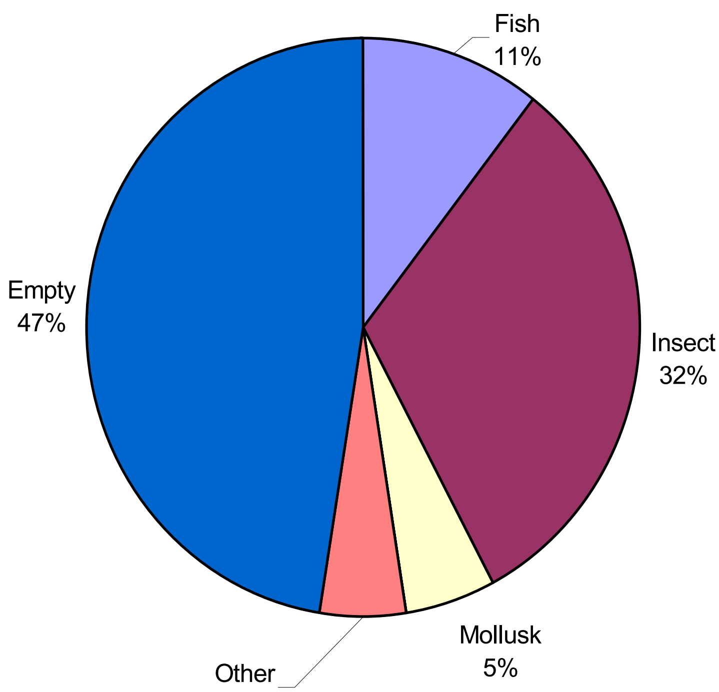

FIGURE 6. Summary of smallmouth bass stomach contents by mass from Spencer Lake, Blakely Island, November 2001 (n=19).

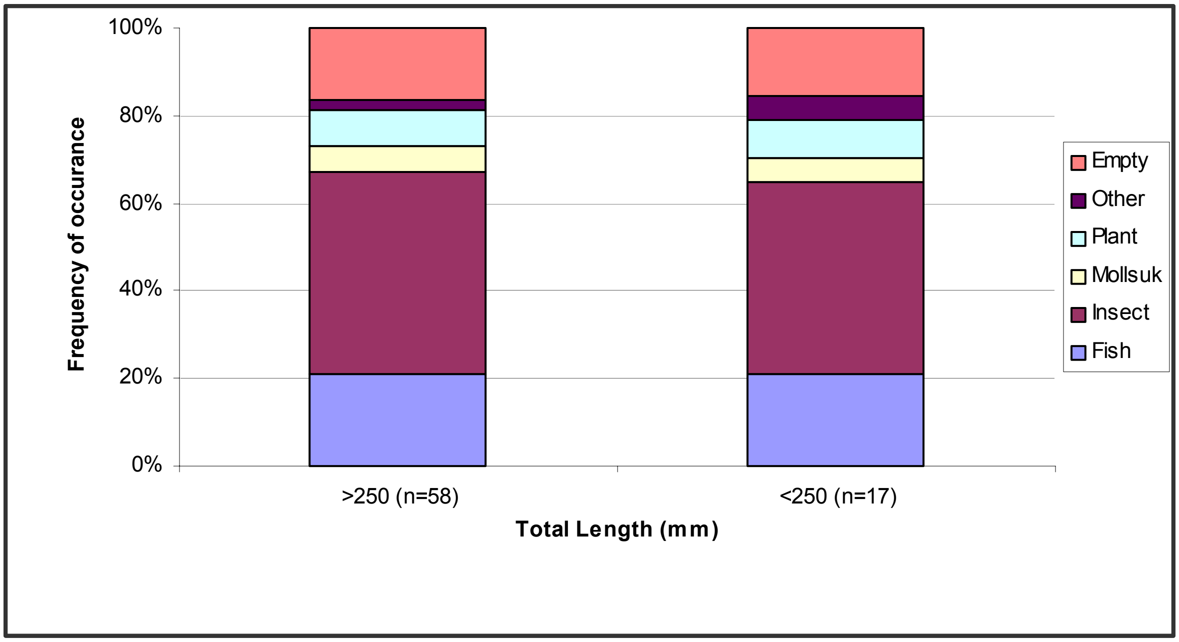

FIGURE 7. Frequency of diet items present in Spencer Lake smallmouth bass captured in August 2001 in relation to total length of the fish.

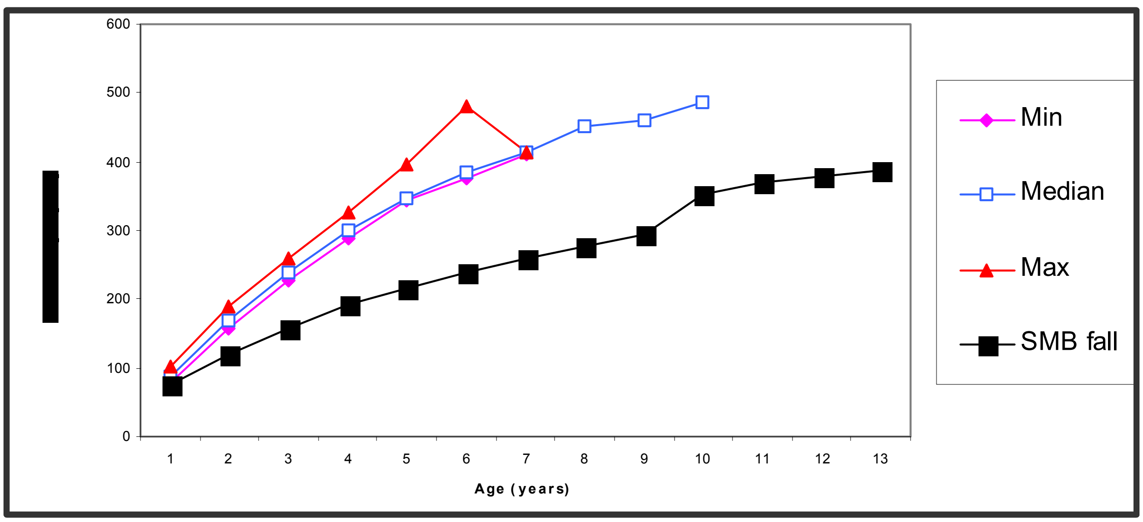

FIGURE 8. Growth of smallmouth bass collected from Spencer Lake, Blakely Island in 2001 compared to Washington State averages.

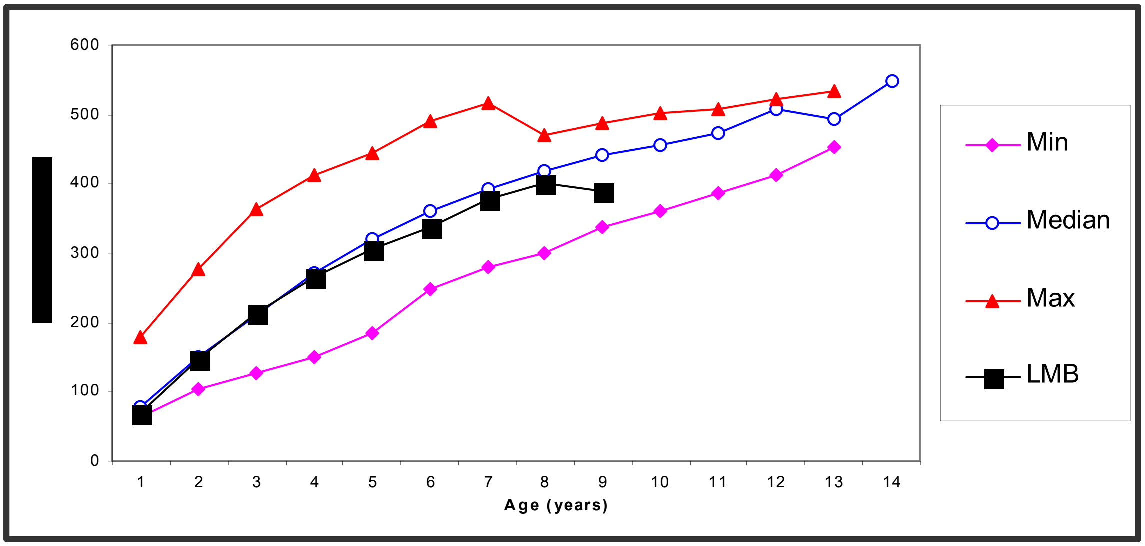

FIGURE 9. Growth of largemouth bass collected from Spencer Lake, Blakely Island in 2001 compared to Washington State averages.

Appendix C

Appendix C. Comparison of ages (years) of prickly sculpin *Cottus asper* (COT), largemouth bass *Micropterus salmoides* (LMB), and smallmouth bass *M. dolomieu* (SMB) sampled from Spencer Lake, Blakely Island during 2001 using three techniques (scales, surfaces of otoliths, and the break-and-burn method of reading otoliths).

			Otoliths		
Species	**Total length (mm)**	**Scales**	**Surface**	**Break-and-burn**	**Comments**
COT	103		4	5	Found in gut of SMB
	135		2	4	Found in gut of LMB
	140		3	6	Found in gut of LMB
	156		5	6	
	162		5	4	
LMB	113	1	1		
	130	1	1		
	138	2	2	2	
	210	3	3	3	
	248	4	4	4	
	250	6	4	3	
	287	4	4		
	363	7	7		
	369		6	6	
	375	4	7	9	
SMB	219	6	5	6	
	226	5	6		
	235	5	6		
	251	9	11	12	
	257		6		
	266	6	6	7	
	305	5	10		
	325	8	8	9	
	327		7	10	
	332		7	11	
			8	10	From head found diving