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Characteristics of Unexploited Black Bass Populations from a Remote Lake in the San Juan Archipelago, Washington

Abstract

Unexploited fish populations provide a valuable reference point for understanding exploited populations, but are relatively rare. In this paper, we describe the characteristics of unexploited black bass populations from Spencer Lake, a remote, oligotrophic body of water located on Blakely Island, Washington which contains only three species of fish (smallmouth bass, largemouth bass, and prickly sculpin) and has no public access. We used a variety of active and passive sampling techniques (angling, diving, gill netting, and fyke netting) to collect or observe fish during spring, summer, and fall 2001. Data on the size and age structure, and condition of smallmouth bass and largemouth bass are provided. The black bass populations at Spencer Lake are similar to some unexploited populations (small to moderate size fish, slow growth, and presence of old fish in poor condition) but differ from others, in particular those having a high proportion of large individuals. Our results indicate that smallmouth bass and, to a lesser degree, largemouth bass are not reaching their full growth potential, which may be due to several factors, including inadequate food supply, low lake productivity, and inter- or intraspecific competition.

Introduction

Data on the size structure, age composition, patterns of individual growth and condition, and other characteristics of recreationally exploited fish populations, as well as the magnitude of human impacts on these characteristics, are vital for management and conservation and necessary to optimize populations for angler enjoyment. The study of unexploited populations provides a valuable basis for comparison, may indicate the potential size, age structure, and maximum age of the species of interest, and can be used as a foundation for management decisions (Toetz et al. 1991; Hillborn and Waters 1992; Paukert and Willis 2001).

The group of sportfish commonly referred to as black bass (*Micropterus* spp.) is comprised of seven species from the family Centrarchidae and includes smallmouth bass (*M. dolomieu*) and largemouth bass (*M. salmoides*) (Kassler et al. 2002). Black bass are highly prized and are the most sought-after group of freshwater fishes in the United States. In Washington, approximately 15% of all freshwater anglers target black bass (U.S. Fish and Wildlife Service 2003), and more than 40% of all U. S. freshwater anglers fish for black bass (Pullis and Laughland 1999). The widespread distribution and perennial popularity of black bass have fostered intense management and study (Noble 2002). However, despite the breadth of black bass research (e.g., Philipp and Ridgway 2002), few unexploited systems have been studied (Clady et al. 1975; Goedde and Coble 1981; Reed and Rabeni 1989; Schindler et al. 1997), and none have been examined in Washington.

Management of black bass fisheries in the Pacific Northwest would benefit from a greater knowledge of unexploited populations (*sensu* Hillborn and Walters 1992). Thus, the primary purpose of this study was to evaluate the size, age structures, and condition of unexploited smallmouth bass and largemouth bass populations from a remote western Washington lake. Furthermore, we describe some differences between the two populations and contrast our findings with those of researchers who have studied unexploited fish populations elsewhere.

Methods

Study Site

The study was conducted at Spencer Lake, a modest-sized (28 ha) body of water centrally

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located (48° 33.357' N, 122° 48.245' W) on Blakely Island in the San Juan Archipelago, Washington. Public access to Blakely Island is limited to a marina and short airstrip located at the north end of the island. Except for several private residences around the marina, the island is largely wooded and natural. Development on Spencer Lake is limited to one private, part-time residence and a seasonal biological teaching facility along the SW and SE shores, respectively. Seattle Pacific University (SPU) owns and operates the latter, which includes one full-time residence. There is no public access to Spencer Lake.

Spencer Lake is fed by precipitation, groundwater, and intermittent overflow from Horseshoe Lake, which is located above and northwest of Spencer Lake. The mean and maximum depths of Spencer Lake are 13.3 and 22.7 m. Shoreline length is 3.7 km. The lake is oligotrophic and surface water drains into Puget Sound through a small dam designed to generate electricity for SPU's biological field station. The dam is located at the west end of the lake.

Smallmouth bass were first introduced into Spencer Lake during the 1920s. The lake is recognized for having the oldest lentic population of smallmouth bass in Washington (Wydoski and Whitney 2003). In June 1980, SPU conducted a rudimentary study of Spencer Lake's fish resources and found that the only other resident fish species were largemouth bass and native prickly sculpin (*Cottus asper*). Gut content analysis of 19 largemouth bass (size range = 83 – 332 mm total length) revealed that aquatic and terrestrial insects comprised the majority of largemouth bass diet. The origin of the introduced population of largemouth bass is unknown. Because of Spencer Lake's remoteness, protection by trespass laws, and lack of measurable harvest, we qualified its black bass populations as unexploited. Similar criteria have been used (e.g., Clady et al. 1975; Toetz et al. 1991) to describe other unexploited fish populations elsewhere.

Sample Collection

Spencer Lake was surveyed during the spring (April 18-20), summer (August 3-5), and fall (November 14-16) of 2001. Our sampling methods were adapted from the standard fish sampling guidelines used by the Washington Department of Fish and Wildlife, which recommends using electrofishing boats, gill nets, and fyke nets during fish surveys to capture the widest variety and greatest number of fish possible in ponds and lakes (Bonar et al. 2000; Bonar and Hubert 2002). Although electrofishing is widely accepted and often the preferred method of sampling black bass for stock assessment purposes (Divens et al. 1998; Sammons and Bettoli 1999; Bonar et al. 2000), budget and travel constraints, and the limited access to the island prevented us from procuring and transporting an electrofishing unit, portable or otherwise, for survey purposes. Thus, we substituted angling and diving for electrofishing in order to complete the survey. Angling provides similar results to electrofishing for estimating density (Gabelhouse and Willis 1986), length and age frequencies (Weis-Glanz and Stanley 1984; Ebbers 1987), and growth (Whitworth 1989) of black bass. Diving also provides similar results to electrofishing for evaluating the density and size structure of black bass, especially in clear, Pacific Northwest lakes (Mueller 2003).

Sampling locations were selected by dividing the shoreline into 11 sections of 400-m length each determined visually from a map, as recommended by Bonar et al. (2000). Because of the lake's modest size and variety of habitat types (e.g., cliffs, rocky slopes, and shallow weedy coves), the shoreline sections were systematically sampled to maximize the dispersion of gear types. During each sampling period, every 400-m shoreline section was assigned one or two of the following gear types: angling, diving (scuba and snorkel), gill net, or fyke net.

Angling sessions were conducted during daylight hours (0800 – 1800) and occurred in all habitat types. Anglers positioned their boat at one end of a 400-m section of shoreline, traveled parallel to the shore, and fished continuously until reaching the other end of the section. During spring, one angler spent 5.8 h sampling seven 400-m sections or 64% of the available shoreline. During summer, two anglers spent 4.6 h sampling six 400-m sections, or 55% of the available shoreline, whereas during fall, two anglers spent 5 h sampling six 400-m sections of shoreline. The duration of each angling session was 50 min. Anglers used light tackle and artificial lures to ensure limited mortality of smallmouth bass and largemouth bass (Clapp and Clark 1989; Quinn 1989).

Diving operations also were conducted during daylight hours (1000 – 1600) and occurred in all habitat types. Using methods adapted from Mueller (2003) and Mueller et al. (2003), divers counted and estimated the size of fish in up to five 400-m shoreline sections during each sampling period. During spring, two divers sampled four 400-m sections or 36% of the available shoreline. During summer, one 400-m section, or 9% of the available shoreline, was sampled by two divers, whereas during fall, one diver sampled five 400-m sections or 45% of the available shoreline. Divers swam transects parallel to shore at the surface and along the 1.5 and 6 m isobaths as determined by depth gauges. 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 40 min or less. All fish observed within the limits of the divers' visibility within the depth bounds were approached, identified to species, and counted, and the total length (TL) was estimated visually by comparing the animals to reference marks spaced 5 mm apart along one edge of a hand-held underwater slate. Divers recorded their observations separately on underwater slates and combined the data upon returning to the surface.

Gill nets and fyke nets were deployed according to Bonar et al. (2000). Experimental gill nets (45.7 m long x 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 fyke net were two 15.2 m wings and a 31 m lead. Because of the variety of habitat types, special consideration was given to net placement to ensure that the nets fished properly. For example, gill nets were placed in shallow to moderately deep (3 – 9 m) shoreline areas, whereas fyke nets were placed in shallow (depth = 1 – 3 m), flat, or gently sloping shoreline areas as recommended by Bonar et al. (2000). The nets were set overnight (~ sunset to sunrise) at four locations during each sampling period (i.e., four 'net nights' for each gear type).

Fish captured while angling and netting were identified to species, and weighed to the nearest 0.5 gram, and TL was measured to the nearest 1 mm. Scales were removed from up to five fish per 10 mm length class and evaluated to determine length at age and growth characteristics according to Carlander (1982) and DeVries and Frie (1996). Otoliths were removed from 10 smallmouth bass and 10 largemouth bass to determine the accuracy of age estimates using scales. At the request of SPU staff, the number of fish sacrificed for these comparisons was kept to a minimum because of the preserve-like nature of the lake and its surroundings. Although otolith aging techniques generally provide the best age estimates for black bass (Long and Fisher 2001), scale aging methods are widely accepted and non-lethal, have been used for most of the last century (DeVries and Frie 1996), and form the basis for much of the historical warm-water fish aging record in Washington (Wydoski and Whitney 2003). The scales and otoliths were read and the fish aged by the Washington Department of Fish and Wildlife's Aging Unit located in Olympia, Washington.

Data Analysis

The size structure of black bass populations in Spencer Lake was evaluated by constructing length frequency distributions by gear type and species. The width of the length groups for the histograms was 20 mm as recommended by Anderson and Neumann (1996). Length frequency distributions were compared using the Kolmogorov-Smirnov *D* test (Zar 1984).

The annular growth of black bass populations in Spencer Lake was evaluated with the Fraser-Lee method of back-calculation, which is a widely accepted technique of determining length at age *n* from hard parts such as fish scales (Carlander 1982; DeVries and Frie 1996). Back-calculation is useful for eliminating seasonal sampling bias relative to fish size, and also useful for obtaining information about the growth of all cohorts or year classes (DeVries and Frie 1996). Using methods described in Van Den Avyle and Hayward (1999), theoretical growth parameters were estimated by fitting back-calculated lengths at age to the von Bertalanffy (1938) growth equation:

$$l_t = L_\infty \left[1 - e^{-K(t - t0)}\right],$$

where l_t = total length at age, L_∞ = theoretical asymptotic length, K = Brody growth coefficient, t = age, and t_0 = theoretical age when fish length is 0. Results were presented in tabular form for easy, visual comparison of growth between year classes, and for visual comparison of the back-calculated and theoretical total lengths at age of Spencer Lake fishes and the state average for each species, which also was determined using scale aging methods (Wydoski and Whitney 2003).

Relative weight, W_r, a widely used index of condition, health, and feeding efficiency based on the length and weight of an individual fish, was calculated and evaluated according to Anderson and Neumann (1996) and Blackwell et al. (2000). A W_r value above 85 generally indicates that a fish is in good condition. Conversely, a W_r value below 85 generally indicates that a fish is thin or in poor condition. The mean W_r was determined for each species by season. These data were compared by using a two sample t test. Linear regressions were then conducted to determine whether total length and W_r were significantly related (Zar 1984). All analyses were completed with Statistix analytical software (Analytical Software, Tallahassee, Florida). The level of significance was set at $P = 0.05$.

Results

Our samples varied by species, season, and gear type, which is typical of freshwater fisheries investigations (Pope and Willis 1996 and references therein). Angling and diving were generally the most effective methods of sampling black bass in Spencer Lake. Smallmouth bass ranged from 50 – 396 mm TL, whereas largemouth bass ranged from 41 – 426 mm TL. Angling selected for larger fish than those observed while diving. Fyke nets selected for young-of-year and small, juvenile fish. Except for a few largemouth bass captured during fall, gill nets were not very effective for sampling black bass in Spencer Lake (Figures 1, 2).

The length frequency distributions of smallmouth bass sampled while angling were significantly different between spring and summer ($D = 0.56$, $P < 0.01$), and between summer and fall ($D = 0.63$, $P < 0.01$), but not between spring and fall ($D = 0.28$). The length frequency distributions of smallmouth bass sampled while angling and diving during summer were significantly different ($D = 0.66$, $P < 0.01$), as were the length frequency distributions of largemouth bass sampled while angling and fyke netting during the same time period ($D = 1.0$, $P < 0.01$). In the only comparison of length frequency distributions between species, those of smallmouth bass and largemouth bass sampled while angling during summer were significantly different ($D = 0.59$, $P < 0.01$). Small sample sizes precluded analyzing other combinations of gear types and species by season.

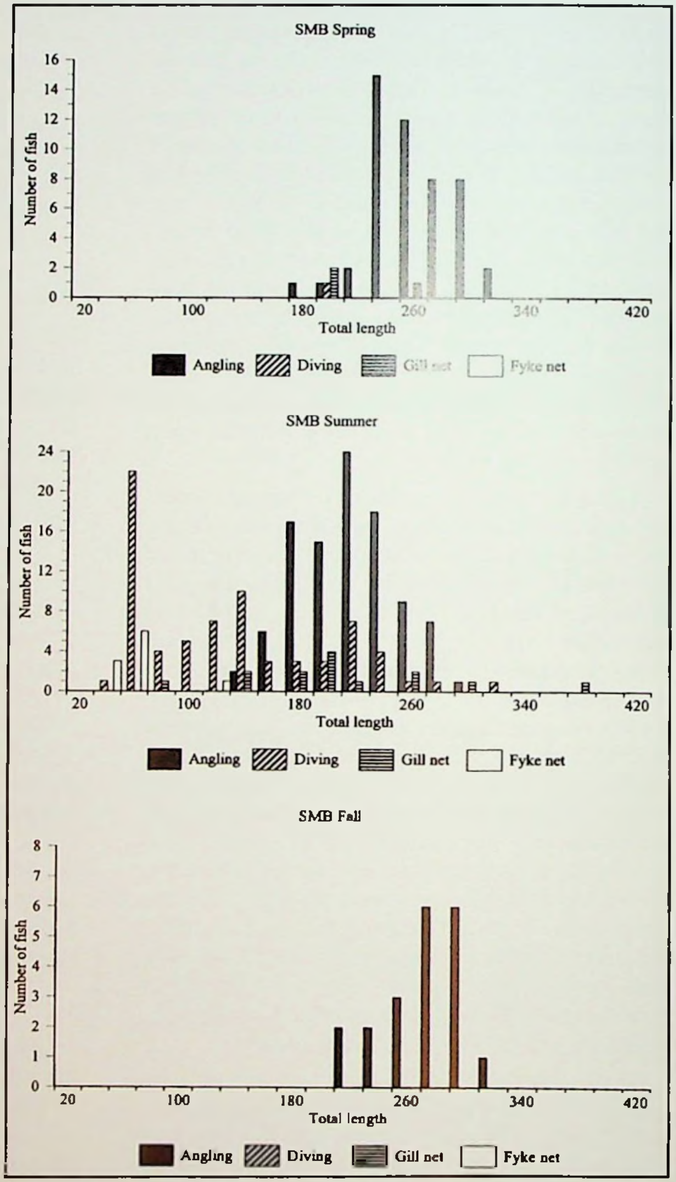

Figure 1. Length frequency distributions of smallmouth bass (SMB) sampled (angling, diving, gill net, and fyke net) at Spencer Lake, Blakely Island, Washington during spring, summer, and fall 2001.

Most (79%) of the smallmouth bass sampled for aging purposes were estimated to be 4 to 8 years old. Few fish (10%) were sampled that were much older than this, although one individual was aged 13 years. Its total length at capture was 396 mm. Total length at age back-calculations revealed slow growth of Spencer Lake smallmouth bass after their first year when compared to the Washington average for the species (Table 1).

Most (69%) of the largemouth bass sampled for aging purposes were estimated to be 1 to 4 years old. Few fish (18%) were of moderate age (5 to 6 years old), and fewer still (< 10%) were sampled that were aged beyond 6 years, making the age estimates for older largemouth bass less reliable. The estimated age of the oldest largemouth bass from our sample was 10 years. Its total length at capture was 331 mm. After their second year, growth of Spencer Lake largemouth bass, as indicated by back-calculated total length at age, was consistent with or lower than the state average for the species (Table 2).

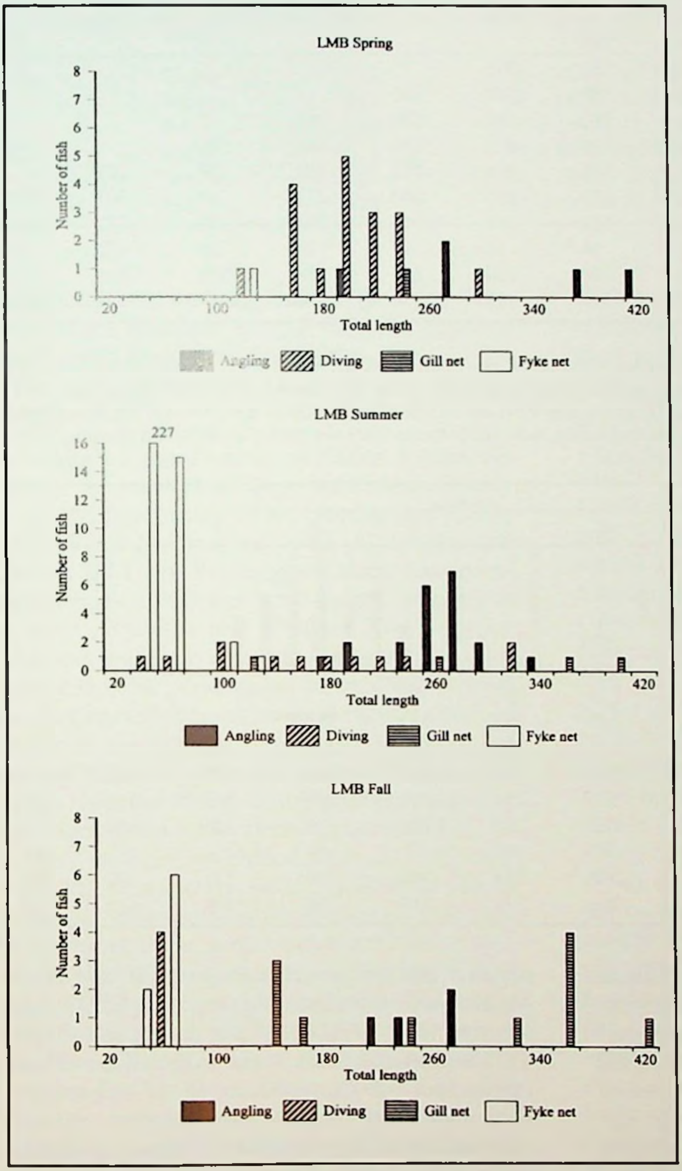

Figure 2. Length frequency distributions of largemouth bass (LMB) sampled (angling, diving, gill net, and fyke net) at Spencer Lake, Blakely Island, Washington during spring, summer, and fall 2001.

In several cases, back-calculated lengths at age for younger fish were larger than those of older fish in the sample irrespective of species (Tables 1, 2). This suggests the occurrence of Lee's phenomenon (DeVries and Frie 1996). Therefore, we estimated the von Bertalanffy growth parameters with total length back-calculated to the most recent scale annulus for each fish sampled, as recommended by Vaughan and Burton (1994). Although much of the growth history of cohorts is lost when using a single back-calculation per fish, Vaughan and Burton's (1994) technique prevents violating the assumption of independence among sample elements and reduces the bias in estimating L_∞ and K. For smallmouth bass, the von Bertalanffy (1938) growth equation, fit to back-calculated total length at age for the last scale annulus (Vaughan and Burton 1994), was $l_t = 421.7[1 - e^{-0.13(t+0.28)}]$. For largemouth bass, the growth equation was $l_t = 516.3[1 - e^{-0.12(t+1.48)}]$.

Our limited comparison of otoliths and scales from 10 fish revealed that three of the smallmouth bass were assessed with the correct age, six were underaged, and one was overaged. In contrast, eight of 10 of the largemouth bass were assessed with the correct age, while one each was underaged and overaged.

TABLE 1. Age and growth of smallmouth bass sampled at Spencer Lake, Blakely Island, Washington during 2001. Values are back-calculated mean total length (mm) at age (year) from scales using the Fraser-Lee method (Carlander 1982; DeVries and Frie 1996). The theoretical length at age from the von Bertalanffy (1938) equation and the unweighted average for smallmouth bass from 10 mainland waters surveyed between 1978 and 1992 (Wydoski and Whitney 2003) are shown for comparison.

		Annulus									
Year class	# fish	1	2	3	4	5	6	7	8	9	10
2000	2	68									
1999	1	70	115								
1998	10	97	140	130							
1997	18	79	124	154	180						
1996	23	75	122	163	193	215					
1995	20	75	120	163	195	219	240				
1994	15	76	122	166	202	229	250	268			
1993	23	73	120	162	194	222	246	264	280		
1992	7	68	102	141	176	204	232	251	268	281	
1991	5	74	110	143	175	210	240	272	294	307	317
Weighted mean		77	121	157	191	219	243	264	280	292	317
Standard deviation		18	24	21	16	18	18	21	20	22	12
Theoretical		65	108	146	180	209	235	258	278	295	311
State average		69	147	211	269	335	356	394	414	424	439

TABLE 2. Age and growth of largemouth bass sampled at Spencer Lake, Blakely Island, Washington during 2001. Values are back-calculated mean total length (mm) at age (year) from scales using the Fraser-Lee method (Carlander 1982; DeVries and Frie 1996). The theoretical length at age from the von Bertalanffy (1938) equation and the unweighted average for largemouth bass from 39 mainland waters surveyed between 1997 and 2002 (Wydoski and Whitney 2003) are shown for comparison. NA = not applicable.

		Annulus									
Year class	# fish	1	2	3	4	5	6	7	8	9	10
2000	8	65									
1999	5	68	144								
1998	6	77	160	232							
1997	15	75	159	221	265						
1996	4	75	169	249	298	324					
1995	5	66	126	186	231	260	276				
1994	1	77	161	226	290	325	343	360			
1993	3	71	136	208	271	301	331	358	369		
1992	1	70	132	183	239	281	325	360	378	390	
1991	1	64	118	153	206	246	261	295	305	317	325
Weighted mean		71	151	217	262	290	300	348	358	354	325
Standard deviation		12	25	36	38	49	47	49	58	52	NA
Theoretical		133	176	215	249	279	306	330	351	369	386
State average		74	124	226	261	310	315	376	394	422	439

The condition of the black bass populations varied with season, species, and size. Smallmouth bass were generally in poor condition except during summer. Furthermore, their relative weights decreased with increasing length irrespective of season. Mean W_r of smallmouth bass was significantly less ($P < 0.005$) in spring and fall than summer; however, mean W_r of smallmouth bass was not significantly different between spring and fall (Table 3). There was a slight but significant negative linear correlation between W_r and TL of smallmouth bass during spring ($P = 0.005$) and summer ($P < 0.001$), but not during fall (Table 4). Largemouth bass were in good condition throughout the study. Mean W_r of largemouth bass did not differ significantly between seasons, yet mean W_r of largemouth bass was significantly greater ($P < 0.005$) than mean W_r of smallmouth bass in all three seasons (Table 3). There was no significant linear relationship between W_r and TL of

TABLE 3. Mean (± SD) relative weights of smallmouth bass (SMB) and largemouth bass (LMB) sampled at Spencer Lake, Blakely Island, Washington during 2001. Values sharing letters are not significantly different.

Fish	Spring	Summer	Fall
SMB	80±6 a (range=68–91, n=52)	91±8 b (range=72-119, n=111)	79±7 a (range=66-93, n=19)
LMB	96±8 c (range=87–103, n=5)	104±10 c (range=87-136, n=24)	100±9 c (range=82-111, n=14)

TABLE 4. Results of linear regression analysis of relative weight (W_r) and total length (TL) for smallmouth bass (SMB) and largemouth bass (LMB) sampled at Spencer Lake, Blakely Island, Washington during 2001. NS = not significant.

Fish	Season	n	Equation	r^2	*P*
SMB	Spring	52	$W_r = 98.79 - 0.07 \times TL$	0.15	0.005
	Summer	111	$W_r = 117.0 - 0.11 \times TL$	0.31	<0.001
	Fall	19	$W_r = 109.78 - 0.11 \times TL$	0.13	NS
LMB	Spring	5	$W_r = 88.82 + 0.03 \times TL$	0.05	NS
	Summer	24	$W_r = 140.2 - 0.13 \times TL$	0.39	<0.005
	Fall	19	$W_r = 105.29 - 0.02 \times TL$	0.03	NS

largemouth bass in spring and fall; however, there was a slight but significant ($P < 0.005$) negative relationship in summer (Table 4).

Discussion

Unexploited populations of fishes frequently have high densities of large individuals (Clady et al. 1975; Johnson 1976; Goedde and Coble 1981; Reed and Rabeni 1989; Kocovsky and Carline 2001). In Washington, black bass commonly exceed 380 mm total length (Bennett et al. 1991; Wydoski and Whitney 2003); yet we observed few large fishes at Spencer Lake. Our finding that the populations of smallmouth bass and largemouth bass contained mostly small to moderate size fish (≤ 280 mm total length) is not unusual for black bass populations in oligotrophic waters (Mueller 2003), where growth, condition, and standing stock may decrease as a result of low primary productivity (Maceina et al. 1996; Ney 1996; Maceina and Bayne 2001). Still, the length frequency distributions we observed resemble those reported for some unexploited fish populations elsewhere. For example, Johnson (1976) observed populations of lake trout (*Salvelinus namaycush*), round whitefish (*Prosopium cylindraceum*), cisco (*Coregonus artedi*) and walleye (*Stizostedion vitreum*) in unexploited Canadian lakes containing mostly small to moderate sized individuals. Goedde and Coble (1981) noted that the size structure of an unexploited population of northern pike (*Esox lucius*) in Wisconsin was unimodal around moderate size fish, and Mueller (1995) described the same for mutton snapper (*Lutjanus analis*) on unexploited artificial patch reefs in the central Bahamas.

Unexploited populations of fishes often exhibit slow growth and contain old individuals (Clady 1975; Clady et al. 1975; Johnson 1976; Kelso and Ward 1977; Reimers 1979; Goedde and Coble 1981; Reed and Rabeni 1989; Kocovsky and Carline 2001). This was evident in the smallmouth bass population at Spencer Lake and, to a lesser degree, the largemouth bass population. Growth of smallmouth bass and older largemouth bass, as indicated by back-calculated lengths at age, was slow by state standards. Furthermore, of the 20 studies of lentic and lotic populations of smallmouth bass in Washington available for comparison (summarized in Bennett et al. 1991 and Wydoski and Whitney 2003), only one (Little Goose Reservoir cited in Bennett et al. 1991) reported fish as old as the oldest fish (13 yr) we detected in Spencer Lake. However, given the results of our limited comparison between otoliths and scales, and the occurrence of Lee's phenomenon, our age and growth results should be viewed with caution. Some possible reasons for Lee's phenomenon are that the oldest fish were the slower-growing survivors of their year classes, our sample was inadequate, or the aging technique was flawed (DeVries and Frie 1996). Caution is advised when interpreting the age of fish from scales, since these structures tend to underestimate the true age (Long and Fisher 2001; this study). It is likely that the black bass in Spencer Lake are older than what we have reported here.

The presence of old fish in poor body condition is often reflective of little or no exploitation (Van Den Avyle and Hayward 1999). Reimers (1979) described an aging, unexploited population of brook trout (*Salvelinus fontinalis*) where individual condition decreased over time. Likewise, Reed and Rabeni (1989) described an unexploited smallmouth bass population where W_r decreased with increasing fish size or age and proposed that this trend was density-related. Our observations of W_r in smallmouth bass are consistent with these studies. Low W_r may be due to poor foraging, competition, or abiotic factors such as low temperatures (Anderson and Neumann 1996; Blackwell et al. 2000). The higher W_r values found in largemouth bass may reflect lower abundance of this species relative to the smallmouth bass population. Indeed, Schindler et al. (1997) found that the condition of unexploited largemouth bass was inversely correlated with population size.

In conclusion, the black bass populations at Spencer Lake are similar to some unexploited populations but differ from others, in particular those having a high proportion of large individuals. Our results indicate that smallmouth bass and, to a lesser degree, largemouth bass are not reaching their full growth potential. Small size and slow growth suggest that the smallmouth bass population is stunted (Emery 1975; Reimers 1979; Diana 1987). Slow growth and increased longevity in unexploited populations have been attributed to inadequate food supply, inter- and intraspecific competition, low primary productivity, or abiotic factors such as cool water temperatures and short growing seasons (Clady 1974, 1975; Emery 1975; Johnson 1976; Kelso and Ward 1977; Reimers 1979; Diana 1987; Toetz et al. 1991; Kocovsky and Carline 2001). Future research should be directed at the influence of these mechanisms on the populations at Spencer Lake. For example, a rigorous analysis of black bass diets and growth *sensu* Olson and Young (2003) might lead to a better understanding of how smallmouth bass and largemouth bass manage to co-exist under conditions of limited available forage and low productivity in this unique system.

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