1997 SILVER LAKE SURVEY: THE FORAGE FISH COMMUNITY AFTER REMOVAL OF AQUATIC VEGETATION BY GRASS CARP

by

Karl W. Mueller
Warmwater Enhancement Program
Washington Department of Fish and Wildlife
600 Capitol Way North
Olympia, Washington 98501-1091

INTRODUCTION AND BACKGROUND

Silver Lake is a large, eutrophic body of water [surface area = 660 hectares (ha); mean depth = 1.5 meters (m); max depth = 2.5 m] located about 40 kilometers (km) west of Mount St. Helens, between the Cowlitz and Toutle Rivers, in Cowlitz County. The lake is fed by Sucker Creek to the south, Hemlock Creek to the east, rainfall, and groundwater. In addition, two small creeks flow into the lake just west of Hemlock Creek. Surface water exits the lake through a man-made outlet dam located at the east end of the lake (Figure 1). The dominant emergent aquatic plants are yellow waterlily (*Nuphar polysepala*), bogbean (*Menyanthes trifoliata*) and, to a lesser extent, watershield (*Brasenia schreberi*). There are few, if any, submersed aquatic plants in Silver Lake. Details of these characteristics can be found in Parsons (1998) and a recent study (KCM 1998) prepared for the Cowlitz County Department of Community Development.

Until recently, Silver Lake was threatened by excessive submersed aquatic plant growth, including the spread of invasive South American waterweed (*Egeria densa*) and Eurasian watermilfoil (*Myriophyllum spicatum*) (KCM 1998; Parsons 1998). For 20 years, dense aquatic macrophyte cover compromised the aesthetic quality of the lake and hindered most water-based recreational activities. These included boating, water skiing, and sport fisheries for warmwater species such as largemouth bass (*Micropterus salmoides*)(KCM 1998).

In 1990, researchers from Washington State University proposed the introduction of sterile grass carp (*Ctenopharyngodon idella*) into Silver Lake to reduce the biomass of submersed aquatic plants (KCM 1998 and references therein). Accordingly, 83,000 triploid grass carp (size range: 200 - 250 mm long) were stocked in the lake at a density of about 124 fish ha^{-1} during May - June 1992 (Scherer et al. 1995). A monitoring program was established and, for the next five years, a private contractor studied the impact of the herbivorous fish on Silver Lake's ecosystem, including changes in the resident warmwater fish community (KCM 1998). By 1994, little, if any, submersed aquatic vegetation was detected in the lake (Scherer et al. 1995).

Currently, much information exists regarding the largemouth bass population before and after stocking grass carp into Silver Lake [Lucas 1986; KCM 1998; John Weinheimer, Washington Department of Fish and Wildlife (WDFW), personal communication]. And although Lucas (1986) characterized the yellow perch (*Perca flavescens*) and bluegill (*Lepomis macrochirus*) populations before stocking grass carp, there is little or no information regarding the forage fish community after stocking grass carp. Given its physical characteristics, Silver Lake is well suited for these species. Therefore, in an effort to monitor the success of the restoration program, as well as improve the warmwater fishery at the lake, personnel from the WDFW's Warmwater Enhancement Program conducted a fisheries survey of Silver Lake during the fall of 1997.

MATERIALS AND METHODS

Silver Lake was surveyed by a three-person investigation team during September 29 - October 2, 1997. Fish were captured using two sampling techniques: electrofishing and gill netting. The electrofishing unit consisted of a 5.5 m Smith-Root 5.0 GPP ‘shock boat’ using a DC current of 120 cycles sec^{-1} at 3 to 4 amps power. 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 (1.3, 1.9, 2.5, and 5.1 cm stretched) monofilament mesh.

Sampling locations were selected by arbitrarily dividing the shoreline into 41 consecutively numbered equidistant sections of about 183 m each (determined visually from a map). Using the random numbers table from Zar (1984), 10 of these sections were then randomly selected as sampling locations. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of approximately 18.3 m $minute^{-1}$ (linear distance covered over time). Gill nets were set perpendicular to the shoreline. The small-mesh end was attached onshore while the large-mesh end was anchored offshore.

Sampling occurred during evening hours to maximize the type and number of fish captured. Nighttime electrofishing occurred along 15% (~ 1.1 km) of the available shoreline, whereas gill nets were set overnight at four locations around the lake (Figure 1). In order to reduce bias between techniques, the sampling time for each gear type was standardized so that the ‘ratio’ of electrofishing to gill netting was 1:1 (Fletcher et al. 1993). Total electrofishing time was 3,612 seconds (‘pedal-down’ time), or roughly two standard units of 0.5 hours each; total gill netting time was 52.4 hours, or roughly two standard units of 24 hours each.

With the exception of sculpin (family Cottidae), all fish captured were identified to the species level. Each fish was measured to the nearest millimeter (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. However, if a sample included several hundred young-of-year or small juveniles (< 100 mm TL) of a given species, then a sub-sample (N ~ 100 fish) was measured and the remainder counted overboard. The length frequency distribution of the sub-sample was then applied to the total number collected. When possible, up to 10 fish from each size class were weighed to the nearest gram (g). Furthermore, scales were removed from these fish for aging. Scale samples (up to six per size class) were mounted and pressed, and the fish aged according to Jearld (1983) and Fletcher et al. (1993). However, members of the catfish family (Ictaluridae) and non-game fish, including carp (Cyprinidae), were not aged.

Water quality data was collected during midday from three locations on October 1, 1997 (Figure 1). Using a Hydrolab® probe and digital recorder, information was gathered on dissolved oxygen, redox, temperature, pH, and conductivity. Secchi disc readings were recorded in feet and then converted to m (Table 1).

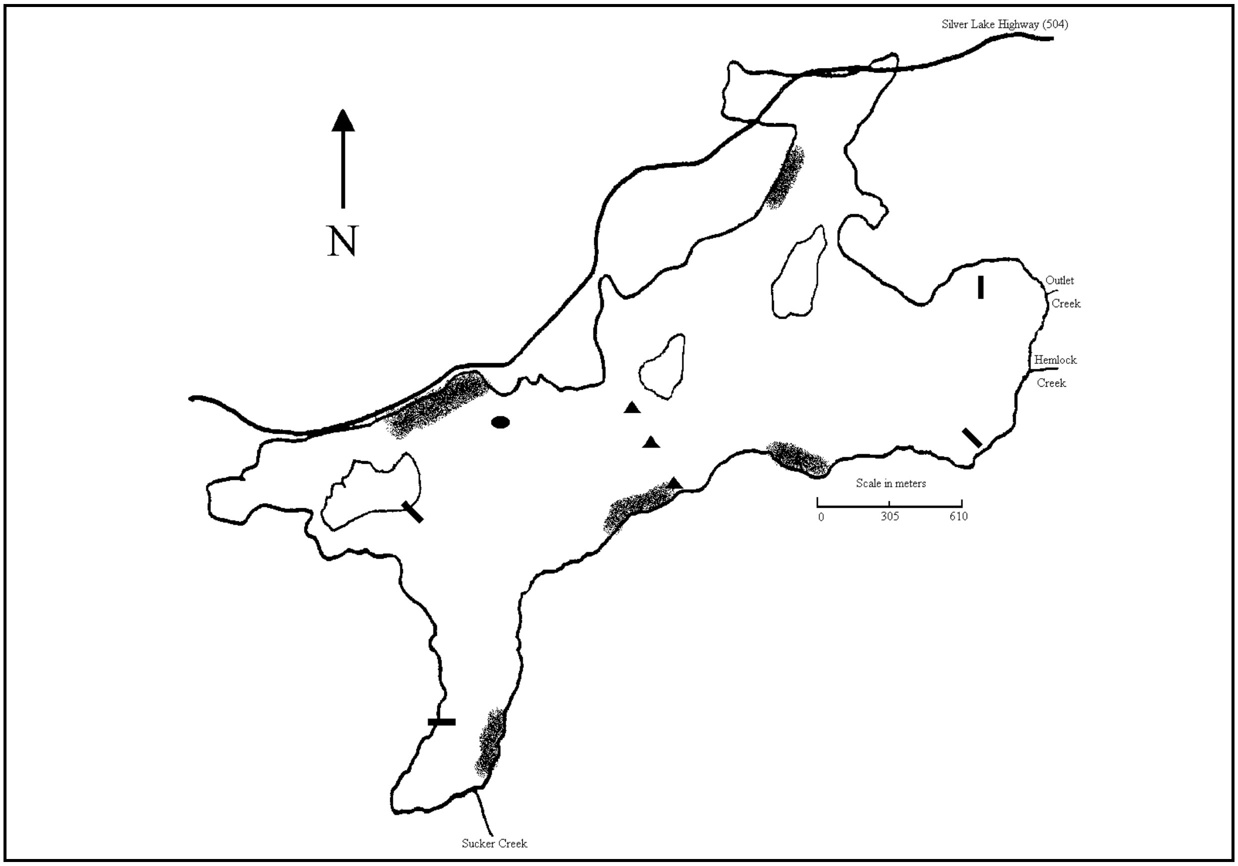

Figure 1. Map of Silver Lake (Cowlitz County) showing sampling locations. Shaded areas indicate sections of shoreline where electrofishing occurred. Bars extending into lake indicate placement of gill nets. Triangles indicate water quality stations. The oval indicates placement of fish attraction devices known as Owen Walls.

Table 1. Water quality from three locations (near shore, offshore, and mid-lake) at Silver Lake (Cowlitz County). Samples were collected midday on October 1, 1997.

		Parameter					
Location	Secchi (m)	Depth (m)	DO	Temp (°C)	pH	Conductivity	Redox
Near shore	1.0	1	6.4	17.4	6.8	43	437
Offshore	1.0	1	6.7	17.3	6.8	43	465
		2	6.6	17.3	6.8	43	465
		2.4	6.5	17.3	6.8	41	420
Mid-lake	0.8	1	7.0	17.3	7.0	43	465
		2	6.9	17.3	6.9	43	468

Data analysis

The species composition by number of fish captured, excluding largemouth bass, was determined using procedures outlined in Fletcher et al. (1993). Species composition by weight (kg) of fish captured, excluding largemouth bass and non-game fish (e.g., sculpin), was determined using procedures adapted from Swingle (1950). Percentage of the aggregate biomass for each species provided useful information regarding the balance and productivity of the community (Swingle 1950; Bennett 1962). Only fish estimated to be at least one year old were used to determine species composition. These were inferred from the length frequency distributions described below, in conjunction with the results of the aging process. Young-of-year or small juveniles were not considered because large fluctuations in their numbers may cause distorted results (Fletcher et al. 1993). For example, the length frequency distribution of yellow perch may suggest successful spawning during a given year, as indicated by a preponderance of fish in the smallest size classes. However, most of these fish would be subject to natural attrition during their first winter, resulting in a different size distribution by the following year.

The catch per unit effort (CPUE) of electrofishing for each warmwater species was determined by dividing the number of fish captured in each size class by the total electrofishing time (Reynolds 1983). The CPUE of gill netting was determined similarly, except that the number of fish captured in each size class was divided by the total soak time of all nets deployed (Royce 1972). These proportions (fish/hour) were then used to make length frequency histograms to evaluate the size structure of the warmwater fish species and their relative abundance in the lake. Furthermore, since it is standardized, the CPUE is useful for comparing stocks between lakes.

A relative weight (W_r) index was used to evaluate the condition (plumpness or robustness) of fish in the lake. A W_r value of 1.0 generally indicates that a fish is in good condition when compared to the national average for that species. Furthermore, relative weights are 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 for the W_s equations of many warmwater fish species, including the minimum length recommendations for their application, are listed in Anderson and Neumann (1996).

With the exception of warmouth (*Lepomis gulosus*), yellow bullhead (*Ameiurus natalis*), brown bullhead (*Ameiurus nebulosus*), and white crappie (*Pomoxis annularis*), the W_r values from this study were compared to the Washington State average (Scott Bonar, WDFW; unpublished data) and the national standard (W_r = 1.0). Since the W_s equations for the species above were lacking, their condition was evaluated according to Fletcher et al. (1993). Condition factors (C) were calculated as $C = W*10^4*L^{-3}$, where W is the weight of an individual fish in pounds, and L is the total length in inches. When possible, C was compared to the state average (listed in Fletcher et al. 1993).

Age and growth of warmwater fish in Silver Lake were evaluated according to Fletcher et al. (1993). Total length at annulus formation, L_n, was back-calculated as $L_n = (A \times TL)/S$, where A is the radius of the fish scale at age n, TL is the total length of the fish captured, and S is the total radius of the scale. Mean back-calculated lengths at age n for each species were presented in tabular form for easy comparison between year classes. Differences in growth between the Silver Lake fish and the state average for the same species (listed in Fletcher et al. 1993) were compared by plotting their overall mean back-calculated lengths versus age n.

Differences in the forage fish community before and after stocking grass carp were evaluated by comparing size structure, condition (expressed as C), and growth of yellow perch and bluegill from Lucas (1986) with this study.

RESULTS

Species composition

The dominant forage fish in terms of biomass and number of fish captured were yellow perch and bluegill (Table 2; Figures 2 and 3). Although less abundant, warmouth still represented 13% of the total biomass. Species other than the warmwater variety accounted for about 10% of the total number captured (Table 2; Figures 2 and 3). Lucas (1986) reported similar findings from a 1979 fisheries survey of Silver Lake.

Table 2. Species composition [excluding largemouth bass (*Micropterus salmoides*) and young-of-year] by weight (kg) and number of fish captured at Silver Lake (Cowlitz County) during a fall 1997 survey of warmwater fish.

	Species composition		
Type of fish	by weight (kg)	by number	Size range (mm TL)
Yellow perch (*Perca flavescens*)	7.9	180	85 - 224
Bluegill (*Lepomis macrochirus*)	5.2	159	63 - 202
Warmouth (*Lepomis gulosus*)	2.6	39	63 - 245
Black crappie (*Pomoxis nigromaculatus*)	2.3	23	90 - 240
Yellow bullhead (*Ameiurus natalis*)	1.2	8	187 - 280
Brown bullhead (*Ameiurus nebulosus*)	0.5	3	229 - 247
Pumpkinseed (*Lepomis gibbosus*)	0.3	7	98 - 150
White crappie (*Pomoxis annularis*)	0.2	25	80 - 115
Largescale sucker (*Catostomus macrocheilus*)	---	34	---
Grass carp (*Ctenopharyngodon idella*)	---	8	---
Common carp (*Cyprinus carpio*)	---	4	---
Rainbow trout (*Oncorhynchus mykiss*)	---	3	---
Cutthroat trout (*Oncorhynchus clarki*)	---	1	---
Sculpin (*Cottus* sp.)	---	1	---
Total	20.2	495	

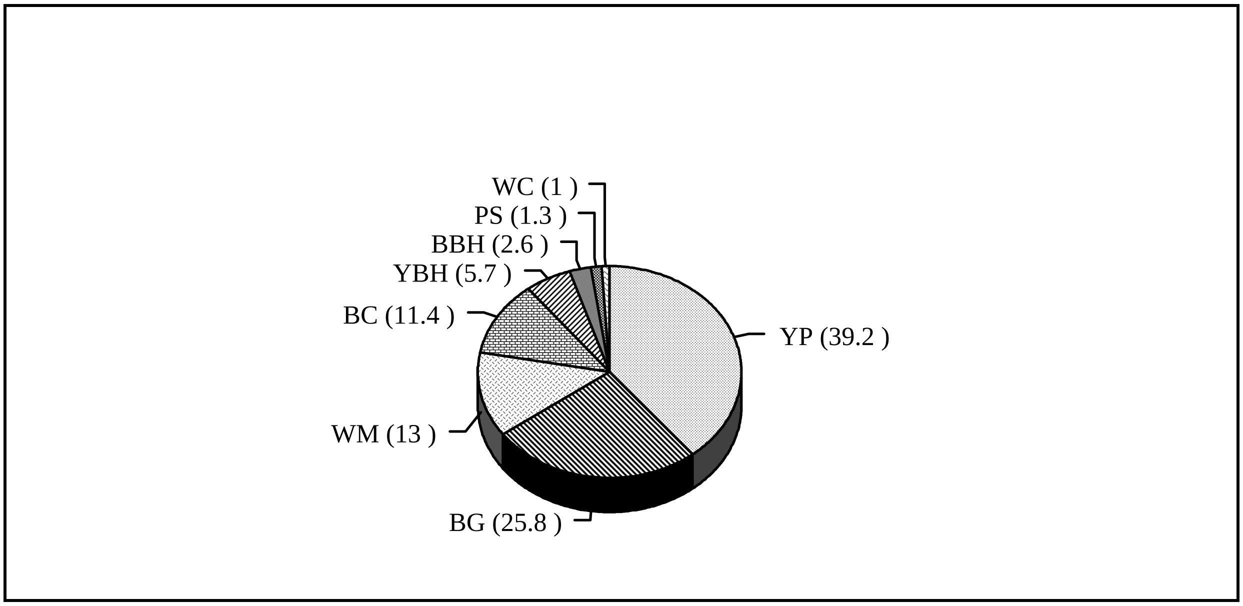

Figure 2. Species composition expressed as percent of total biomass captured (20.2 kg, excluding largemouth bass, non-game fish, and young-of-year) at Silver Lake (Cowlitz County) during fall 1997. YP = yellow perch, BG = bluegill, WM = warmouth, BC = black crappie, YBH = yellow bullhead, BBH = brown bullhead, PS = pumpkinseed, and WC = white crappie.

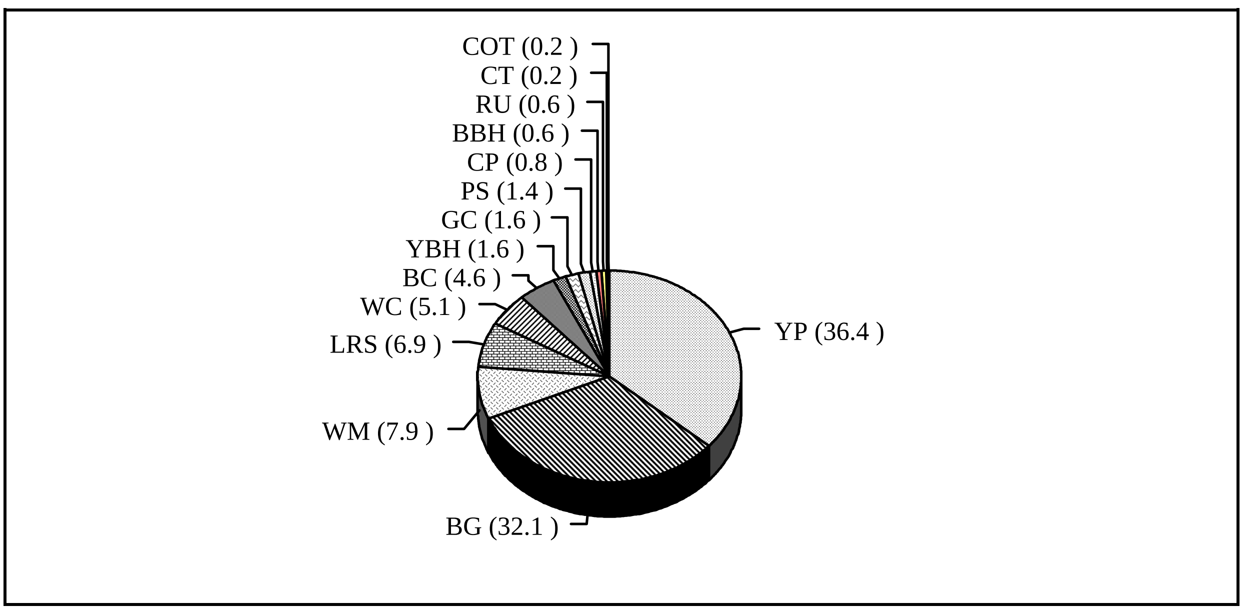

Figure 3. Species composition expressed as percent of total number captured (N = 495, excluding largemouth bass and young-of-year) at Silver Lake (Cowlitz County) during fall 1997. YP = yellow perch, BG = bluegill, WM = warmouth, LRS = largescale sucker, WC = white crappie, BC = black crappie, YBH = yellow bullhead, GC = grass carp, PS = pumpkinseed, CP = common carp, BBH = brown bullhead, RU = rainbow trout (unknown race), CT = cutthroat trout, and COT = sculpin (Cottidae).

Yellow perch

Silver Lake yellow perch ranged from 46 to 224 mm TL (age 0+ to 5+). Most of these were young-of-year and age 1+ fish (< 120 mm TL). Moderate numbers of intermediate size (age) fish were captured, whereas no large, old fish were observed (Table 3; Figures 4 and 5). Less than 5% of the fish captured (N=180, excluding young-of-year) were of quality size ($\geq$ 203 mm TL). Quality size varies by species, and is defined as the minimum size which most anglers would like to catch (Anderson 1980 cited in Fletcher et al. 1993). Growth rates of Silver Lake fish before and after (1986 and 1997, respectively) stocking grass carp were comparable to yellow perch statewide (Table 3; Figure 6), yet changes in size structure occurred after stocking grass carp. For example, intermediate size fish (152 to 202 mm TL) were more abundant in 1986 than 1997, whereas small fish (< 152 mm TL) were more abundant in 1997 than 1986 (Figure 8). Although yellow perch condition factors were remarkably similar before and after stocking grass carp (Table 4), relative weights of fish in 1997 were below the state average and national standard for the species (Figure 7).

Table 3. Age and growth of yellow perch (*Perca flavescens*) captured at Silver Lake (Cowlitz County) during fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age				
Year class	# fish	1	2	3	4	5
1997	7	74.9				
1996	16	64.0	126.6			
1995	11	60.4	122.5	155.0		
1994	19	60.7	122.6	154.8	176.2	
1993	8	60.4	123.4	158.7	183.1	201.0
	Overall mean	63.1	123.9	155.7	178.3	201.0
	Data from Lucas (1986)	45.7	111.8	157.5	182.9	208.3
	State average	59.7	119.9	152.1	192.5	206.0

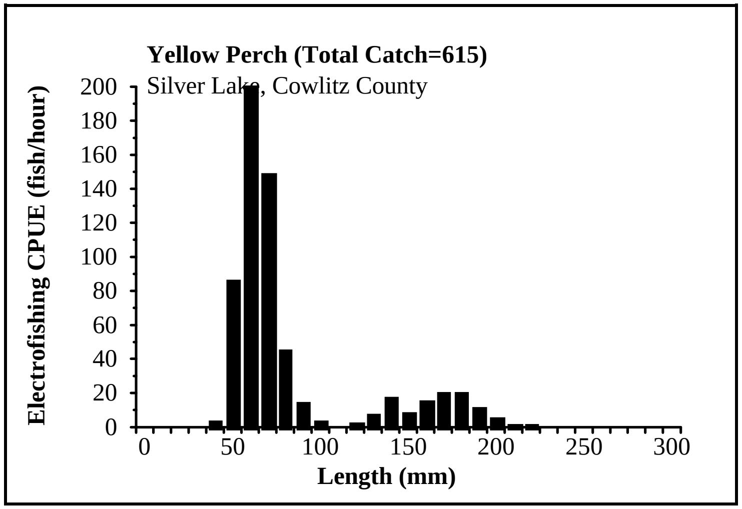

Figure 4. Relationship between total length and catch per unit effort of electrofishing for yellow perch (*Perca flavescens*) at Silver Lake (Cowlitz County) during fall 1997.

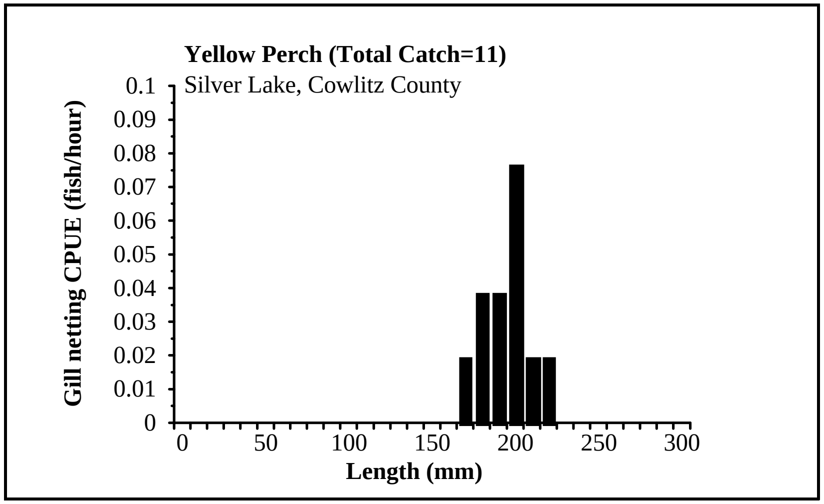

Figure 5. Relationship between total length and catch per unit effort of gill netting for yellow perch (*Perca flavescens*) at Silver Lake (Cowlitz County) during fall 1997.

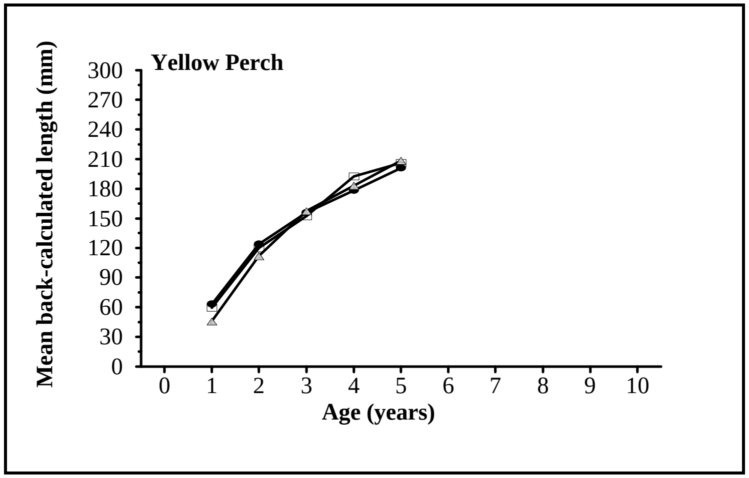

Figure 6. Growth of yellow perch (*Perca flavescens*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Lucas (1986) data (closed, shaded triangles) and Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

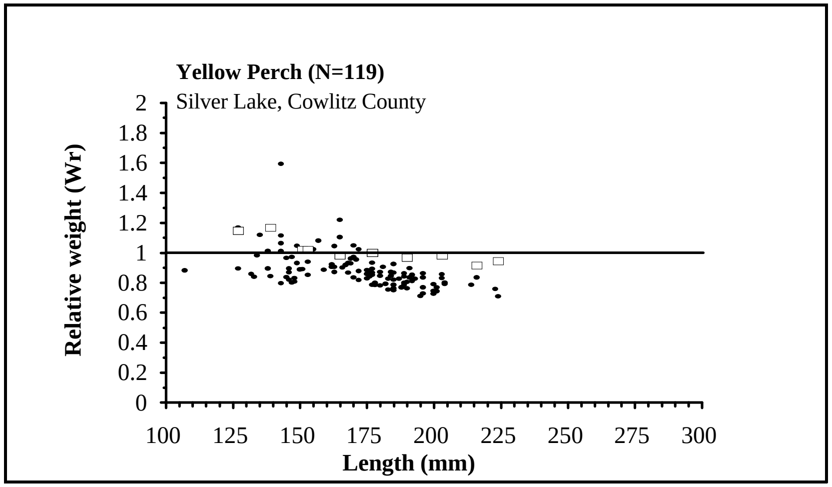

Figure 7. Relationship between total length and relative weight (W_r) of yellow perch (*Perca flavescens*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles) and national standard (horizontal line at 1.0).

Yellow Perch

Table 4. Condition of yellow perch (*Perca flavescens*) 6 years before (late spring 1986) and 5 years after (early fall 1997) stocking grass carp (*Ctenopharyngodon idella*) into Silver Lake, Cowlitz County. Data from Lucas (1986) and this study.

	Mean condition factor (*C*)			
	1986		1997	
Fish size	*C*	# fish	*C*	# fish
114 - 163 mm TL	4.27	12	4.46	40
> 163 mm TL	4.10	37	4.18	67

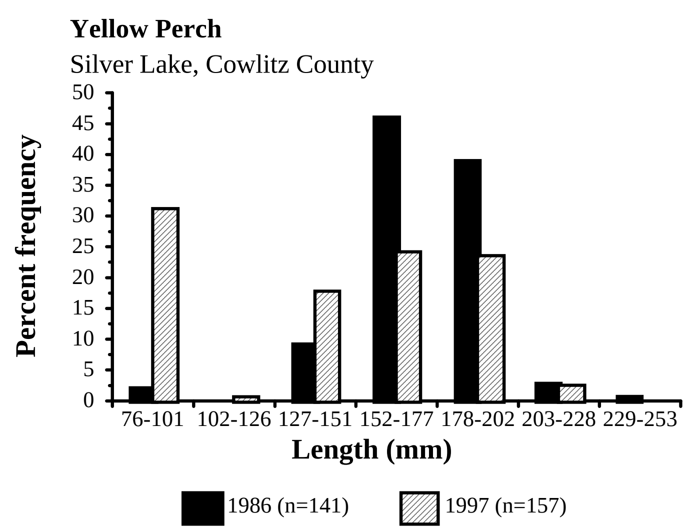

Figure 8. Comparison of yellow perch (*Perca flavescens*) length frequencies (excluding young-of-year) 6 years before (late spring 1986) and 5 years after (early fall 1997) stocking grass carp (*Ctenopharyngodon idella*) into Silver Lake, Cowlitz County. Electrofishing data from Lucas (1986) and this study.

Bluegill

Table 5. Condition of bluegill (*Lepomis macrochirus*) 6 years before (late spring 1986) and 5 years after (early fall 1997) stocking grass carp (*Ctenopharyngodon idella*) into Silver Lake, Cowlitz County. Data from Lucas (1986) and this study.

	Mean condition factor (*C*)			
	1986		1997	
Fish size	*C*	# fish	*C*	# fish
76 - 151 mm TL	7.31	10	6.90	101
> 151 mm TL	8.03	30	7.52	16

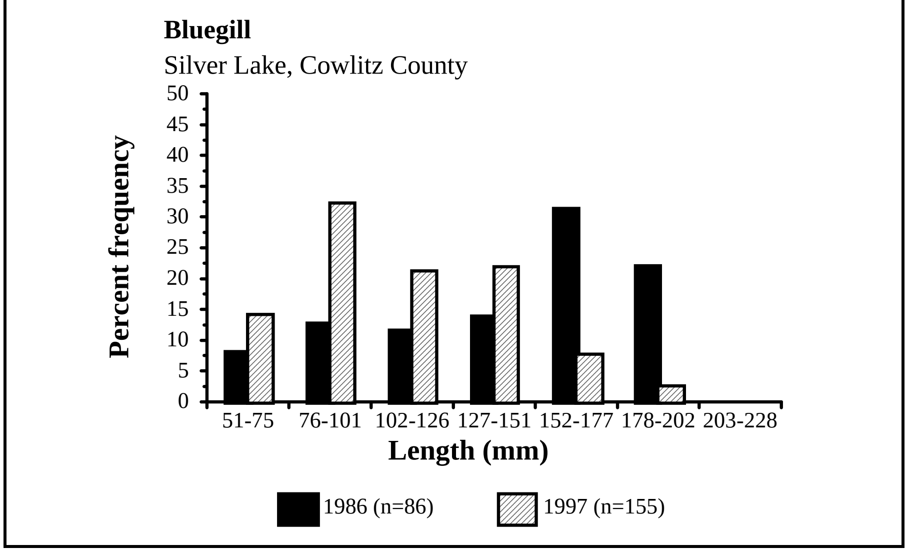

Figure 9. Comparison of bluegill (*Lepomis macrochirus*) length frequencies (excluding young-of-year) 6 years before (late spring 1986) and 5 years after (early fall 1997) stocking grass carp (*Ctenopharyngodon idella*) into Silver Lake, Cowlitz County. Electrofishing data from Lucas (1986) and this study.

Bluegill

Size of bluegill ranged from 27 to 202 mm TL (age 0+ to 9+). Fish up to age 6+ (~ 150 mm TL) were well represented; however, the 1990 year-class (age 8) was not observed (Table 6; Figures 10 and 11). Approximately 10% of the fish captured (N=159, excluding young-of-year) were of quality size ($\geq$ 152 mm TL). Growth of Silver Lake bluegill before and after stocking grass carp was slow compared to fish statewide. The 1997 fish grew faster than the 1986 fish through age 3. Conversely, after age 4, the 1986 fish grew faster than the 1997 fish (Table 6; Figure 12). Changes in size structure were also apparent. For example, small to intermediate size bluegill (< 152 mm TL) were more abundant in 1997 than 1986, whereas large fish (152 to 202 mm TL) were more abundant in 1986 than 1997 (Figure 9). The condition factors of fish captured before stocking grass carp were slightly higher than those captured after stocking grass carp (Table 5). Moreover, relative weights of Silver Lake bluegill were relatively poor by national standards and below average for the species statewide (Figure 13).

Table 6. Age and growth of bluegill (*Lepomis macrochirus*) captured at Silver Lake (Cowlitz County) during fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age								
Year class	# fish	1	2	3	4	5	6	7	8	9
1997	7	38.9								
1996	13	40.4	88.1							
1995	8	47.5	82.4	105.4						
1994	15	57.0	83.6	106.7	124.8					
1993	10	45.2	88.0	113.4	130.8	148.0				
1992	5	42.3	81.1	110.3	131.5	146.7	159.4			
1991	1	44.2	76.4	111.0	131.3	145.6	163.5	176.6		
1990	0									
1989	1	44.7	98.4	118.9	139.4	154.7	163.6	179.0	193.0	199.4
Overall mean		46.4	85.3	109.0	128.4	147.8	160.6	177.8	193.0	199.4
Data from Lucas (1986)		25.4	61.0	104.1	127.0	157.5	177.8	190.5	---	---
State average		37.3	96.8	132.1	148.3	169.9	200.9	195.8	---	---

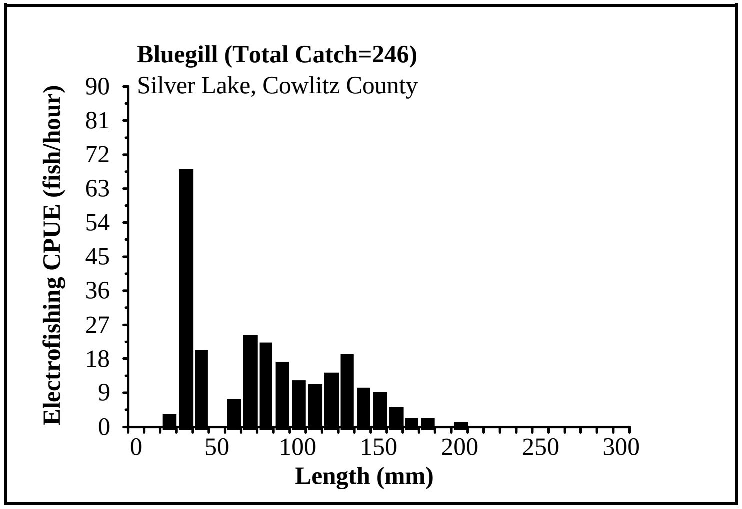

Figure 10. Relationship between total length and catch per unit effort of electrofishing for bluegill (*Lepomis macrochirus*) at Silver Lake (Cowlitz County) during fall 1997.

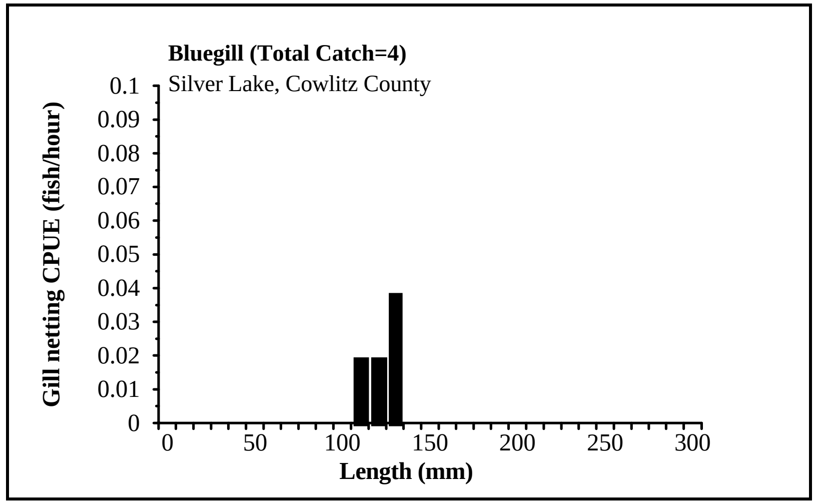

Figure 11. Relationship between total length and catch per unit effort of gill netting for bluegill (*Lepomis macrochirus*) at Silver Lake (Cowlitz County) during fall 1997.

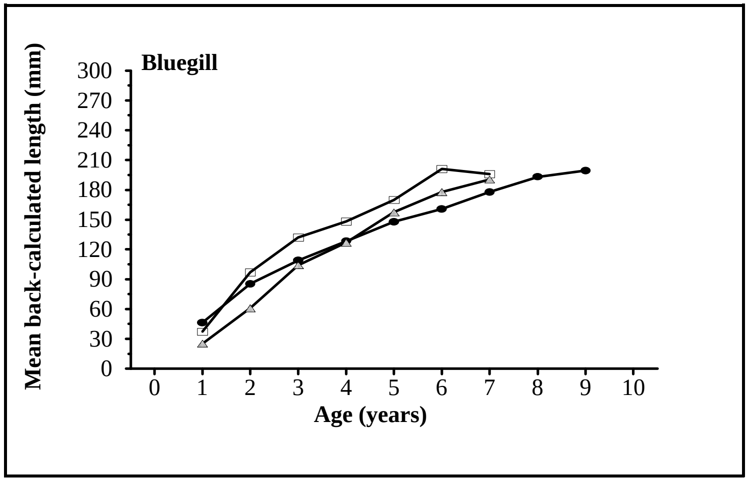

Figure 12. Growth of bluegill (*Lepomis macrochirus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Lucas (1986) data (closed, shaded triangles) and Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

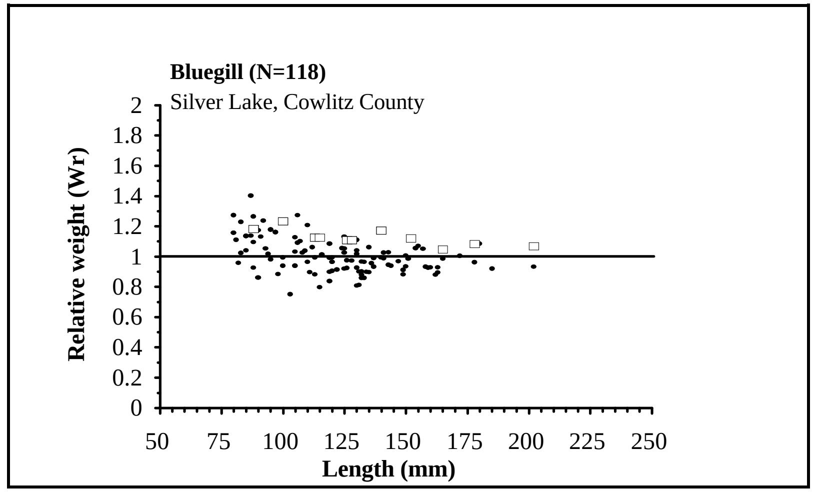

Figure 13. Relationship between total length and relative weight (W_r) of bluegill (*Lepomis macrochirus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles) and national standard (horizontal line at 1.0).

Warmouth

Silver Lake warmouth ranged from 35 to 245 mm TL (age 0+ to 9+). With the exception of age 1+ fish (< 60 mm TL), most year classes were well represented; however, young-of-year and large, old fish were rarely observed (Table 7; Figures 14 and 15). Approximately 25% of the fish captured (N=39, excluding young-of-year) were of quality size (≥ 152 mm TL). One individual measured 245 mm TL and weighed 345 g, which exceeded the current state record (also captured at Silver Lake) by roughly 100 g. When compared to warmouth statewide, the Silver Lake fish grew similarly (Figure 16), but displayed slightly lower than average condition (Figure 17).

Table 7. Age and growth of warmouth (*Lepomis gulosus*) captured at Silver Lake (Cowlitz County) during fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age								
Year class	# fish	1	2	3	4	5	6	7	8	9
1997	0									
1996	4	39.0	60.8							
1995	2	41.4	59.1	78.8						
1994	5	38.3	61.8	85.7	102.7					
1993	7	36.5	60.4	85.0	103.8	118.5				
1992	9	36.4	65.2	90.4	111.4	128.0	141.0			
1991	2	36.6	62.5	88.4	110.0	125.6	137.2	148.7		
1990	1	39.5	66.8	91.4	114.5	135.0	147.3	156.8	173.2	
1989	2	39.1	67.0	88.4	115.6	142.2	160.3	175.1	182.8	189.7
Overall mean		37.6	62.7	87.1	108.0	126.3	143.6	160.9	179.6	189.7
State average		22.6	57.7	88.9	116.1	130.6	134.6	155.2	170.7	---

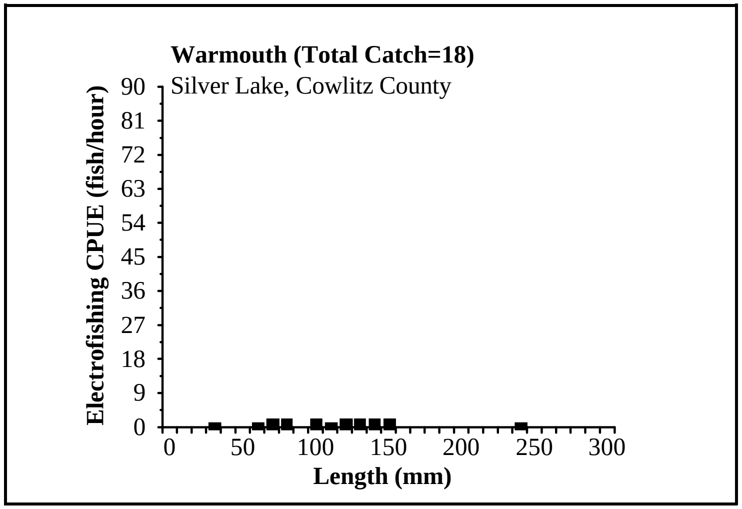

Figure 14. Relationship between total length and catch per unit effort of electrofishing for warmouth (*Lepomis gulosus*) at Silver Lake (Cowlitz County) during fall 1997.

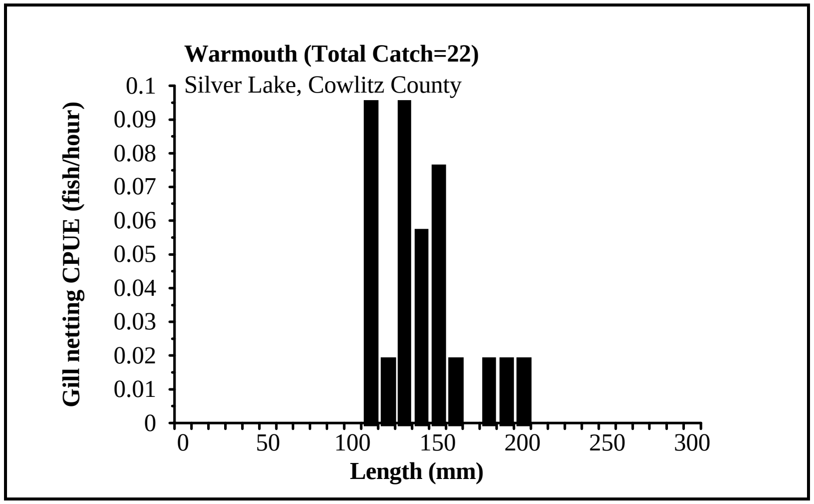

Figure 15. Relationship between total length and catch per unit effort of gill netting for warmouth (*Lepomis gulosus*) at Silver Lake (Cowlitz County) during fall 1997.

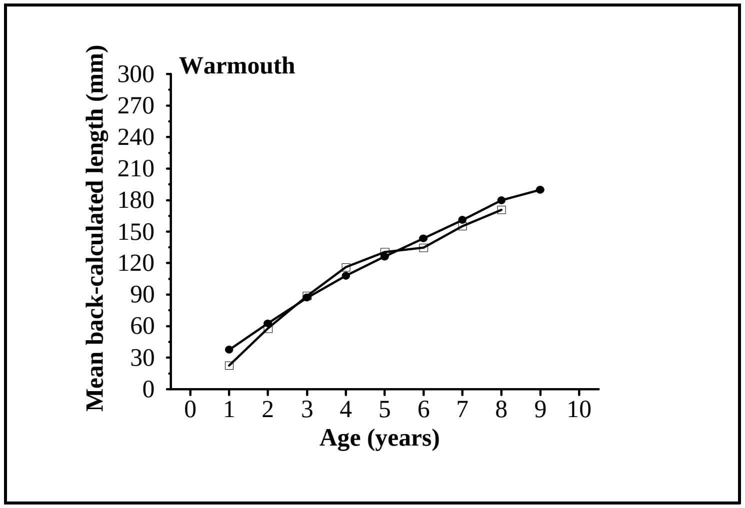

Figure 16. Growth of warmouth (*Lepomis gulosus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

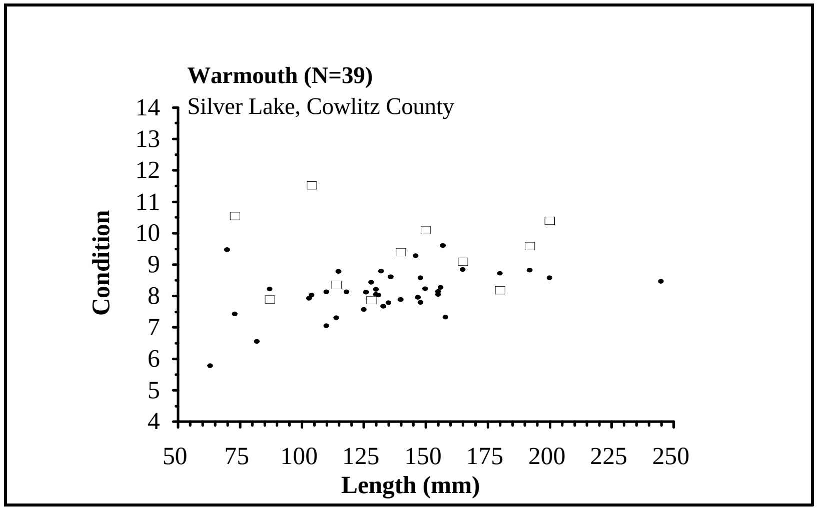

Figure 17. Relationship between total length and condition (*C*) of warmouth (*Lepomis gulosus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles).

Black crappie

Size range of black crappie (*Pomoxis nigromaculatus*) was 62 to 240 mm TL (age 0+ to 6+). The predominant fish were young-of-year and age 1+ (< 110 mm TL); two and three year old fish (~120 - 190 mm TL) were conspicuously lacking, whereas age 4+ fish (about 200 mm TL) were moderately abundant (Table 8; Figures 18 and 19). Nearly half of the fish captured (N=23, excluding young-of-year) were of quality size ($\geq$ 203 mm TL). During their first four years, growth of Silver Lake black crappie was slightly higher than the state average (Figure 20), but relative weights were below average irrespective of length (Figure 21).

Table 8. Age and growth of black crappie (*Pomoxis nigromaculatus*) captured at Silver Lake (Cowlitz County) during fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age					
Year class	# fish	1	2	3	4	5	6
1997	8	75.5					
1996	1	56.1	132.4				
1995	1	46.6	122.8	155.3			
1994	8	50.9	128.3	169.0	195.7		
1993	4	54.0	138.7	175.2	198.0	215.8	
1992	1	40.4	107.9	155.1	183.4	206.3	226.5
	Overall mean	59.6	129.6	168.8	195.5	213.9	226.5
	State average	46.0	111.2	156.7	183.4	220.0	224.0

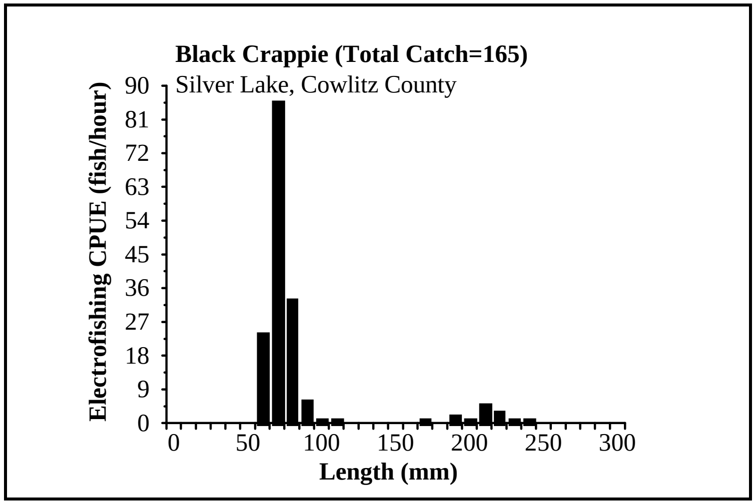

Figure 18. Relationship between total length and catch per unit effort of electrofishing for black crappie (*Pomoxis nigromaculatus*) at Silver Lake (Cowlitz County) during fall 1997.

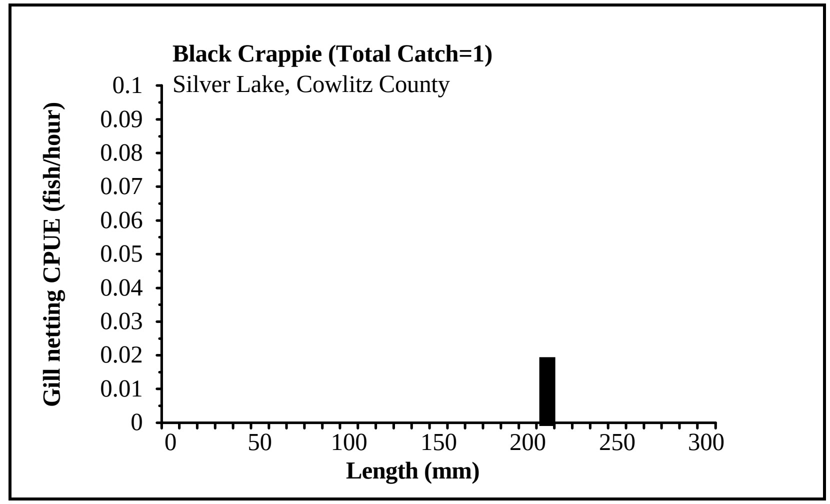

Figure 19. Relationship between total length and catch per unit effort of gill netting for black crappie (*Pomoxis nigromaculatus*) at Silver Lake (Cowlitz County) during fall 1997.

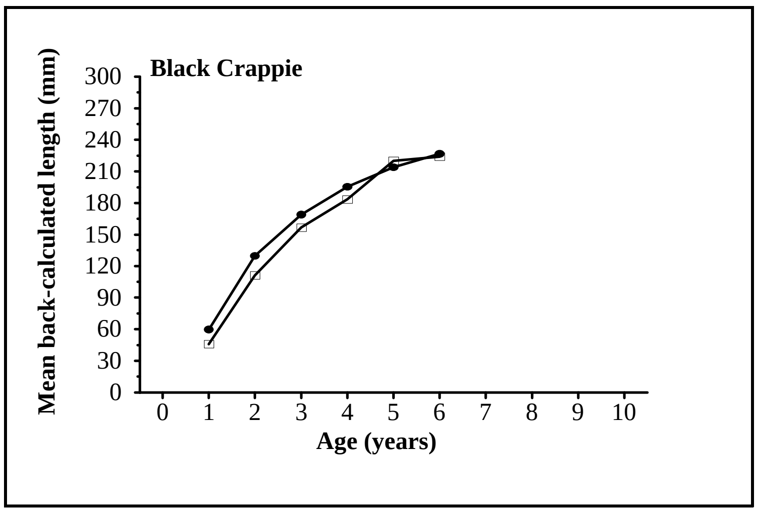

Figure 20. Growth of black crappie (*Pomoxis nigromaculatus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

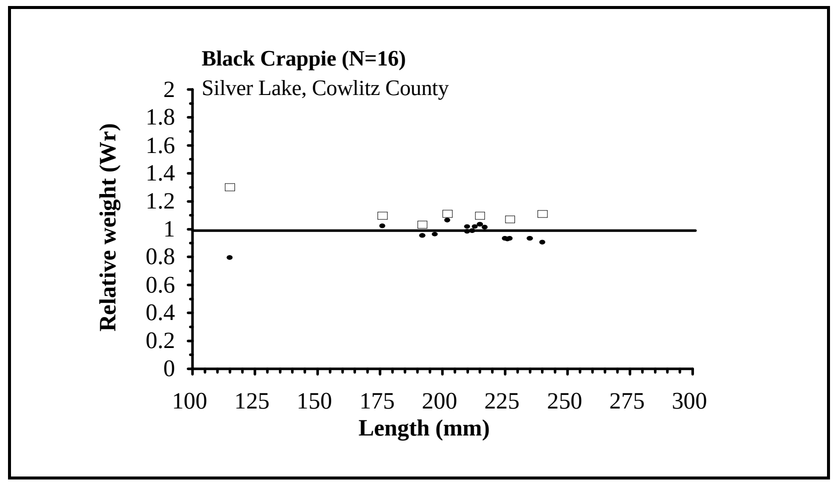

Figure 21. Relationship between total length and relative weight (W_r) of black crappie (*Pomoxis nigromaculatus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles) and national standard (horizontal line at 1.0)

Yellow bullhead

Size range of yellow bullhead was 187 to 280 mm TL (Table 2). Only one of the eight fish captured was of quality size ($\geq$ 229 mm TL). Condition factors ranged from 4.4 to 5.8, which was consistent with the state average. Gill netting proved to be the best sampling method for these fish. Although two year classes were evident from the length frequencies (Figures 22 and 23), their actual ages were unknown.

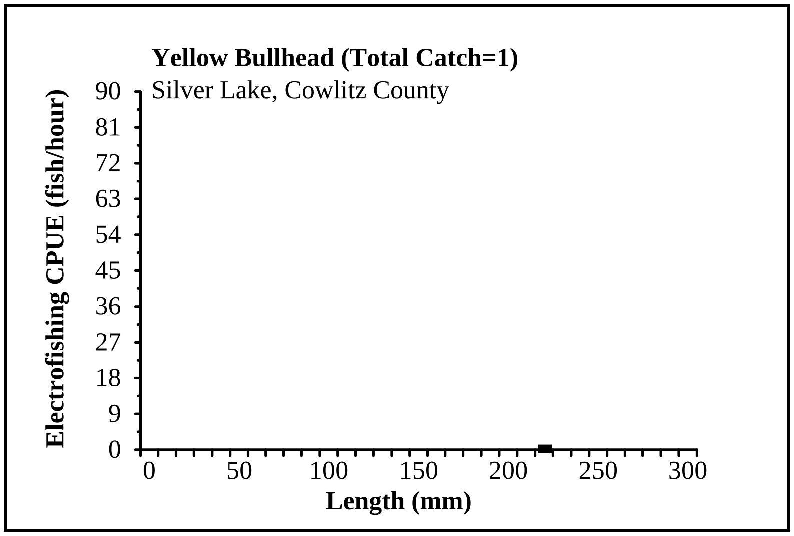

Figure 22. Relationship between total length and catch per unit effort of electrofishing for yellow bullhead (*Ameiurus natalis*) at Silver Lake (Cowlitz County) during fall 1997.

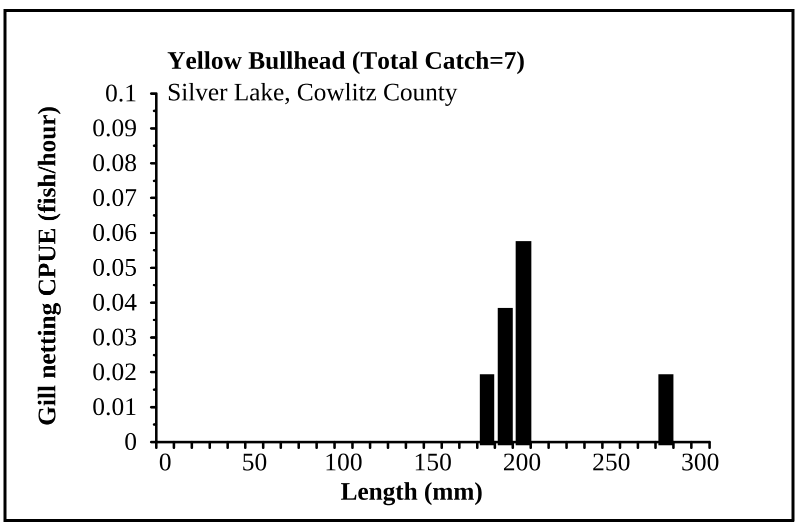

Figure 23. Relationship between total length and catch per unit effort of gill netting for yellow bullhead (*Ameiurus natalis*) at Silver Lake (Cowlitz County) during fall 1997.

Brown bullhead

Silver Lake brown bullhead ranged from 229 to 247 mm TL (Table 2). The three individuals captured were all of quality size ($\geq$ 229 mm TL), but displayed slightly lower than average condition (about 4.4 compared to 4.7). Although their ages were unknown, the fish appeared to be from the same year class (Figures 24 and 25).

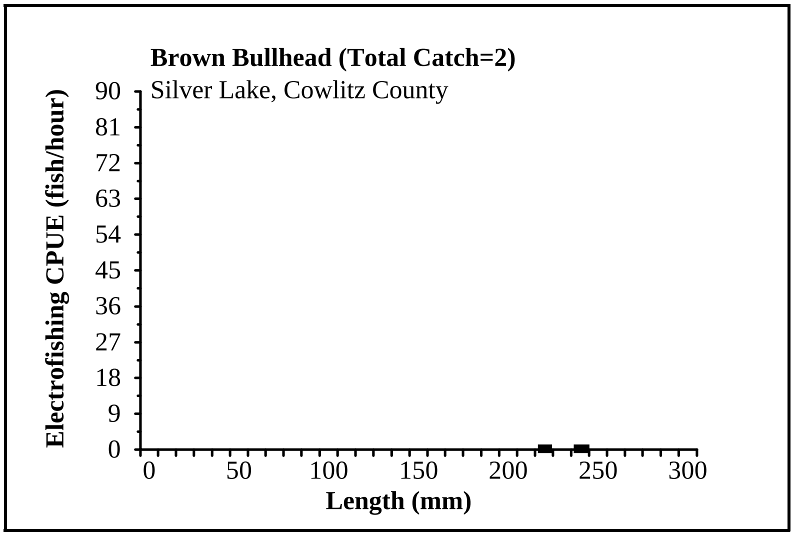

Figure 24. Relationship between total length and catch per unit effort of electrofishing for brown bullhead (*Ameiurus nebulosus*) at Silver Lake (Cowlitz County) during fall 1997.

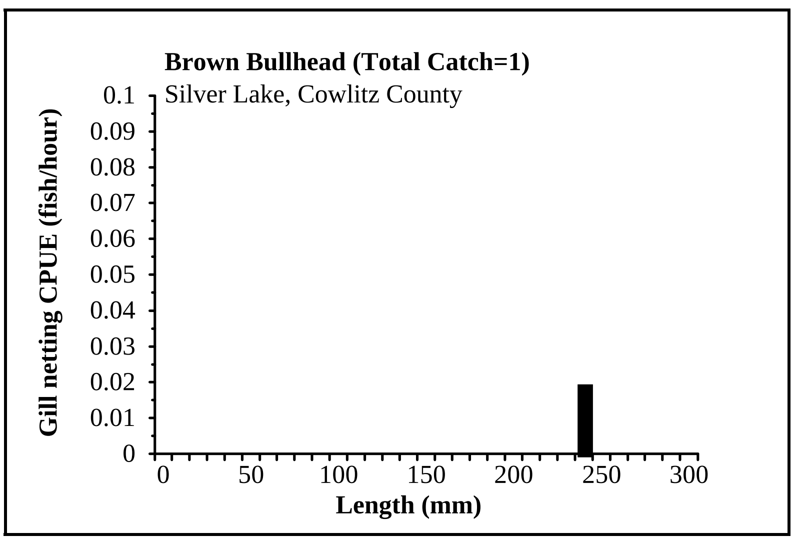

Figure 25. Relationship between total length and catch per unit effort of gill netting for brown bullhead (*Ameiurus nebulosus*) at Silver Lake (Cowlitz County) during fall 1997.

Pumpkinseed

Size range of pumpkinseed (*Lepomis gibbosus*) was 98 to 150 mm TL (age 2+ to 5+). No young-of-year or age 1+ fish (< 90 mm TL) were captured (Tables 2 and 9; Figure 26), nor any quality size fish (≥ 152 mm TL). During their first two years, growth of the Silver Lake fish was slightly higher when compared to pumpkinseed statewide; however, after age 2, there was little difference (Figure 27). Relative weights were below average irrespective of length (Figure 28).

Table 9. Age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Silver Lake (Cowlitz County) during fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age				
Year class	# fish	1	2	3	4	5
1997	0					
1996	2	34.8	85.4			
1995	3	46.0	77.1	96.6		
1994	1	38.6	81.1	97.8	119.7	
1993	1	36.2	85.0	103.7	123.7	140.0
	Overall mean	40.4	81.2	98.3	121.7	140.0
	State average	23.6	72.1	101.6	122.7	139.4

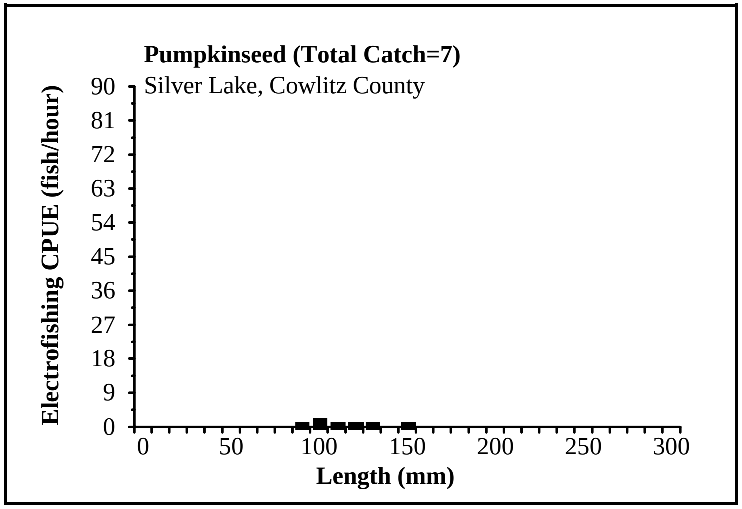

Figure 26. Relationship between total length and catch per unit effort of electrofishing for pumpkinseed (*Lepomis gibbosus*) at Silver Lake (Cowlitz County) during fall 1997.

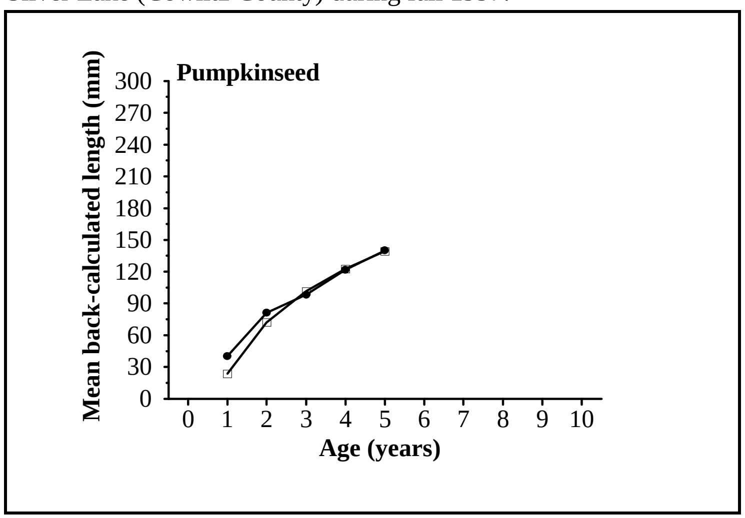

Figure 27. Growth of pumpkinseed (*Lepomis gibbosus*) from Silver Lake, Cowlitz County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

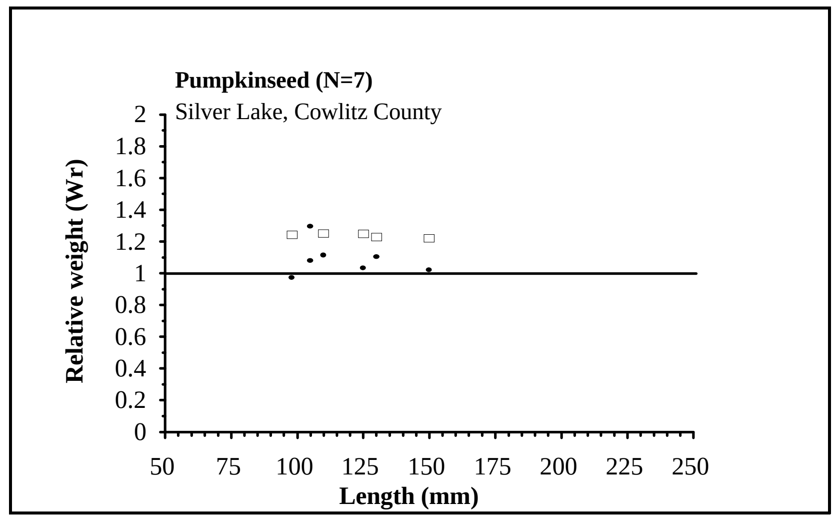

Figure 28. Relationship between total length and relative weight (W_r) of pumpkinseed (*Lepomis gibbosus*) from Silver Lake, Cowlitz County (closed, black circles) compared to the Washington State average (open, clear rectangles) and the national standard (horizontal line at 1.0).

White crappie

White crappie ranged from 66 to 115 mm TL. Only young-of-year and age 1+ fish were observed (Figure 29). No quality size fish (≥ 203 mm TL) were captured. Average mean back-calculated length at first annulus formation was 75.5 mm (N = 13 fish). Condition of Silver Lake white crappie was variable (Figure 30); however, further comparison was not possible since state averages for this species were lacking.

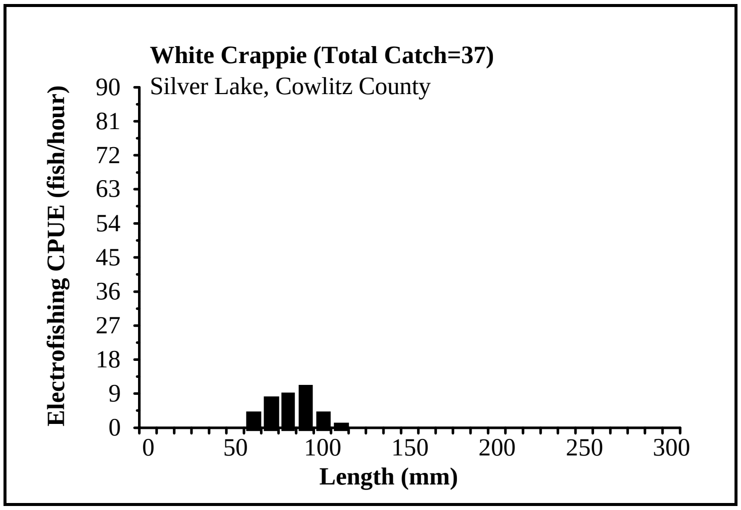

Figure 29. Relationship between total length and catch per unit effort of electrofishing for white crappie (*Pomoxis annularis*) at Silver Lake (Cowlitz County) during fall 1997.

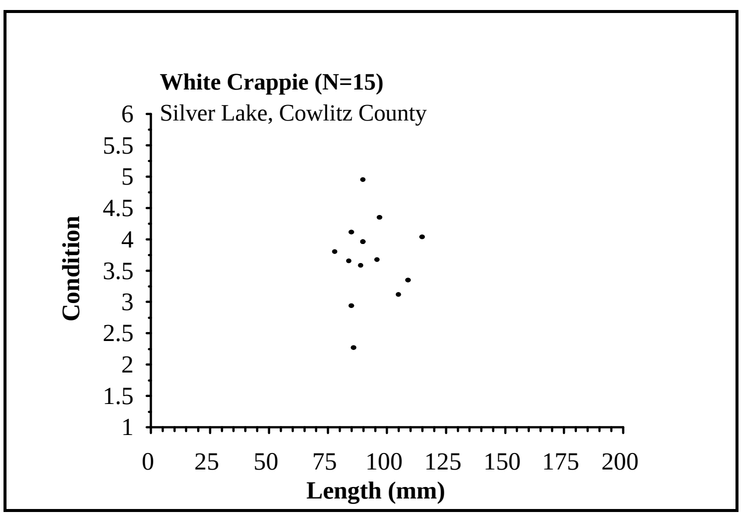

Figure 30. Relationship between total length and condition (*C*) of white crappie (*Pomoxis annularis*) from Silver Lake, Cowlitz County.

DISCUSSION

Balancing predator and prey fish populations is the hallmark of warmwater fisheries management. According to Bennett (1962a), the term 'balance' is used loosely to describe a system in which omnivorous forage fish or prey, such as yellow perch or bluegill, maximize food resources to produce harvestable-size stocks for fishermen and an adequate forage base for piscivorous fish or predators, such as largemouth bass. Predators must reproduce and grow to control overproduction of both 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 size structure, growth, and condition (W_r or C) provide useful information on the adequacy of the food supply (Kohler and Kelly 1991) and balance within a body of water. Characteristics of unbalanced populations include poor growth or condition, and low recruitment (Swingle 1950, 1956; Kohler and Kelly 1991; Masser *undated*).

During fall 1997, Silver Lake showed some indications of having an unbalanced fish community. The size structure, growth pattern, and condition of Silver Lake fish suggest that the fish were not foraging satisfactorily. The dominant forage fish species in the lake (yellow perch and bluegill) exhibited either below average growth, condition, or both. Although most forage fish appeared to be reproducing adequately, as indicated by their size structures, juvenile warmouth, pumpkinseed, and bullheads were lacking, as were intermediate size black crappie. With the exception of warmouth and black crappie, few, if any, quality size fish were captured. Therefore, despite the recent increase of benthic invertebrates and rapid reproduction of zooplankton subsequent to stocking grass carp (KCM 1998), these fish were unable to find sufficient forage.

Over the years, Silver Lake's largemouth bass population has undergone some changes as well. For example, the mean condition factor (C) of fish measuring $\geq$ 203 mm TL decreased from about 5.0 in 1979 (Lucas 1986) to 4.6 in 1996 (KCM 1998), or 8% during the 17-year period. Furthermore, before grass carp were stocked into the lake, the density of fish measuring > 254 mm TL decreased from 24 fish ha^{-1} in 1986 (Lucas 1986) to 18 fish ha^{-1} in 1991 (KCM 1998), or 25% during the 5-year period. By 1996, 4 years after stocking grass carp, the density of largemouth bass measuring > 254 mm TL remained at 18 fish ha^{-1} , although the number of larger fish (> 356 mm TL) increased (KCM 1998). Still, growth of Silver Lake largemouth bass has changed little since 1986 (Lucas 1986; John Weinheimer, WDFW, personal communication).

Causes for the variation described above are complex and difficult to isolate from a single survey; however, some inferences can be drawn from previous studies. For example, disparate fishing pressure within a lake may lead to an unbalanced fish community. Bennett (1962b) characterized underfished populations by high survival of all year classes, with small intermediate age fish and few, harvestable size fish. Overfished populations were characterized by overabundant, slow-growing young fish and few, large old fish. Additional research may show that the forage fish at Silver Lake are subject to underfishing, while largemouth bass are being overfished.

Introduction of grass carp may also affect the balance of a fish community. For example, Bailey (1978) found that aquatic plant removal generally improved the condition of largemouth bass and forage fish (*Lepomis* sp.) in Arkansas lakes 3 to 5 years after stocking grass carp, yet 32% of the lakes studied (N = 31) had warmwater fish communities exhibiting decreased condition. Other studies (Colle and Shireman 1980; Maceina et al. 1991) showed increases in growth or condition of warmwater fish species after removal of aquatic vegetation by grass carp, whereas Pauley et al. (1995) found little difference in condition before and 3 years after the introduction of the herbivorous fish. Although Silver Lake yellow perch showed little difference in growth and condition 5 years before and 6 years after the introduction of grass carp, bluegill growth and condition decreased.

The unbalanced fish community at Silver Lake may be the result of overcrowding, either by yellow perch, bluegill, or both. The decrease in the number of Silver Lake's largemouth bass between 1986 and 1991 (i.e., before the introduction of grass carp) and the recent increase of benthic invertebrates, including rapid reproduction of zooplankton (KCM 1998), may have led to overproduction of these species. The conditions observed during fall 1997 resemble those described by Swingle (1956) and Masser (*undated*) for populations experiencing intra- and interspecific competition because of crowding. According to Swingle (1956), crowding in warmwater fish populations results in slow growth (less food per individual) and reduced or inhibited reproduction.

However, given the elimination of submersed aquatic plants by grass carp (Scherer et al. 1995; KCM 1998), and the probable loss of prey items associated with these plants, the unbalanced fish community at Silver Lake may be the result of increased competition for an inadequate food supply rather than overproduction of forage fish. This hypothesis is supported by at least one model (Wiley et al. 1984), which showed a positive correlation between the concentration of aquatic plants and the production of both epiphytic invertebrates and forage fish.

Although the impact of stocking grass carp on resident fish communities remains controversial (Hoyer et al. 1985; Hoyer and Canfield 1996), it has been demonstrated that herbivory by the fish is a cost-effective aquatic plant management tool in the Pacific Northwest (Pauley et al. 1994). In Washington, public satisfaction concerning the use of grass carp has been moderate to high (Bonar et al. 1996). Still, it should be noted that stocking grass carp may result in population declines and/or changes in the structure of the sport fish community (Forester and Lawrence 1978; Krzywosz et al. 1980; Bettoli et al. 1992, 1993).

RECOMMENDATIONS

Conduct grass carp population study and, if necessary, reduce the density of grass carp

Grass carp were stocked into Silver Lake at a density of about 124 fish ha^{-1} (Scherer et al. 1995). After review, researchers at WDFW now recommend an initial stocking rate of no more than 60 fish vegetated ha^{-1} in Washington lakes (Bonar et al. 1996). A grass carp population estimate should reveal whether it is necessary to adjust the density of fish in Silver Lake to meet current management goals. Colle et al. (1978) recommended low doses of a natural piscicide (rotenone) to selectively remove grass carp from Florida lakes for population estimate and/or control purposes. But given the large size of Silver Lake, this method may be impractical. Alternatively, a recent study by Morrow et al. (1997) described methods of successfully evaluating the population density and growth of grass carp from a large reservoir system in South Carolina, which may be more appropriate for the sizeable Silver Lake.

Although it is currently illegal to capture grass carp in Washington, a provision should be made to allow the legal capture and/or removal of some fish (Bonar et al. 1996) from Silver Lake *if indicated* by the population study. Several methods have been used to successfully remove low numbers of grass carp from lakes, including rotenone (Colle et al. 1978) or rotenone-based pelleted bait (Fajt 1996), angling (Wilson and Cottrell 1979; Bonar et al. 1993a), herding (Bonar et al. 1993a), bowfishing (Morrow et al. 1997), and electrofishing (this study). If non-lethal methods are used to capture unwanted grass carp, the herbivorous fish may be transferred live to other lakes in need of aquatic plant control. However, Fajt (1996) recommended rotenone-based pelleted bait as the technique of choice for removing grass carp because of its efficacy and species-specificity.

Increase the density of aquatic plants

Little, if any, submersed aquatic vegetation was detected in Silver Lake two years after stocking grass carp (Scherer et al. 1995). Although one study (Shireman et al. 1984, cited in Hoyer et al. 1985) showed a fourfold increase in harvestable biomass of sport fish after removal of aquatic macrophytes by grass carp, most researchers agree that a low or moderate level of aquatic vegetation is better than none or too much (Savino and Stein 1982; Durocher et al. 1984; Wiley et al. 1984; Killgore et al. 1989; Davies and Rwangano 1991). For example, in Virginia, Killgore et al. (1989) collected up to seven times more fish in areas with aquatic plants than in areas lacking plants.

When feeding, grass carp discriminate between aquatic plant species (Colle et al. 1978; Mitzner 1978; Cassani 1981; Bonar et al. 1990, 1993b; Pauley et al. 1994; Scherer et al. 1995). Furthermore, food preference is related to grass carp size (Colle et al. 1978; Bonar et al. 1993b). The relative preference of many Pacific Northwest aquatic macrophytes was summarized and ranked by Pauley et al. (1994). Not surprisingly, two of the dominant emergent aquatic plant species at Silver Lake (yellow waterlily and watershield) were the least preferred by grass carp. Colle et al. (1978) found that grass carp discriminated against common naiad (*Najas flexilis*) and coontail (*Ceratophyllum demersum*). Although Scherer et al. (1995) reported that grass carp eliminated Silver Lake coontail within two years of stocking the herbivorous fish, Bonar et al. (1993b) found that large grass carp preferred other plants over coontail. Therefore, it may be possible to introduce or encourage expansion of native vegetation considered unpalatable (e.g., common naiad) by the large grass carp in Silver Lake. By increasing aquatic plant densities, production of epiphytic invertebrates should increase (Wiley et al. 1984), resulting in more food available to forage fish.

Partially submersed fences (‘exclosures’) were used to successfully recolonize aquatic vegetation eliminated by grass carp in Devils Lake, Oregon (Sytsma 1996). The exclosures, which measured 3 x 3 m each, were constructed of plastic fabric (2.5 cm mesh) and posts. To prevent grass carp entry, the fabric extended from the substrate to 1.5 m above the water surface. Although not fool-proof (grass carp broke into two of the exclosures), Sytsma’s (1996) study showed that aquatic plants rapidly recolonized when grass carp herbivory was suppressed.

An alternative to the exclosures used by Sytsma (1996) would be to construct basket-style structures from steel rebar and plastic mesh. The mesh should be of a size to allow forage fish to come and go, yet keep grass carp out. When placed ‘bottom up’ on the substrate, the exclosures will form a three-dimensional barrier. Although completely mobile, the structures will be heavy enough to keep grass carp from breaking in underneath the rims. Unlike the fences used by Sytsma (1996), these exclosures will be totally submersed, resulting in no visual impacts.

Enhance littoral zone with natural or artificial structures

Underwater structure provides warmwater fish with food and shelter (i.e., refuge from predation). Although Hoyer and Canfield (1996) demonstrated that largemouth bass in small Florida lakes can exist without submersed or emergent aquatic vegetation (the result of grass carp herbivory), Colle et al. (1989) found that Florida largemouth bass had significant preferences for natural and artificial structures, such as water tupelo (*Nyssa aquatica*) and piers, after removal of all aquatic vegetation by grass carp. Furthermore, largemouth bass and bluegill were rapidly attracted to artificial vegetation (green polypropylene ribbons tied to square plastic mesh mats) placed in a small Ohio lake lacking natural plants (Hayse and Wissing 1996).

Two years after stocking grass carp into Silver Lake, the warmwater fish community experienced the loss of important food and shelter with the elimination of submersed aquatic plants. During fall 1997, WDFW personnel deployed seven fish attraction devices to enhance both the littoral zone and warmwater fishing opportunities at the lake. The frame-like structures, known as Owen Walls, measured 1.2 x 2.4 m each and were constructed of 100 mm (4") PVC pipe, plastic webbing, and concrete blocks. The honeycomb pattern of the plastic webbing allows small fish to swim easily in and around the structures while avoiding predation from large fish, which are attracted to the newly concentrated prey base. Thus, the devices should provide additional habitat and refuge for small and large fish alike.

Given the reduction of Silver Lake’s natural cover in recent years, the fish community would probably benefit by increasing the amount of underwater structure (vegetation or otherwise) in the littoral zone. The exclosures described above would not only provide shelter, but act as foci for the colonization of aquatic plants. If artificial structures such as Owen Walls or the ‘vegetation’ used by Hayse and Wissing (1996) are cost-prohibitive, then natural structures such as tree stumps or root wads should be considered.

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