1997 GREEN LAKE SURVEY: THE WARMWATER FISH COMMUNITY OF AN URBAN LAKE PLAGUED BY ALGAL BLOOMS AND EURASIAN WATERMILFOIL

by

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INTRODUCTION AND BACKGROUND

Green Lake is a highly eutrophic, relatively shallow (mean depth = 3.8 m; max depth = 9.1 m) body of water located within the city limits of Seattle, King County. The lake is fed by rainfall, stormwater runoff, city drinking water, and subsurface seepage. There are no natural surface water inflows to Green Lake. Surface water exits the lake (surface area = 105 ha) through three man-made outflows located along the northeast shoreline. The dominant emergent aquatic plant is white water lily (*Nymphaea odorata*), which is located only along the western shoreline. The dominant submerged aquatic plant is, unfortunately, invasive Eurasian watermilfoil (*Myriophyllum spicatum*). Others include waterweed (*Elodea canadensis*), coontail (*Ceratophyllum demersum*) and brittlewort (*Nitella* sp.). Details of these characteristics can be found in previous studies prepared for the Seattle Department of Parks and Recreation (SDPR) by private contractors (URS 1987; KCM 1995) and through the Washington Department of Ecology (Kirk Smith; personal communication).

Because of its central location, just north of downtown Seattle, Green Lake is valued by residents for its unique, aesthetic qualities as well as its recreational opportunities. Shoreline activities include walking, jogging, bicycling, roller skating, and fishing [the lake is stocked with rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and channel catfish (*Ictalurus punctatus*)]. Water sports include swimming, wind surfing, and crew (rowing). The SDPR maintains all public access, including a small, primitive boat launch at the south end of the lake.

Throughout most of the 20th century, intense blue-green algae blooms have hindered recreational activities around the lake. Both internal and external sources of nutrients, primarily phosphorous, are known to induce the blooms (URS 1987; KCM 1995). These include aquatic plant senescence and decay, translocation by vertically migrating blue-green algae, bioturbation by bottom-feeding common carp (*Cyprinus carpio*), waterfowl excretion, and stormwater runoff (KCM 1995). Furthermore, during the 1980's, Green Lake was invaded by Eurasian watermilfoil which covered up to 90% of the lake bottom. In recent years, restoration efforts included treating the lake with alum (aluminum sulfate) and sodium aluminate to inactivate sediment phosphorous (1991), relocating or sterilizing resident Canada geese (ongoing since 1991), mechanical harvesting of lake vegetation (ongoing since 1992), and diverting/filtering stormwater runoff (drain improvements completed in 1993).

In addition to the activities described above, the Green Lake management program, which was largely funded by the Washington Department of Ecology and the United States Environmental Protection Agency (EPA), recommended enhancing the warmwater fish community [e.g., largemouth bass (*Micropterus salmoides*) or crappie (*Pomoxis* sp.)] to control the common carp population through predation, and to provide better fishing opportunities (KCM 1995). Given its physical characteristics, Green Lake is well suited for warmwater fish species. Therefore, in an ongoing effort to monitor the success of the restoration program, as well as improve the warmwater fishery at the lake, personnel from the Washington Department of Fish and Wildlife's (WDFW) Warmwater Enhancement Program conducted a fisheries survey of Green Lake during the early fall of 1997.

MATERIALS AND METHODS

Green Lake was surveyed by a three-person investigation team during September 22 - 25, 1997. Fish were captured using two sampling techniques: electrofishing and gill netting. The electrofishing unit consisted of a 5.5 meter (m) Smith-Root 5.0 GPP ‘shock boat’ using a DC current of 120 cycles/sec at ~ 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 26 consecutively numbered equidistant sections of ~ 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 the sampling locations. While electrofishing, the boat was maneuvered through the shallows (depth range ~ 0.2 to 1.5 m), adjacent to the shoreline, at a rate of ~ 18.3 m/minute (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 23% (~ 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 3629 seconds (‘pedal-down’ time), or roughly *two* standard units of 0.5 hours each; total gill netting time was 54.4 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 1 mm and assigned to a 10-mm size class based on its 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 1 gram (g). Furthermore, scales were removed from these fish for aging purposes. 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). Members of the carp and catfish families (Cyprinidae and Ictaluridae, respectively) were not aged.

Water quality data was collected during midday from three locations on September 24, 1997 (Figure 1). Using a Hydrolab® probe and digital recorder, information was gathered concerning five parameters: dissolved oxygen, redox, temperature, pH, and conductivity. Secchi disc readings were recorded in feet then converted to m (Table 1).

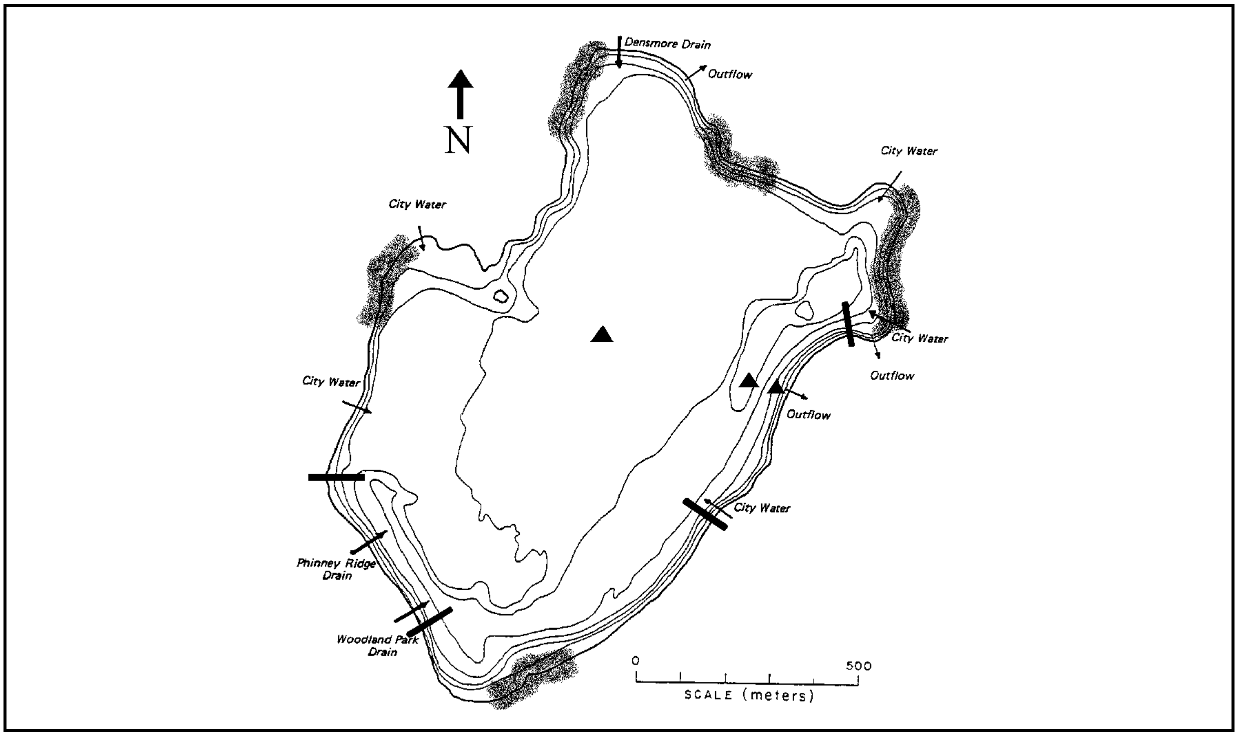

Figure 1. Map of Green Lake (King County) showing sampling locations. Shaded areas indicate sections of shoreline where electrofishing occurred. Bars extending into lake indicate placement of gill nets. Triangles indicate water quality stations. Arrows indicate flow of water into and out of lake (redrawn from URS 1987).

Table 1. Water quality from three locations (near shore, offshore, and mid-lake) at Green Lake (King County). Samples were collected midday on September 24, 1997.

		Parameter					
Location	Secchi (m)	Depth (m)	DO	Temp (°C)	pH	Conductivity	Redox
Near shore	1.2	1	11.3	19.7	9.2	102	331
(by outfall)		2	11.6	19.5	9.3	102	331
		2.9	6.1	18.0	7.9	103	385
Offshore	---	1	12.0	19.7	9.3	102	329
		2	12.1	19.4	9.3	102	329
		3	9.1	18.2	8.7	102	359
		4	5.8	17.6	7.8	105	394
		5	5.6	17.6	7.6	107	402
Mid-lake	1.2	1	11.9	19.5	9.3	102	331
		2	11.8	19.1	9.4	104	328
		3	9.2	18.0	8.5	105	361
		4	6.4	17.6	7.8	104	388

Data analysis

The species composition by number of the fish captured at Green Lake was determined using procedures outlined in Fletcher et al. (1993). The species composition by weight (kg) of the fish captured, excluding 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 1962a). Only those 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 largemouth bass may suggest very 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 (Chew 1974) resulting in a totally different size distribution by the following year. For panfish, such as pumpkinseed (*Lepomis gibbosus*), the cut-off was 80 mm TL. For larger fish, such as common carp (*Cyprinus carpio*) or largemouth bass, the cut-off was 100 mm TL.

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. The 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 W_s equations for many warmwater fish species, including the minimum length recommendations for their application, are listed in Murphy et al. (1991). Liao et al. (1995) derived the W_s equation for pumpkinseed. 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 (ODFW 1997). With the exception of rock bass (*Ambloplites rupestris*), yellow perch (*Perca flavescens*), and smallmouth bass (*Micropterus dolomieui*), the W_r values from this study were compared to both the state average and national standard. Furthermore, given the inherent differences in growth between eastern and western Washington largemouth bass, the W_r values of the Green Lake fish were plotted against the western Washington average only.

Age and growth of warmwater fish in Green 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 Green 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 vs. age n. However, for the same reason above, the back-calculated lengths of the Green Lake largemouth bass were plotted against the western Washington average only.

RESULTS

Species composition

Table 2 summarizes the species composition and size of fish captured at Green Lake during the study period. The predominant fish in the lake were common carp and largemouth bass. The former was dominant by weight (61.9%), the latter by number (43.3%). Although pumpkinseed were fairly abundant (12.1%), they contributed little to the total biomass (4.3%). Conversely, rainbow trout were relatively low in number, but represented over 8% of the total biomass. Species other than the warmwater variety accounted for less than 11% of the total biomass and number captured. Rock bass, brown bullhead (*Ameiurus nebulosus*), yellow perch, and smallmouth bass were the least abundant warmwater fish (Table 2; Figures 2 and 3).

Table 2. Species composition (excluding young-of-year) by weight (kg) and number, and total number and size of fish captured (including young-of-year) at Green Lake (King County) during an early fall 1997 survey of warmwater fish.

	Species composition		Total #	
Type of fish	by kg	by #	captured	Size range (mm TL)
Common carp (*Cyprinus carpio*)	80.9	696	705	100 - 630
Largemouth bass (*Micropterus salmoides*)	27.5	761	1542	75 - 193
Rainbow trout (*Oncorhynchus mykiss*)	10.7	49	53	63 - 687
Pumpkinseed (*Lepomis gibbosus*)	5.6	212	258	26 - 137
Brown trout (*Salmo trutta*)	2.6	2	2	488 - 510
Rock bass (*Ambloplites rupestris*)	1.7	18	90	47 - 232
Brown bullhead (*Ameiurus nebulosus*)	1.1	9	9	147 - 271
Yellow perch (*Perca flavescens*)	0.3	2	2	230 - 233
Smallmouth bass (*Micropterus dolomieui*)	0.2	1	1	221
Sculpin (*Cottus* sp.)	---	8	8	$\leq$ 125
Total	130.6	1758	2670	

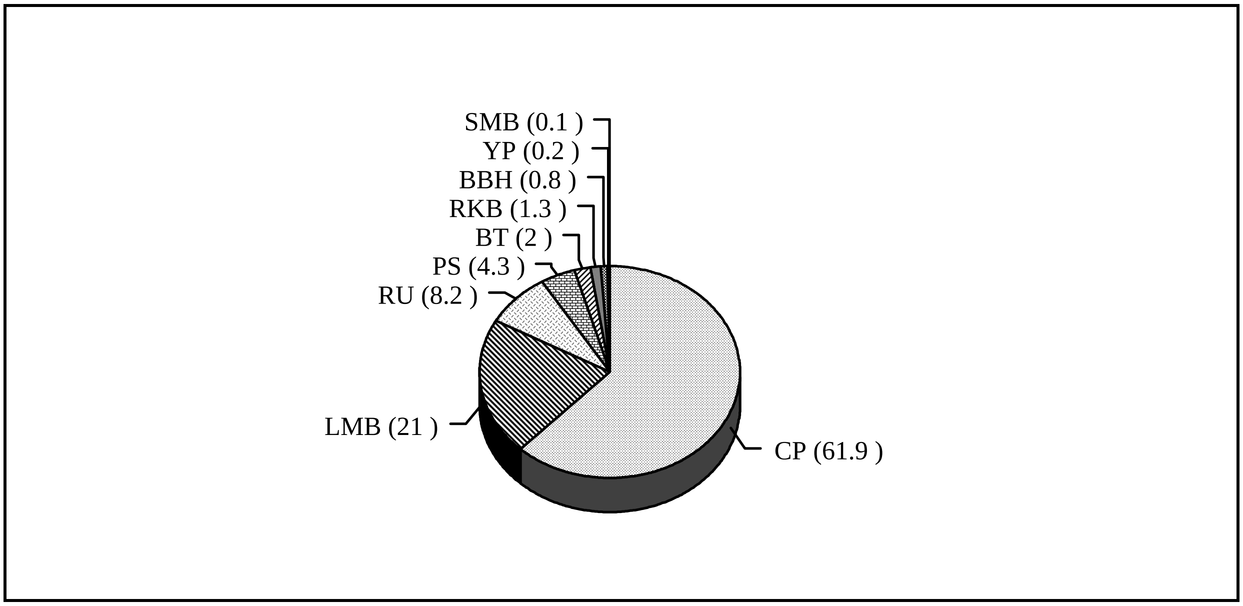

Figure 2. Species composition by weight (kg) of fish captured at Green Lake (King County) during early fall 1997. CP = common carp, LMB = largemouth bass, RU = rainbow trout (unknown race), PS = pumpkinseed, BT = brown trout, RKB = rock bass, BBH = brown bullhead, YP = yellow perch, and SMB = smallmouth bass. Values are percent of total biomass (130.6 kg, excluding young-of-year and non-game fish).

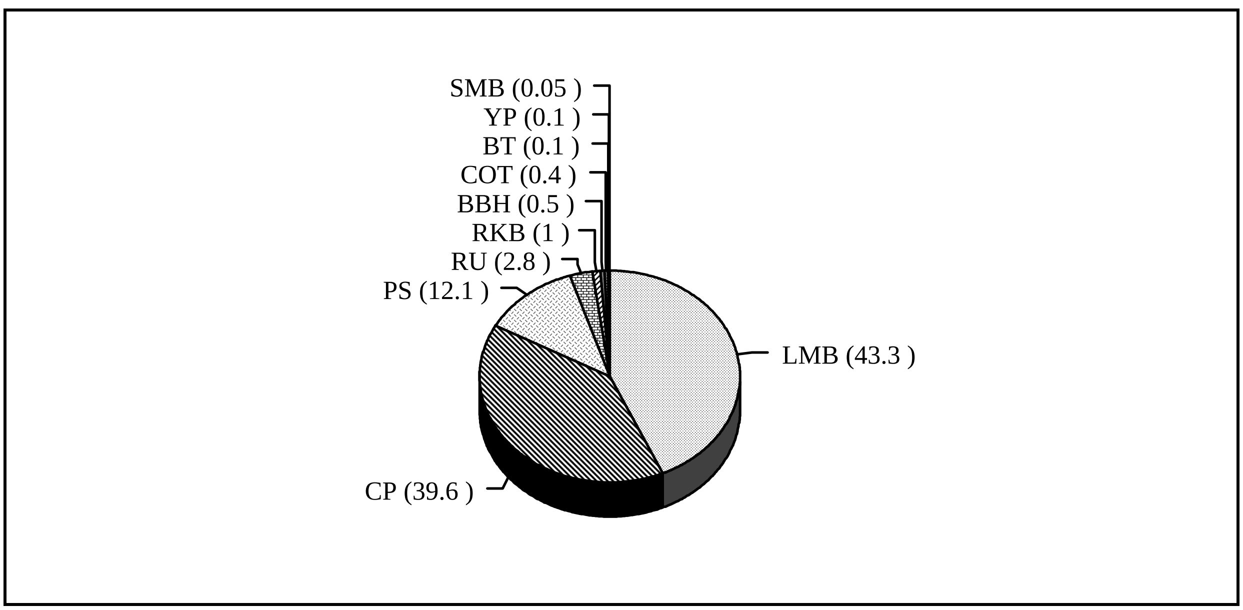

Figure 3. Species composition by number of fish captured at Green Lake (King County) during early fall 1997. LMB = largemouth bass, CP = common carp, PS = pumpkinseed, RU = rainbow trout (unknown race), RKB = rock bass, BBH = brown bullhead, COT = sculpin (Cottidae), BT = brown trout, YP = yellow perch, and SMB = smallmouth bass. Values are percent of total (N = 1758, excluding young-of-year).

Common carp

The size range of common carp was 100 to 630 mm TL (Table 2). Most of these were between 130 and 190 mm TL (Figures 4 and 5). At least two year classes (young and old) were evident from the length frequency histograms, however, their actual ages were unknown. No medium size (or age) fish were captured. Roughly 25% of the carp observed were the 'mirror' variety (few, irregularly distributed scales).

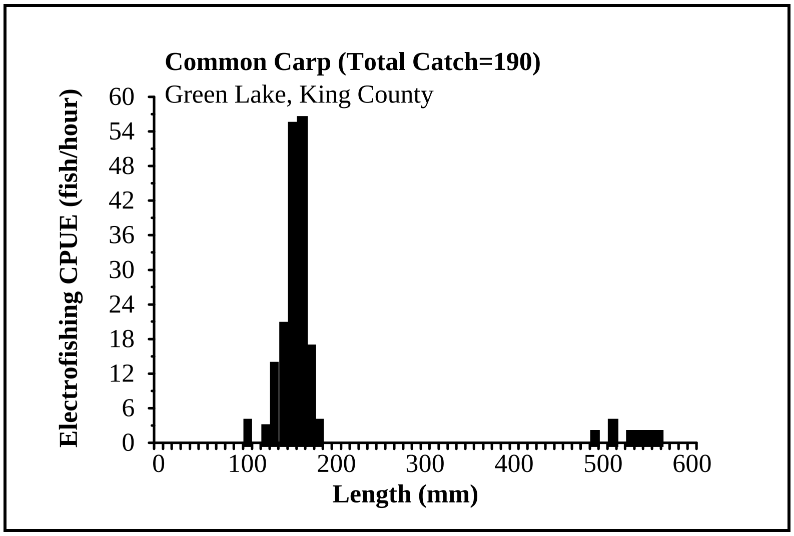

Figure 4. Relationship between total length and catch per unit effort of electrofishing for common carp (*Cyprinus carpio*) at Green Lake (King County) during early fall 1997.

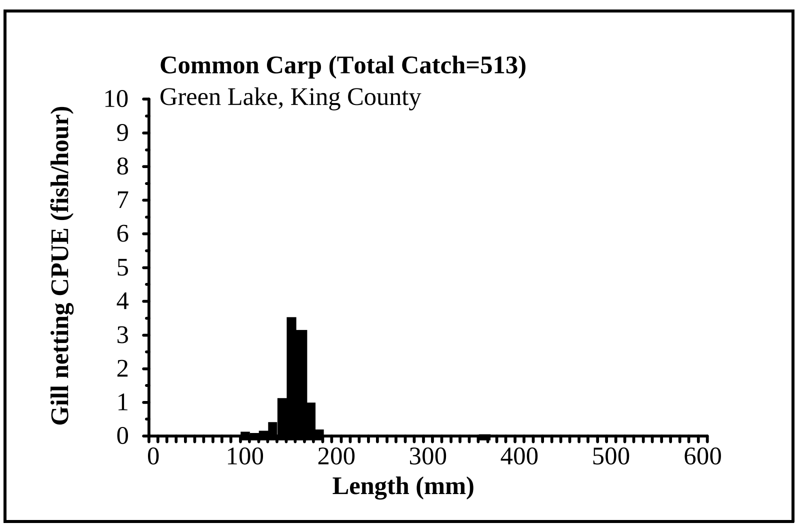

Figure 5. Relationship between total length and catch per unit effort of gill netting for common carp (*Cyprinus carpio*) at Green Lake (King County) during early fall 1997.

Largemouth bass

The size range of Green Lake largemouth bass was 75 to 193 mm TL (Table 2; age 0+ to 4+). No large, old fish were captured. The CPUE of electrofishing was extraordinarily high because of the number of largemouth bass in the smallest size classes (Figure 6). For example, over 700 young-of-year ($\leq$ 100 mm TL) were captured per hour of electrofishing. Of the remaining year classes, ages 1+ (~ 135 mm TL) and 2+ (~ 160 mm TL) were dominant (Table 3; Figures 6 and 7). Growth of Green Lake largemouth bass was lower when compared to the western Washington average, as indicated by lower mean back-calculated lengths irrespective of age *n* (Table 3; Figure 8). However, the relative weights were consistent with the western Washington average and constant with length or age (Figure 9).

Table 3. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Green Lake (King County) during early fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age			
Year class	# fish	1	2	3	4
1997	23	**42.2**			
1996	28	45.2	**135.6**		
1995	15	44.8	115.2	**160.4**	
1994	5	41.2	95.7	146.2	**176.8**
	Overall mean	**43.9**	**125.1**	**156.8**	**176.8**
Western Washington average		60.4	145.5	222.2	261.1

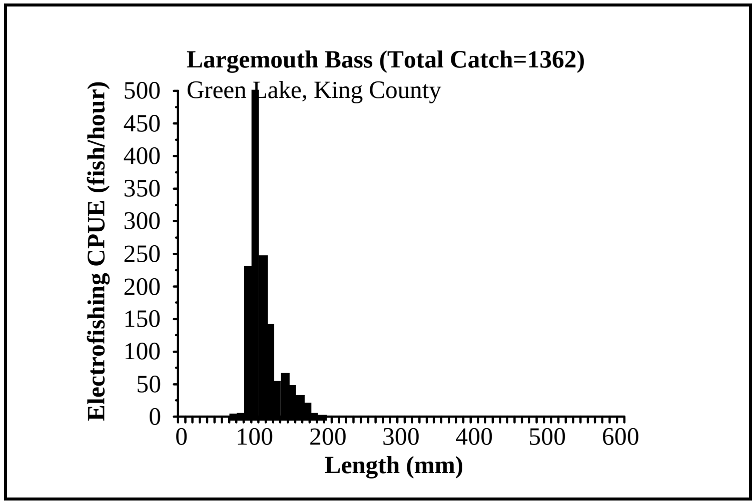

Figure 6. Relationship between total length and catch per unit effort of electrofishing for largemouth bass (*Micropterus salmoides*) at Green Lake (King County) during early fall 1997.

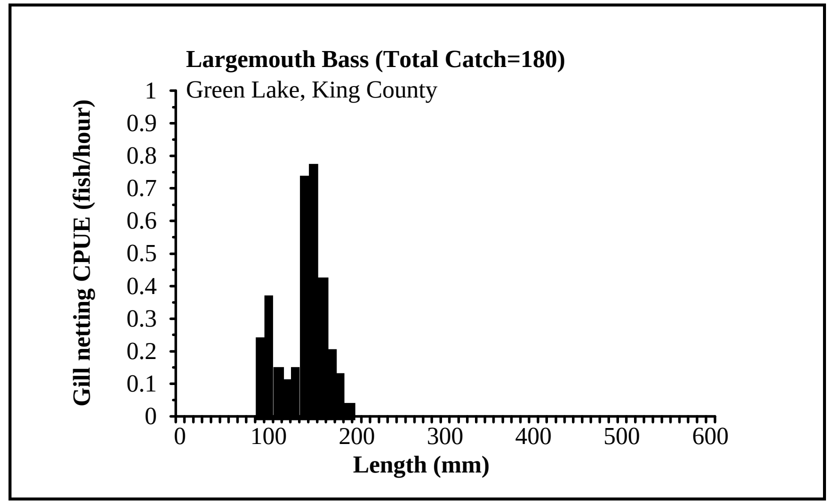

Figure 7. Relationship between total length and catch per unit effort of gill netting for largemouth bass (*Micropterus salmoides*) at Green Lake (King County) during early fall 1997.

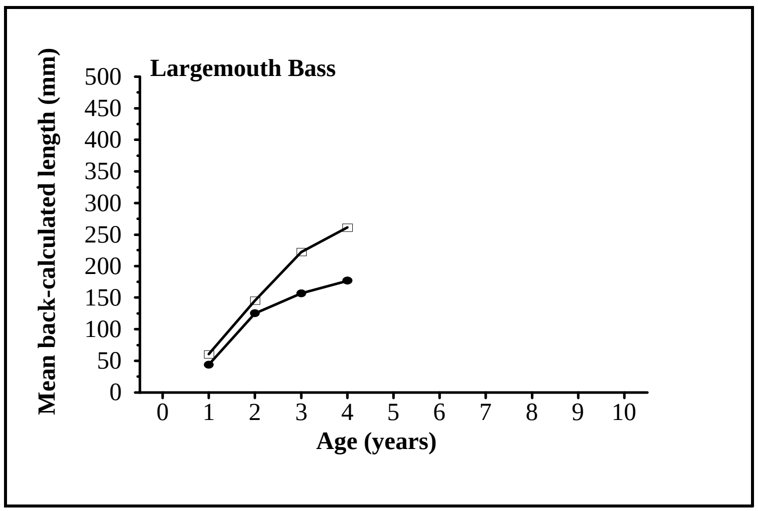

Figure 8. Growth of largemouth bass (*Micropterus salmoides*) from Green Lake, King County (closed, black circles), compared to the western Washington average (open, clear rectangles). Values are mean back-calculated lengths at age.

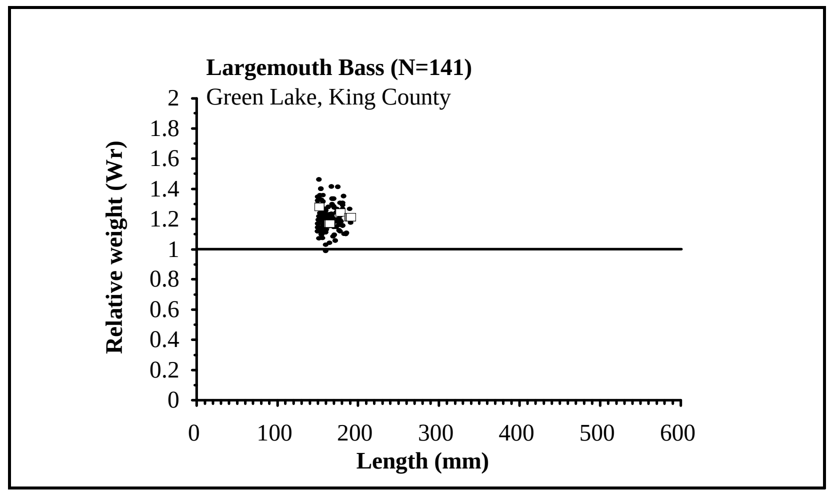

Figure 9. Relationship between total length and relative weight (W_r) of largemouth bass (*Micropterus salmoides*) from Green Lake, King County (closed, black circles) compared to the western Washington average (open, clear rectangles) and the national standard (horizontal line at 1.0).

Pumpkinseed

Green Lake pumpkinseed ranged in size from 26 to 137 mm TL (Table 2; age 0+ to 4+). Most of these exceeded 80 mm TL (age 0+); however, large, old fish were not observed. The predominant year classes (ages 1+ and 2+) consisted of fish measuring ~ 90 - 110 mm TL (Table 4; Figures 10 and 11). Although growth of Green Lake pumpkinseed was generally higher when compared to the state average, their relative weights were lower (Table 4; Figures 12 and 13).

Table 4. Age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Green Lake (King County) during early fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age			
Year class	# fish	1	2	3	4
1997	10	**39.5**			
1996	26	43.6	**89.9**		
1995	13	43.8	86.4	**110.3**	
1994	2	37.9	69.8	106.5	**123.7**
	Overall mean	**42.6**	**87.8**	**109.8**	**123.7**
	State average	23.6	72.1	101.6	122.7

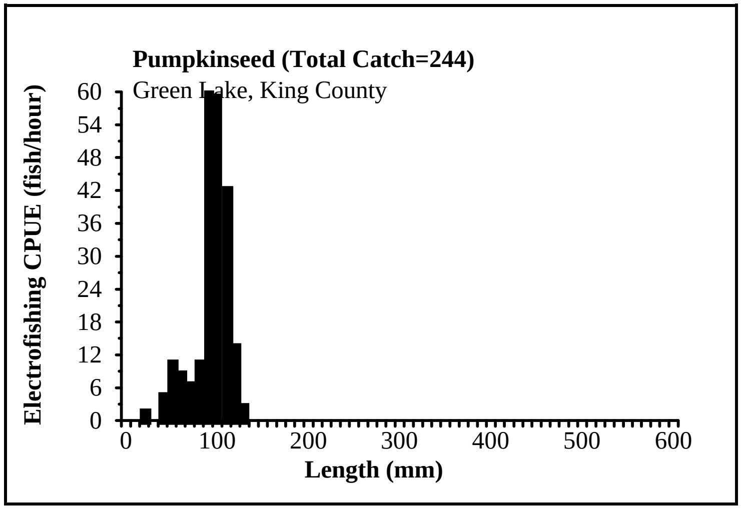

Figure 10. Relationship between total length and catch per unit effort of electrofishing for pumpkinseed (*Lepomis gibbosus*) at Green Lake (King County) during early fall 1997.

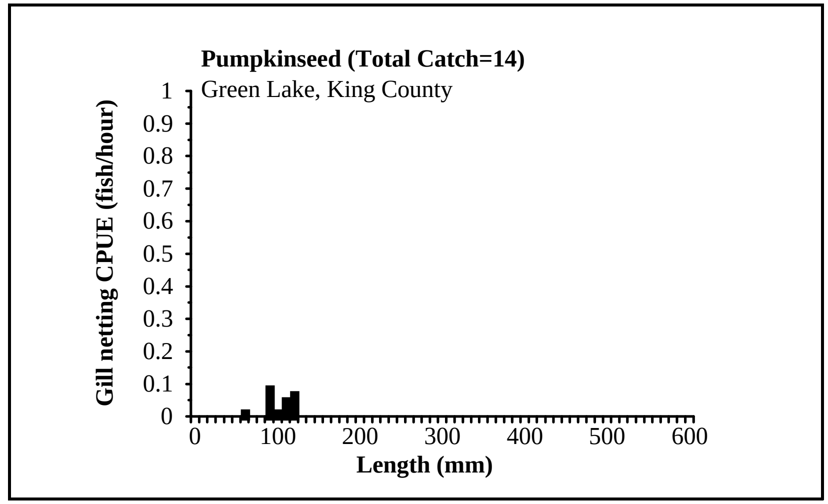

Figure 11. Relationship between total length and catch per unit effort of gill netting for pumpkinseed (*Lepomis gibbosus*) at Green Lake (King County) during early fall 1997.

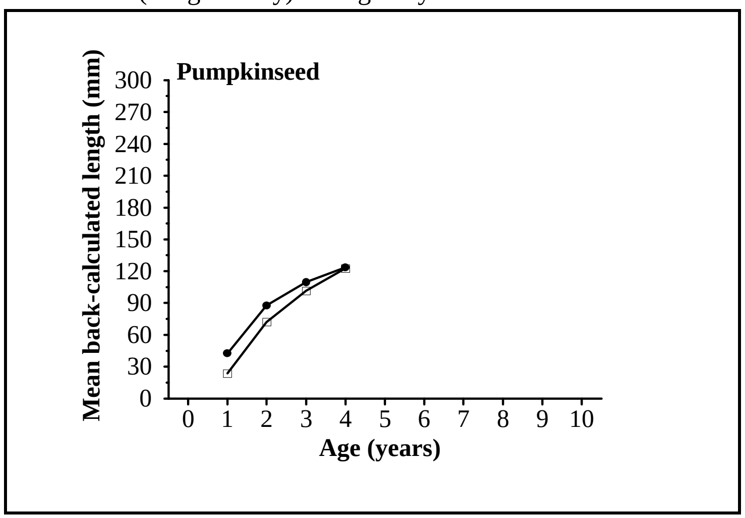

Figure 12. Growth of pumpkinseed (*Lepomis gibbosus*) from Green Lake, King County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

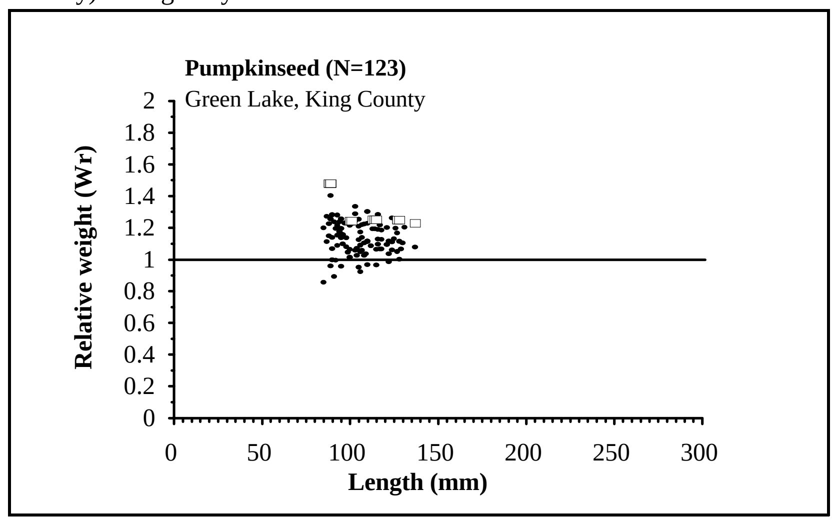

Figure 13. Relationship between total length and relative weight (W_r) of pumpkinseed (*Lepomis gibbosus*) from Green Lake, King County (closed, black circles) compared to the Washington State average (open, clear rectangles) and the national standard (horizontal line at 1.0).

Rock bass

The size of rock bass ranged from 47 to 232 mm TL (Table 2; age 0+ to 9+). Most of these were young-of-year and age 1+ fish (< 80 mm TL; Figures 14 and 15). Only one large, old fish was observed (232 mm TL, age 9+); furthermore, the 1990 year class (age 8+) was absent from samples (Table 5; Figure 15). During the first three years, growth of Green Lake rock bass was slightly higher than the state average. However, after age 3, growth was lower when compared to rock bass statewide (Table 5; Figure 16). These fish were in relatively good condition by national standards (Figure 17), but no state average relative weights exist for further comparison.

Table 5. Age and growth of rock bass (*Ambloplites rupestris*) captured at Green Lake (King County) during early 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	1	**57.7**								
1996	1	42.7	**111.0**							
1995	3	44.5	92.1	**124.5**						
1994	3	50.7	88.0	122.2	**141.1**					
1993	3	52.6	82.5	106.6	129.1	**148.0**				
1992	2	47.4	97.8	122.9	144.1	160.6	**156.5**			
1991	2	47.1	85.7	109.0	127.0	147.0	162.1	**182.0**		
1990	0									
1989	1	56.9	92.6	119.3	149.5	168.4	185.2	196.3	208.6	**224.2**
Overall mean		**49.3**	**90.6**	**117.4**	**136.6**	**153.5**	**160.6**	**186.8**	**208.6**	**224.2**
State average		29.0	69.6	117.6	151.6	178.1	192.8	202.7	**----**	**----**

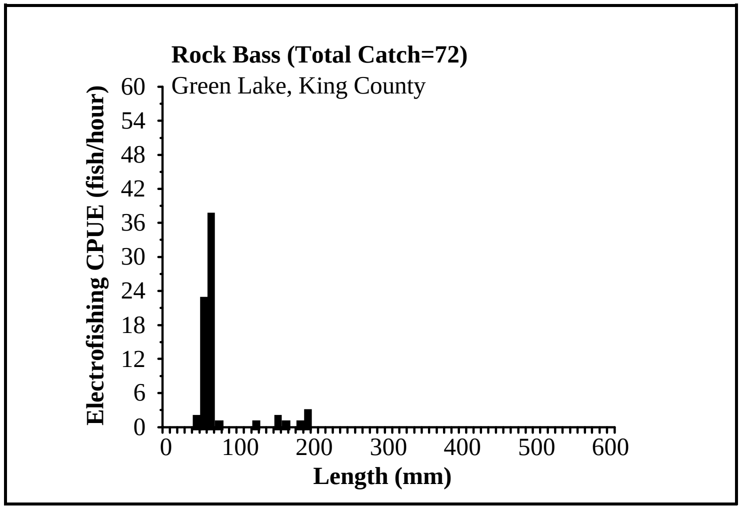

Figure 14. Relationship between total length and catch per unit effort of electrofishing for rock bass (*Ambloplites rupestris*) at Green Lake (King County) during early fall 1997.

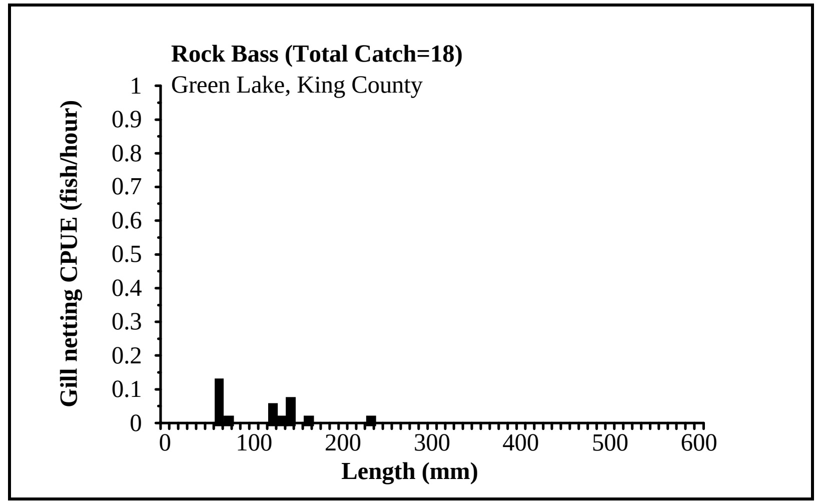

Figure 15. Relationship between total length and catch per unit effort of gill netting for rock bass (*Ambloplites rupestris*) at Green Lake (King County) during early fall 1997.

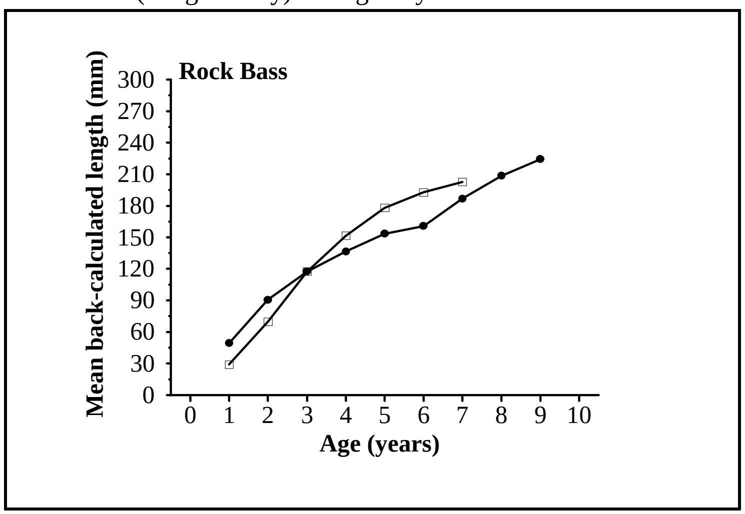

Figure 16. Growth of rock bass (*Ambloplites rupestris*) from Green Lake, King County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

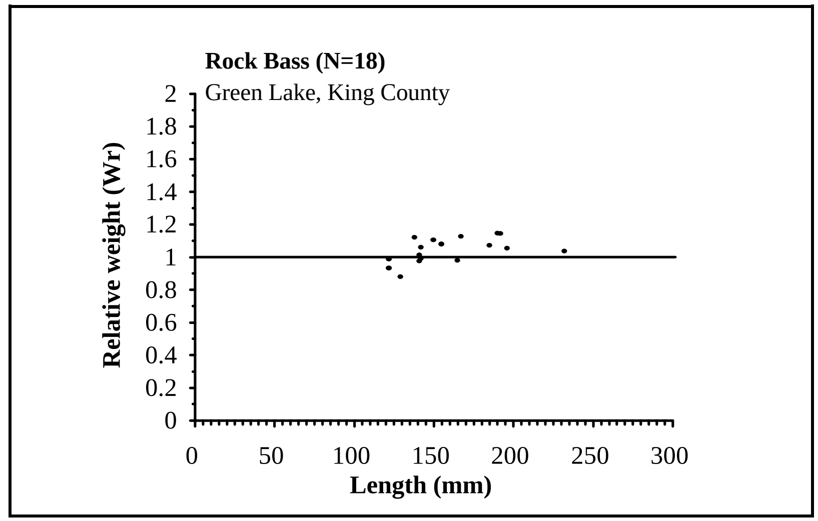

Figure 17. Relationship between total length and relative weight (W_r) of rock bass (*Ambloplites rupestris*) from Green Lake, King County (closed, black circles) compared to the national standard (horizontal line at 1.0).

Brown bullhead

The size range of brown bullhead was 147 to 271 mm TL (Table 2). At least two year classes were evident from the length frequency histograms (Figures 18 and 19), however, their actual ages were unknown.

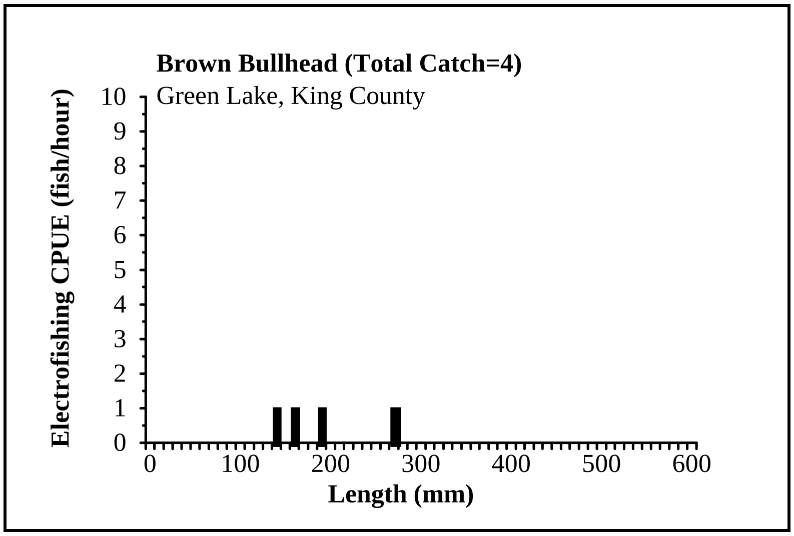

Figure 18. Relationship between total length and catch per unit effort of electrofishing for brown bullhead (*Ameiurus nebulosus*) at Green Lake (King County) during early fall 1997.

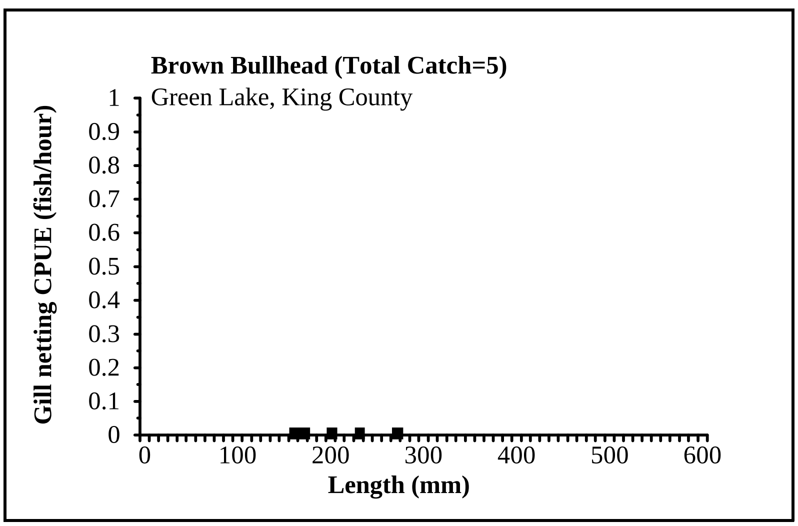

Figure 19. Relationship between total length and catch per unit effort of gill netting for brown bullhead (*Ameiurus nebulosus*) at Green Lake (King County) during early fall 1997.

Yellow perch

Only two yellow perch were captured during the study period. One fish measured 230 mm TL and weighed 152 g, the other measured 233 mm TL and weighed 194 g. Although the growth of these individuals (age 4+) was above average when compared to yellow perch statewide (Table 6; Figure 20), their condition factors (4.5 and 5.5, respectively) were consistent with the state average (determined using procedures from Fletcher et al. 1993).

Table 6. Age and growth of yellow perch (*Perca flavescens*) captured at Green Lake (King County) during early fall 1997. Values are mean back-calculated lengths at annulus formation.

		Mean length (mm) at age			
Year class	# fish	1	2	3	4
1994	2	**102.5**	**182.4**	**206.0**	**223.0**
	State average	59.7	119.9	152.1	192.5

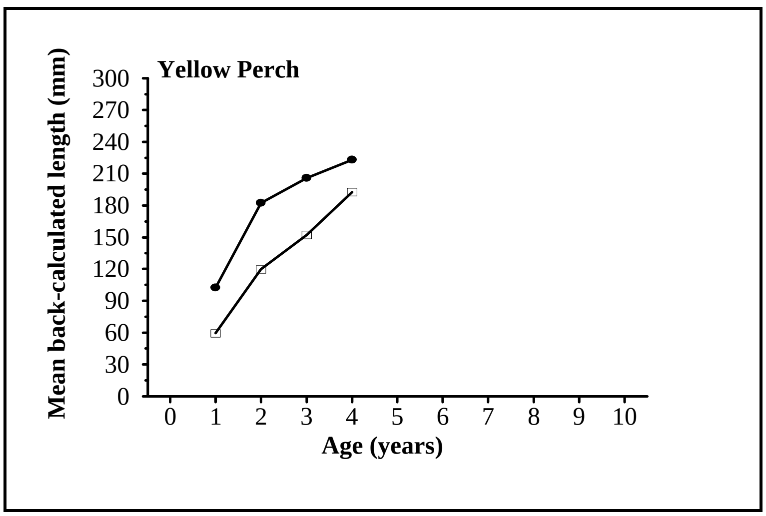

Figure 20. Growth of yellow perch (*Perca flavescens*) from Green Lake, King County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are mean back-calculated lengths at age.

Smallmouth bass

One smallmouth bass was captured at Green Lake during the early fall of 1997. The fish measured 221 mm TL and weighed 194 g. Although growth of the individual (age 3+) was consistent with smallmouth bass statewide (Table 7; Figure 21), its condition factor (6.5) was above average (determined using procedures from Fletcher et al. 1993).

Table 7. Age and growth of smallmouth bass (*Micropterus dolomieui*) captured at Green Lake (King County) during early fall 1997. Values are back-calculated lengths at annulus formation.

		Length (mm) at age		
Year class	# fish	1	2	3
1995	1	**65.3**	**148.2**	**190.9**
	State average	70.4	146.3	211.8

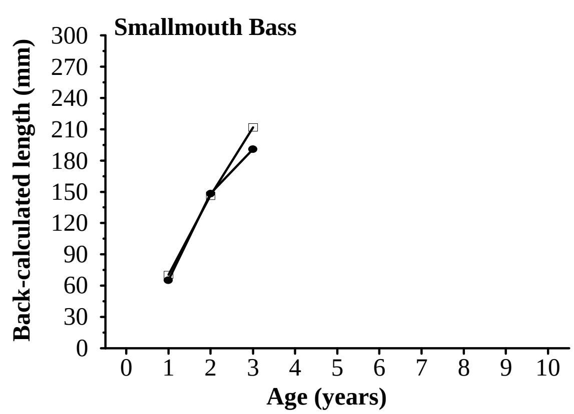

Figure 21. Growth of smallmouth bass (*Micropterus dolomieui*) from Green Lake, King County (closed, black circles), compared to the Washington State average (open, clear rectangles). Values are back-calculated lengths at age.

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 (e.g., common carp or pumpkinseed), maximize food resources to produce harvestable-size stocks for fishermen and an adequate forage base for piscivorous fish, such as largemouth bass (predator). Predators must reproduce and grow to control overproduction of both prey and predator species, as well as provide adequate fishing. Characteristics of unbalanced populations include poor growth or condition, and low recruitment (Swingle 1950, 1956; Kohler and Kelly 1991; Masser *undated*). Therefore, in order to maintain balance within a body of water, fish must be able to forage effectively. An evaluation of size structure, growth, and relative weight (W_r) provides useful information on the adequacy of the food supply (Kohler and Kelly 1991).

During the early fall of 1997, Green Lake showed indications of having an imbalanced fish community. For example, in terms of biomass, the lake was clearly dominated by common carp. Although largemouth bass were abundant, their size structure and growth pattern suggest that these predators were unable to find sufficient forage to attain the size necessary to control overproduction of the common carp. Quality size largemouth bass were not observed. Furthermore, other forage fish (i.e., pumpkinseed and rock bass) were lacking, and exhibited either diminished growth or below average condition.

The 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, common carp tend to rapidly overpopulate a body of water (EPA 1993; Masser *undated*). The conditions at Green Lake resemble those described by Swingle (1956) for populations experiencing inter- and intraspecific crowding. According to Swingle, crowding in warmwater fish populations results in slow growth (less food per individual) and reduced or inhibited reproduction. This was evident in the other forage fish populations at Green Lake. Their size structure, growth pattern, and condition (i.e., W_r values) suggest that these fish were not able to feed effectively, possibly due to over-crowding and competition with the dominant common carp and juvenile largemouth bass.

Disparate fishing pressure within a lake may cause an imbalanced fish community. Bennett (1962c) 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 common carp and largemouth bass are being overfished at Green Lake.

However, besides the prolific common carp, the other likely cause of imbalance at Green Lake is excessive aquatic plant cover. Currently, the lake remains plagued by an invasion of submerged Eurasian watermilfoil. Hoyer and Canfield (1996) showed an inverse relationship between macrophyte abundance and growth of one and two year old largemouth bass. As macrophyte density increases, predator foraging efficiency decreases because of increased refuge available to prey. The increased survival of prey leads to greater population density (crowding) and more competition among these fish (Olson et al. 1998 and references therein). Clearly, the fish community at Green Lake would benefit by reducing the macrophyte cover (Davies and Rwangano 1991; Olson et al. 1998) and density of common carp (Bennett 1962b; EPA 1993; Masser *undated*). Furthermore, the Eurasian watermilfoil and bottom-feeding common carp are the major impediments to continued improvement in Green Lake water quality (KCM 1995).

RECOMMENDATIONS

Support stocking sterile grass carp to control nuisance aquatic plants

Since the mid-1980's, it has been demonstrated that grass carp (*Ctenopharyngodon idella*) could be 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). In their report to the SDPR, KCM (1995) recommended stocking sterile grass carp, rather than applying herbicides, to eradicate Eurasian watermilfoil. Prudent implementation of such a plan (i.e., stocking no more than 60 fish per vegetated ha), in conjunction with the recommendations by Bonar et al. (1996), may improve the water quality and warmwater fishery at Green Lake. For example, the subsequent decrease in plant biomass should cause a reduction in phosphorous loading from plant senescence and decay. Moreover, a recent study (Olson et al. 1998) showed that growth rates of certain age classes of largemouth bass and bluegill (*Lepomis macrochirus*) increased substantially by removing macrophytes from only 20% of the littoral zone.

However, it should be noted that grass carp excretion may temporarily increase phosphorous levels in the water column, and thus algal blooms, requiring additional alum treatments. This may be necessary until the plant biomass is under control (KCM 1995). Barriers should be placed at all three outlets to prevent escapement of the fish. Furthermore, when feeding, grass carp will discriminate between aquatic plant species (Bonar et al. 1990 and references therein). For example, although grass carp were used to successfully eradicate Eurasian watermilfoil in Silver Lake (Cowlitz County), it was only after other submerged aquatic plants were consumed that the fish turned to the nuisance aquatic weed (Scherer et al. 1995). Green Lake should be surveyed within two years of stocking grass carp in order to reevaluate its plant and fish communities.

Support selective removal of common carp

According to the EPA (1993 and references therein), a reduction in biomass of bottom-feeding fish can result in decreased water turbidity, nutrient availability and, in some cases, phytoplankton abundance. Although common carp dominate Green Lake, the fish are not particularly susceptible to predation (EPA 1993), leaving the abundant largemouth bass with an unsuitable forage base. Therefore, within two years of stocking grass carp, a concerted effort should be made to remove the common carp from Green Lake to improve its water quality and warmwater fishery. By then, the plant biomass should be sufficiently reduced (Bonar et al. 1996) to allow easier capture of the fish.

The SDPR, with assistance from the WDFW, may be able to reduce the common carp population using minimal resources. For example, baited ‘big-M’ traps were used to remove nuisance common carp from lakes in Ohio and Pennsylvania. These leadless, stackable traps can be handled by one person (Schwartz 1986). If necessary, the remaining fish may be held in check using toxic baits developed to control common carp (Rach et al. 1994).

An alternative would be to hire a private contractor to capture the fish, as suggested by KCM (1995), or allow a small-scale commercial fishery on the lake. For example, the traps described above were used to successfully harvest common carp in the southwest U.S. for live markets in Asia (Schwartz 1986). In the southeast U.S., the Florida Game and Fresh Water Fish Commission implemented a large-scale commercial fishing program to improve the valuable recreational fishery on Lake Okeechobee (Schramm et al. 1985). Furthermore, Kentucky officials allowed the commercial harvest of common carp and other nongame species as a way to generate revenue and improve the sport fisheries in that state (Bronte and Johnson 1983, 1984).

Rehabilitate lake using natural piscicide

If the selective removal of common carp is ineffective, the SDPR should consider rehabilitating Green Lake with rotenone, a natural, plant-derived piscicide. Given the prolific nature of common carp, this may be the only way to control the nuisance fish (EPA 1993). Removal of the bottom-feeding fish with rotenone can be expected to lower phosphorous levels and thus algal blooms (Bradbury 1986), since the major source of phosphorous is lake sediments (URS 1987; KCM 1995). Furthermore, if the density of grass carp becomes problematic (e.g., resulting in an increase in bioturbation or paucity of aquatic plants), some fish may be captured by herding or angling, but selective removal is unlikely (Bonar et al. 1993). Therefore, a whole-lake rotenone treatment may be the only effective means of eradicating this fish as well (Bonar et al. 1996).

For centuries, rotenone has been used to collect fish for human consumption in parts of Asia, and throughout Central and South America. Since the 1930's, the most common aquatic use of rotenone has been the elimination of nuisance or competitor species, such as common carp, to improve sport fisheries (Bradbury 1986). In fact, Green Lake was rehabilitated five times between 1950 and 1972 (about once every five years) by the WDFW, then acting as the Washington Department of Game. During this period, the sport fishing opportunities were considered to be excellent (Bob Pfeifer, Washington Department of Fish and Wildlife; personal communication).

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