1999 Green Lake Surveys: Aspects of The Biology of Common Carp With Notes on The Warmwater Fish Community

by

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Introduction and Background

To many Seattle residents and visitors, Green Lake is the crown jewel of one of the most popular urban recreation areas in the Northwest. However, throughout much of the latter 20th century, poor water quality hindered recreational opportunities at the lake. For example, during late early summer 1999, the Seattle Department of Parks and Recreation (SDPR) temporarily banned all water–based activities because of a toxic, blue–green algae bloom (Fries 1999). As its name implies, Green Lake is no stranger to algal blooms. However, the late early summer 1999 event was disturbing because it was the first to pose a threat of illness despite SDPR's efforts in the early 1990s to reduce the nutrient (primarily phosphorus) inputs that fuel such blooms. KCM (1995) suggested that the two main impediments to improved water quality at Green Lake were the dense stands of invasive Eurasian watermilfoil (*Myriophyllum spicatum*) and the prolific common carp (*Cyprinus carpio*). For example, seasonal senescence and decay of aquatic vegetation contribute to the release of phosphorus, as do high pH values that arise from photosynthesis in macrophyte stands (Scheffer 1998). Common carp elevate nutrient levels through normal digestive processes (e.g., excretion) and bioturbation of sediments (Lamarra 1975, cited in Bradbury 1986; Panek 1987; Scheffer 1998).

A variety of government–approved algi–, herbi–, and piscicides are commercially available for lake and sport fishery restoration. For example, from 1950 through 1972, the Washington Department of Fish and Wildlife (WDFW), formerly the Washington Department of Game (WDG), routinely treated Green Lake with the natural, plant–derived piscicide, rotenone, to eradicate nuisance species that tended to overpopulate and compete with desirable sport fish. In 1991, SDPR treated the lake with buffered aluminum sulfate (a.k.a., alum) to precipitate phosphorus from the water column and to prevent release of sediment phosphorus that fuels nuisance algal blooms. However, in recent years, SDPR discontinued the use of chemical control measures in managing Green Lake and other parks. Subsequently, since 1993, Green Lake restoration efforts have been limited mostly to seasonal removal of submersed aquatic vegetation using a mechanical harvester. The introduction of herbivorous grass carp (*Ctenopharyngodon idella*) was also proposed as a cost–effective alternative to herbicidal control of Eurasian watermilfoil (KCM 1995; Mueller 1998). Still, no effort has been made to manage the common carp population.

Common carp belong to the minnow family (Cyprinidae). Like many introduced aquatic species, the origin of the Green Lake stock remains enigmatic. A California entrepreneur and the U.S. Fish Commission first imported common carp from Europe into the continental United States during the 1870s. At the time, resource managers were convinced that the "fish of the masses" would augment commercial and recreational freshwater fisheries throughout the country. An ambitious, widespread stocking program ensued. Within 25 years of being transplanted, common carp had become naturalized in most of the major watersheds of the Midwest, eastern seaboard, and Pacific Coast. Their rapid expansion is a testament to their reproductive potential and suitability to a wide variety of habitat types (Fritz 1987).

Common carp were well ensconced in Washington State by the 1890s (WDFW 1999); but it was not until the 1990s that the fish became a problem at Green Lake (KCM 1995; Mueller 1998). WDFW records indicate that common carp were not observed during the period from 1950 to 1972 when the lake was customarily treated with rotenone. However, by early summer 1983, a WDG biologist noted their presence for the first time when conducting a routine fish survey. Within ten years, common carp underwent a population explosion to become the dominant fish in Green Lake (Table 1). Spot–checks during 1994 and 1995 suggested a population in decline (KCM 1995). Nevertheless, a comprehensive survey conducted by WDFW in fall 1997 revealed that common carp were indeed dominant, at least in terms of biomass (Mueller 1998).

Table 1. Fish species composition changes at Green Lake (King County) since 1950 (Washington Department of Fish and Wildlife, unpublished data).

Date	Sample method	Sample size (# fish)	Species composition by number
Fall 1950	Whole-lake rotenone treatment	665,000	45.1% three-spine stickleback (*Gasterosteus aculeatus*), 22.6% yellow perch (*Perca flavescens*), 15.0% unidentified sucker (*Catostomus* sp.), 7.5% northern pikeminnow (*Ptychocheilus oregonensis*), 7.5% brown bullhead (*Ameiurus nebulosus*), and 2.3% largemouth bass (*Micropterus salmoides*).
Fall 1957	"	2,226,000	89.8% unidentified sculpin (*Cottus* sp.), 9.1% yellow perch, 0.7% largemouth bass, 0.3% rainbow trout (*Oncorhynchus mykiss*), and 0.1% goldfish (*Carassius auratus*).
Fall 1962	"	1,535,650	97.6% sculpin, 2.0% yellow perch, 0.3% rainbow trout, and 0.1% brown bullhead.
Fall 1967	"	586,250	85.6% yellow perch, 13.0% brown bullhead, 0.8% sculpin, 0.5% goldfish, and 0.1% rainbow trout.
Fall 1972	"	56,005	89.3% brown bullhead, 8.9% sculpin, 0.9% black crappie (*Pomoxis nigromaculatus*), 0.8% rainbow trout, and 0.1% yellow perch.
Spring 1982	Angling survey [a]	206	65.1% rainbow trout, 22.3% yellow perch, 6.8% brown bullhead, and 5.8% sculpin.
Summer 1983	Electrofishing and gill netting	59	47.4% yellow perch, 44.1% brown bullhead, 5.1% brown trout (*Salmo trutta*), and 3.4% common carp (*Cyprinus carpio*).
Summer 1993	Electrofishing [b]	206	87.4% common carp, 6.3% pumpkinseed (*Lepomis gibbosus*), 2.9% largemouth bass, 2.4% rainbow trout, 0.5% yellow perch, and 0.5% brown bullhead.

Table 1. Fish species composition changes at Green Lake (King County) since 1950 (Washington Department of Fish and Wildlife, unpublished data) (continued).

Date	Sample method	Sample size (# fish)	Species composition by number
Fall 1997	Electrofishing and gill netting [c]	2,670	57.7% largemouth bass, 26.4% common carp, 9.7% pumpkinseed, 3.4% rock bass (*Ambloplites rupestris*), 2.0% rainbow trout, 0.3% brown bullhead, 0.3% sculpin, 0.1% yellow perch, and 0.1% brown trout. [d]

[a] Data from Glass (1982).
[b] Data from KCM (1995).
[c] Data from Mueller (1998).
[d] In addition to the species listed, one smallmouth bass (*Micropterus dolomieu*) was captured during fall 1997.

Little information exists concerning the common carp population of Green Lake. That which is available can be found in two recent technical reports (KCM 1995; Mueller 1998) and WDFW management files. The successful management of this population (and ultimately the water quality of Green Lake) hinges on a better understanding of their biology and ecology. Moreover, common carp may affect angler catch rates of, and compete or interfere with, desirable warmwater sport fishes (Forester and Lawrence 1978; Drenner et al. 1997). To this end, personnel from WDFW's Warmwater Enhancement Program conducted surveys of Green Lake's warmwater fish community, with an emphasis on common carp, during early summer and fall 1999. Furthermore, since it was gathered before implementing additional management activities, the information presented here will be useful when monitoring the long–term effects of future restoration efforts.

Materials and Methods

Green Lake was surveyed by a three–person team on June 10, 1999, and during September 20-22, 1999. During early summer, fish were captured while electrofishing only. During fall, fish were captured using three sampling techniques: electrofishing; gill netting; and fyke netting. The electrofishing unit consisted of a 4.9 m Smith-Root 5.0 GPP ‘shock boat’ set to a pulsed DC of 120 Hz and 6 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 (13, 19, 25, and 51 mm stretched) monofilament mesh. Fyke nets were constructed of a single 30.4 m lead and two 15.2 m wings of 130 mm nylon mesh. The bodies of the nets were stretched around four 1.2-m aluminum rings in each of two sections.

Sampling locations were selected by dividing the shoreline into 15 consecutively numbered sections of about 400 m each (determined visually from a USGS map in Wolcott 1973). During early summer, approximately one–third of the shoreline was sampled by electrofishing five randomly selected sections (Figure 1) for a total ‘pedal down’ time of 3,051 seconds. During fall, ten sections were randomly selected as sampling locations (Figure 2). In order to reduce bias between capture techniques, the sampling time for each gear type was standardized to a ratio of 1:1:1 (Fletcher et al. 1993). One unit of electrofishing equal to three 600–second periods was applied for each unit of gill netting and fyke netting, which equaled 24 hours soak time or two 12-hour ‘net nights’. Thus, three sections were electrofished for every two sections sampled with gill nets or fyke nets. Sampling occurred during evening hours to maximize the type and number of fish captured. Nighttime electrofishing occurred along six sections or 40% (~ 2.4 km) of the available shoreline. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of 18.3 m/minute. Total ‘pedal down’ time was 3,635 seconds. Gill and fyke nets were set overnight at four locations each (= 4 net nights for each gear type). The small–mesh end of the gill net was attached onshore while the large–mesh end was anchored offshore perpendicular to the shoreline. The fyke nets were set in water less than 3 m deep with wings extended at 70° angles from the lead.

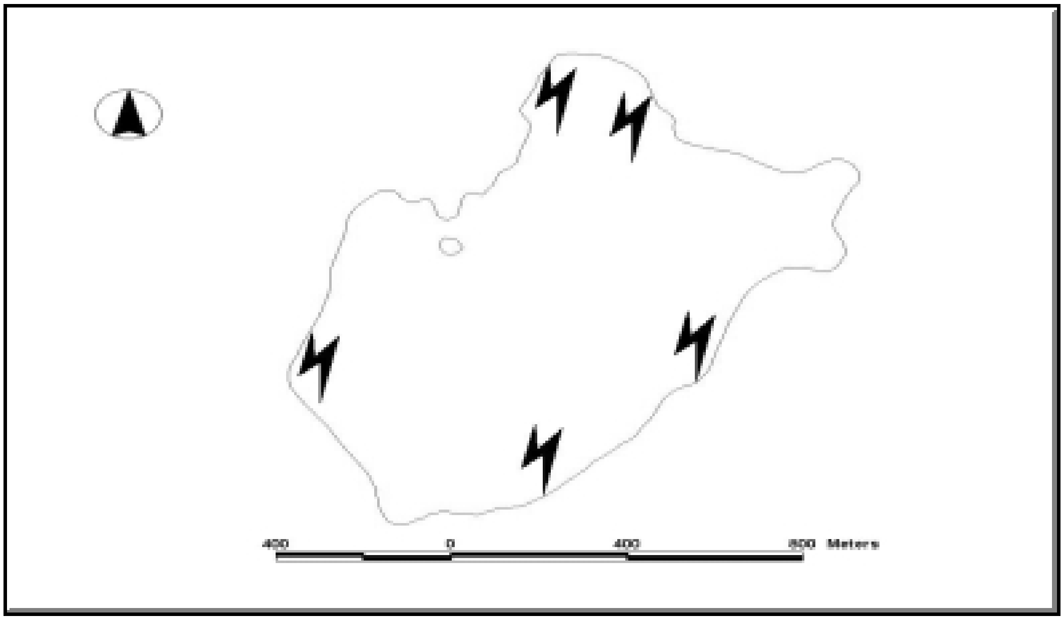

Figure 1. Map of Green Lake (King County) showing electrofishing sampling locations during early summer 1999.

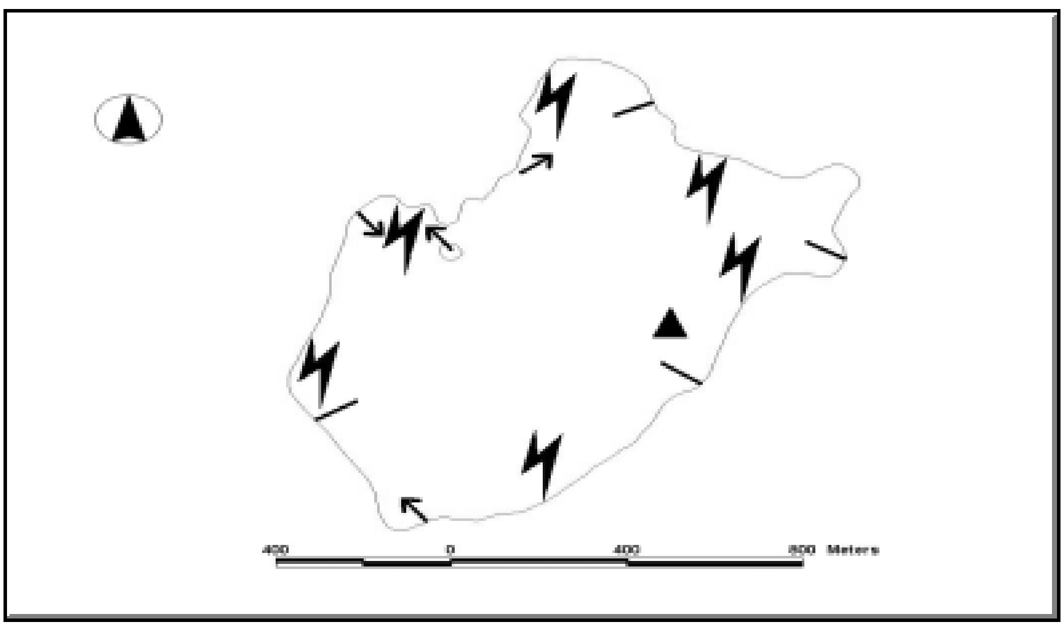

Figure 2. Map of Green Lake (King County) showing sampling locations during fall 1999. Bolts indicate sections of shoreline where electrofishing occurred. Bars extending into lake indicate placement of gill nets. Arrows indicate placement of fyke nets whereas triangle indicates water quality station.

With the exception of sculpin (*Cottus* sp.), 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 total length (TL). For example, a fish measuring 156 mm TL was assigned to the 150–mm size class for that species, a fish measuring 113 mm TL was assigned to the 110–mm size class, and so on. When possible, up to 10 fish from each size class were weighed to the nearest 1 g. However, if a sample included several hundred individuals of a given species, then a subsample ($n \geq 100$ fish) was measured and weighed while the remainder was counted overboard. The length frequency distribution of the subsample was then applied to the total number collected. Weights of individuals counted overboard were estimated using a simple linear regression of $\log_{10}$-length on $\log_{10}$-weight of fish from the subsample. Scales were removed from up to ten fish from each size class for aging. Scale samples were mounted, pressed, and the fish aged according to Jearld (1983) and Fletcher et al. (1993). However, a lack of technical resources precluded aging members of the Family *Ictaluridae* (catfish). Furthermore, given the emphasis of this study on common carp and warmwater species, age and growth were not assessed for salmonids.

Water quality data was collected during midday on September 21, 1999, from the deepest part of the lake, as determined from the bathymetric map in Wolcott 1973 (Figure 2). Secchi disc readings were recorded in m. Using a Hydrolab® probe and digital recorder, information was also gathered on dissolved oxygen (mg/l), total dissolved solids (g/l), temperature (° C), pH, and specific conductance (uS/cm) (Table 2).

Table 2. Water quality from the northeast shore (the deepest basin) of Green Lake (King County). Samples were collected midday on September 21, 1999.

Location	Secchi (m)	Depth (m)	DO (mg/l)	Parameter Temp (°C)	pH	Conductance (uS/cm)	Total dissolved solids (g/l)
Northeast shore	0.7	1	11.23	20.27	9.00	62.2	0.0398
		2	11.38	20.15	9.08	62.4	0.0400
		3	11.19	20.11	9.13	62.4	0.0399
		4	8.24	18.90	8.93	62.6	0.0400
		5	6.29	18.49	8.59	62.9	0.0403
		6	6.10	18.43	8.68	63.9	0.0408
		7	3.98	18.40	8.37	64.9	0.0417

Data Analysis

Balancing predator and prey fish populations is the hallmark of warmwater fisheries management. According to Bennett (1962), the term ‘balance’ is used loosely to describe a system in which omnivorous forage fish or prey maximize food resources to produce harvestable–size stocks for fishermen while maintaining an adequate forage base for piscivorous fish or predators. 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 species composition, size structure, growth, and condition (plumpness or robustness) of fish provide useful information on population age class structures, relative species abundances and the potential for interaction, and the adequacy of food supplies for various foraging niches (Ricker 1975; Kohler and Kelly 1991; Olson 1995). The balance and productivity of a fish community can also be addressed using such evaluations (Swingle 1950; Bennett 1962).

Except for data collected during early summer 1999, species composition by weight (kg) was calculated as the weight of fish captured of a given species divided by the total weight of all fish captured × 100. The species composition by number was calculated as the number of fish captured of a given species divided by the total number of all fish captured × 100. Young–of–year or small juveniles are often not considered when analyzing species composition because large fluctuations in their numbers may distort results (Fletcher et al. 1993). For example, the overall length frequency distribution of fish species may suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes. However, many young–of–year and small juveniles would be subject to high mortality during their first winter (Chew 1974), resulting in a different size distribution the following year. Still, the presence of these fish in the system relates directly to fecundity and inter– and intraspecific competition at lower trophic levels (Olson et al. 1995). For these reasons, and since their relative contribution to the total biomass captured was small, we chose to include young–of–year and small juveniles when analyzing species composition data.

The size structure of each species captured was evaluated by constructing stacked length frequency histograms. By using this chart style, we were able to show the relative contribution of each gear type to the total catch (number of fish captured in each size class by gear type divided by the total number of fish captured by all gear types × 100). Since selectivity of gear types not only biases species catch based on body form and behavior, but also size classes within species, length frequencies are generally reported by gear type (Willis et al. 1993). However, we assumed our standardized 1:1:1 gear type ratio adjusted for differences in sampling effort between sampling times and locations. Furthermore, differences in size selectivity of gear types can sometimes result in offsetting biases (Anderson and Neumann 1996). Therefore, we chose to report the length frequency of each species based on the total catch from combined gear types broken down by the relative contribution each gear type made to each size class. This changed the scale, but not the shape, of the length frequencies by gear type. If concern arises that pooled gear does not represent the least biased assessment of length frequency for a given species, then the shape of the gear type–specific distributions is still represented on the graphs, and these may be interpreted independently.

Catch per unit effort (CPUE) by gear type was determined for all species (number of fish/hour electrofishing and number of fish/net night). Except for sculpin, only stock size fish and larger were used to determine CPUE. Stock length, which varies by species (see Table 3 and discussion below), refers to the minimum size of fish having recreational value. Since sample locations were randomly selected, which might introduce high variability due to habitat differences within the lake, 80% confidence intervals (CI) were determined for each mean CPUE by species and gear type. CI was calculated as the mean ± $t_{(\alpha, N\text{-}1)} \times SE$, where t = Student's t for α confidence level with N-1 degrees of freedom (two-tailed) and SE = standard error of the mean. Since it is standardized, CPUE is a useful index for comparing relative abundance of stocks between lakes. The CPUE values from this study were compared to the mean values from up to 12 western Washington warmwater lakes (Table 4) sampled during 1997 and 1998 (Scott Bonar, WDFW, unpublished data).

Table 3. Length categories for cold– and warmwater fish species used to calculate stock density indices (PSD and RSD; Gabelhouse 1984) of fish captured at Green Lake (King County) during 1997 and 1999. Measurements are minimum total lengths (mm) for each category (Anderson and Neumann 1996; Bister et al. *in press*).

	Size				
Type of fish	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
Brown bullhead	130	200	280	360	430
Brown trout	150	230	300	380	460
Channel catfish	280	410	610	710	910
Chinook salmon	280	460	610	760	940
Common carp	280	410	530	660	840
Largemouth bass	200	300	380	510	630
Pumpkinseed	80	150	200	250	300
Rainbow trout	250	400	500	650	800
Rock bass	100	180	230	280	330
Smallmouth bass	180	280	350	430	510

Table 4. Mean catch per unit effort (# fish/hour and # fish/net night) for stock–size warmwater fishes sampled from western Washington lakes while electrofishing and gill netting during 1997 and 1998 (Scott Bonar, WDFW, unpublished data). Values in parentheses are number of lakes averaged. EB = electrofishing boat, FN = fyke net, and GN = gill net.

Gear type	Brown bullhead	Largemouth bass	Pumpkinseed	Yellow perch
EB	7.8 (10)	41.6 (12)	70.8 (11)	97.5 (8)
FN	12.7 (6)	0.3 (1)	7.9 (4)	0.2 (2)
GN	14.4 (7)	1.9 (8)	3.8 (9)	13.7 (6)

Except for sculpin, the proportional stock density (PSD) for each species was determined following procedures outlined in Anderson and Neumann (1996). PSD, which was calculated as the number of fish ≥ quality length/number of fish ≥ stock length × 100, is a numerical descriptor of length frequency data that provides useful information about population dynamics. Stock and quality lengths, which vary by species (Table 3), are based on percentages of world–record lengths. Again, stock length (20-26% of world-record length) refers to the minimum size fish with recreational value, whereas quality length (36-41% of world-record length) refers to the minimum size fish most anglers like to catch.

The relative stock density (RSD) of each species was examined using the five–cell model proposed by Gabelhouse (1984). In addition to stock and quality length, Gabelhouse (1984) introduced preferred, memorable, and trophy length categories (Table 3). Preferred length (45-55% of world–record length) refers to the minimum size fish anglers would prefer to catch when given a choice. Memorable length (59-64% of world-record length) refers to the minimum size fish most anglers remember catching, whereas trophy length (74-80% of world-record length) refers to the minimum size fish considered worthy of acknowledgment. Like PSD, RSD provides useful information regarding population dynamics, but is more sensitive to changes in year–class strength. RSD was calculated as the number of fish $\geq$ specified length/number of fish $\geq$ stock length $\times$ 100. For example, RSD P was the percentage of stock length fish that also were longer than preferred length, RSD M, the percentage of stock length fish that also were longer than memorable length, and so on.

Stock density indices have become important tools for assessing size structures of warmwater fish populations and developing management strategies for warmwater fisheries (Willis et al. 1993). Strategies commonly used in warmwater fisheries management include panfish, balanced predator–prey, and big bass options. The stock density index ranges for these options are listed in Table 4. The PSD and RSD values for species other than largemouth bass and bluegill can be compared loosely to the values below. The PSD and RSD values from this study were evaluated with the common management options in mind and compared to the mean values from up to 12 western Washington warmwater lakes sampled during 1997 and 1998 (Table 5) (Scott Bonar, WDFW, unpublished data).

Table 5. Stock density index ranges for largemouth bass and bluegill under three commonly implemented management strategies (from Willis et al. 1993). PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), and memorable length fish (RSD-M).

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

Table 6. Mean stock density indices for warmwater fishes sampled from western Washington lakes during 1997 and 1998 (Scott Bonar, WDFW, unpublished data). PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T). EB = electrofishing boat, GN = gill net, and FN = fyke net.

Species	Gear type	No. lakes	PSD	RSD-P	RSD-M	RSD-T
Brown bullhead	EB	3	11	2	0	0

	FN	2	50	17	0	0
	GN	5	12	1	0	0
Largemouth bass	EB	12	29	13	0	0
Pumpkinseed	EB	12	8	0	0	0
Yellow perch	EB	12	20	2	0	0
	GN	12	53	1	0	0

Age and growth of warmwater fishes in Green Lake were evaluated using the direct proportion method (Jearld 1983; Fletcher et al. 1993) and Lee's modification of the direct proportion method (Carlander 1982). Using the direct proportion method, 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 at capture. Using Lee's modification, L_n was back–calculated as $L_n = a + A \times (TL - a)/S$, where a is the species–specific standard intercept from a scale radius–fish length regression. Mean back–calculated lengths at age n for each species were presented in tabular form for easy comparison of growth between year classes, as well as between Green Lake fish and the state average for the same species (listed in Fletcher et al. 1993).

A relative weight (W_r) index was used to evaluate the condition of all species except sculpin. A W_r value of 100 generally indicates that a fish is in good condition when compared to the national standard (75th percentile) for that species. Furthermore, W_r is useful for comparing the condition of different size groups within a single population to determine if all sizes are finding adequate forage or food (ODFW 1997). Trends in the dispersion of points on the relative weight graph have been used to infer ecological dynamics of fish populations (Blackwell et al. *in press*). For example, a decrease in relative weight with increasing total length often occurs where competition is high among larger size classes. Conversely, low relative weights in small fish suggest competition and crowding among smaller size classes. 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 cold– and warmwater fish species, including the minimum length recommendations for their application, are listed in Anderson and Neumann (1996) and Bister et al. (*in press*). The W_r values from this study were compared to the national standard ($W_r = 100$) and, where available, the mean W_r values from up to 25 western Washington warmwater lakes sampled during 1997 and 1998 (Steve Caromile, WDFW, unpublished data).

Results and Discussion

Species Composition

Human–mediated species changes at Green Lake have resulted in a wildly dynamic fish community for over 50 years. However, common carp, largemouth bass (*Micropterus salmoides*), and pumpkinseed (*Lepomis gibbosus*) have dominated the catches of fishery professionals, at least by number, since 1993 (Table 1). During fall 1999, the same species were prevalent in our catch as well, yet in terms of biomass, common carp were clearly dominant (Table 7). Channel catfish (*Ictalurus punctatus*) are a recent introduction by WDFW to augment the sport fishery, whereas rock bass (*Ambloplites rupestris*) were introduced illegally and first recorded by Mueller (1998) in fall 1997. The presence of chinook salmon (*Oncorhynchus tshawytscha*) should be considered ephemeral; several thousand fish measuring approximately 60 mm TL each were transplanted from the University of Washington's (UW) School of Fisheries hatchery during early spring 1999 (Mark Tetrick, UW, personal communication).

Table 7. Species composition by weight (kg) and number of fish captured at Green Lake (King County) during a fall 1999 survey of warmwater fish.

	Species composition				
	by weight		by number		Size range
Type of fish	(kg)	(%)	(#)	(%)	(mm TL)
Brown bullhead (*Ameiurus nebulosus*)	1.234	0.714	11	1.062	164 - 289
Channel catfish (*Ictalurus punctatus*)	0.364	0.210	2	0.193	238 - 277
Chinook salmon (*Oncorhynchus tshawytscha*)	18.602	10.766	187	18.050	173 – 215 [a]
Common carp (*Cyprinus carpio*)	139.114	80.513	169	16.313	87 - 715
Largemouth bass (*Micropterus salmoides*)	3.187	1.844	318	30.695	47 - 266
Pumpkinseed (*Lepomis gibbosus*)	4.822	2.791	240	23.166	27 - 164
Rainbow trout (*Oncorhynchus mykiss*)	2.828	1.636	29	2.799	138 - 290
Rock bass (*Ambloplites rupestris*)	2.594	1.501	64	6.178	42 - 215
Sculpin (*Cottus* sp.)	0.041	0.024	16	1.544	39 - 97
Total	172.784		1,036		

[a] Measured as fork lengths.

CPUE

During fall 1997 and 1999, catch rates were highest for stock–size common carp and pumpkinseed (Table 8). The electrofishing catch rate for common carp increased four–fold from 1997 (15.9 ± 11.3) to 1999 (63.5 ± 45.7), yet decreased for pumpkinseed during the same period. Extremely poor visibility (Table 2) may have contributed to the latter; however, interference with pumpkinseed reproduction by, or competition with, the dominant common carp cannot be ruled out as a contributing factor (Forester and Lawrence 1978). Still, electrofishing catch rates for pumpkinseed (140.2 ± 92.4) far exceeded the average (70.8) from several western Washington lakes (Tables 4 and 8). In 1999, the electrofishing catch rate for common carp was highest during early summer (81.2 ± 36.9); ostensibly, a reflection of their aggregating behavior while spawning. The higher catch rate for rock bass while electrofishing during fall 1999 (24.8 ± 17.1) compared to 1997 (7.9 ± 4.2) suggests an expanding population. Although abundant, most largemouth bass were below stock size, resulting in below average catch rates for stock–size fish (Tables 4, 7, and 8).

Table 8. Catch per unit effort (# fish/hour electrofishing or # fish/net night) for stock–size warmwater fish, salmonids, and non–game fish collected from Green Lake (King County) while electrofishing (EB), gill netting (GN), and fyke netting (FN) during 1997 and 1999. Values in parentheses are number of sample locations.

	Sample period					
	Fall 1997		Early summer 1999	Fall 1999		
Type of fish	**EB (6)**	**GN (4)**	**EB (5)**	**EB (6)**	**FN (4)**	**GN (4)**
Brown bullhead	3.0 ± 2.6	1.2 ± 0.8	---	1 [a]	0	2.5 ± 1.3
Brown trout	0	0.5 [a]	---	---	---	---
Channel catfish	---	---	---	0	0	0
Chinook salmon	---	---	---	0	0	0
Common carp	15.9 ± 11.3	0.2 [a]	81.2 ± 36.9	63.5 ± 45.7	0	5.2 ± 2.8
Largemouth bass	0	0	4.8 [a]	1 [a]	0	0.5 [a]
Pumpkinseed	208.8 ± 83.8	3.2 ± 1.7	---	140.2 ± 92.4	0.5 [a]	2.0 ± 1.2
Rainbow trout	0	1.5 [a]	---	3.9 [a]	0	0.5 ± 0.4
Rock bass	7. 9 ± 4.2	2.5 ± 1.5	---	24.8 ± 17.1	0	3.0 ± 0.9
Sculpin	6.9 ± 6.1	0.2 [a]	---	13.9 ± 9.0	0.2 [a]	0.2 [a]
Smallmouth bass	1 [a]	0	---	---	---	---
Yellow perch	0	0.5 [a]	---	---	---	---

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

Stock Density Indices

Very few quality–size largemouth bass and pumpkinseed were captured, whereas quality–size common carp were abundant in Green Lake during all sample periods (Table 9). The only quality–size largemouth bass captured were four mature adults from one location along the eastern shoreline. Given the season (early summer), the fish were probably spawning and/or guarding their nests. During fall 1997 and 1999, the electrofishing and gill netting PSD values for brown bullhead were above average, whereas those of largemouth bass and pumpkinseed were below average (Tables 6 and 9). However, the stock density indices for brown bullhead and largemouth bass should be viewed with caution, especially given the low catch rates for stock–size fish and small sample sizes used to determine the indices (Divens et al. 1998). The PSD and RSD values of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) from fall 1997 indicate that Green Lake is capable of supporting memorable– and trophy–size salmonids.

Table 9. Traditional stock density indices for stock–length warmwater fishes, salmonids, and non–game fish collected from Green Lake (King County) while electrofishing (EB), gill netting (GN), and fyke netting (FN) during 1997 and 1999. PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T).

Type of fish	Sample period	Gear type	# fish	PSD	RSD-P	RSD-M	RSD-T
Brown bullhead	Fall 1997	EB	3	33 [a]	0	0	0
		GN	5	40 ± 28	0	0	0
	Fall 1999	EB	1	100	0	0	0
		FN	0	0	0	0	0
		GN	10	0	0	0	0
Brown trout	Fall 1997	EB	0	0	0	0	0
		GN	2	100	100	100	100
Channel catfish	Fall 1999	EB	0	0	0	0	0
		FN	0	0	0	0	0
		GN	0	0	0	0	0
Chinook salmon	Fall 1999	EB	0	0	0	0	0
		FN	0	0	0	0	0
		GN	0	0	0	0	0
Common carp	Fall 1997	EB	16	100	75 ± 14	0	0
		GN	1	0	0	0	0
	Early summer 1999	EB	69	48 ± 8	39 ± 8	3 [a]	0
	Fall 1999	EB	64	67 ± 8	34 ± 8	3 [a]	0
		FN	0	0	0	0	0
		GN	21	24 ±12	0	0	0
Largemouth bass	Fall 1997	EB	0	0	0	0	0
		GN	0	0	0	0	0
	Early summer 1999	EB	4	100	100	0	0

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

Table 9. Traditional stock density indices for stock–length warmwater fishes, salmonids, and non–game fish collected from Green Lake (King County) while electrofishing (EB), gill netting (GN), and fyke netting (FN) during 1997 and 1999 (continued). PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T).

Type of fish	Sample period	Gear type	# fish	PSD	RSD-P	RSD-M	RSD-T
largemouth bass	Fall 1999	EB	1	0	0	0	0
(cont'd.)		FN	0	0	0	0	0
		GN	2	0	0	0	0
Pumpkinseed	Fall 1997	EB	210	0	0	0	0
		GN	13	0	0	0	0
	Fall 1999	EB	141	4 ±2	0	0	0
		FN	2	100	0	0	0
		GN	8	0	0	0	0
Rainbow trout	Fall 1997	EB	0	0	0	0	0
		GN	6	33 ± 25	33 ± 25	17 ± 19	0
	Fall 1999	EB	4	0	0	0	0
		FN	0	0	0	0	0
		GN	2	0	0	0	0
Rock bass	Fall 1997	EB	8	88 ± 15	0	0	0
		GN	10	20 ± 16	10 ± 12	0	0
	Fall 1999	EB	25	36 ± 12	0	0	0
		FN	0	0	0	0	0
		GN	12	0	0	0	0
Smallmouth bass	Fall 1997	EB	1	0	0	0	0
		GN	0	0	0	0	0
Yellow perch	Fall 1997	EB	0	0	0	0	0
		GN	2	100	0	0	0

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

Common Carp

Distribution and Habitat

The wide confidence intervals associated with electrofishing CPUE values for common carp (Table 8) reflect the variable distribution of this fish in Green Lake. For example, using all gear types and during all sample periods, most common carp (64-93%) were captured in the lower half of the lake. Of these, the majority (58-86%) came from sample locations along the southeast shoreline (Figures 1 and 2). Compared to the central and northern parts of the lake, this area is characterized by stands of Eurasian watermilfoil with low to moderate biomass (0-200 g/m^2), stem counts (170 stems/m^2), and rootmass densities (2.7 g/m^2). Coontail (*Ceratophyllum demersum*) and common elodea (*Elodea canadensis*) are the dominant forms of aquatic vegetation here (KCM 1995). The disruptive foraging behavior of common carp may have contributed to the conditions observed by KCM (1995) within the heavily populated southeast corner of Green Lake (Smith and Pribble 1979). During early summer 1999, large numbers of common carp were also captured or observed among the dense bed of white waterlily (*Nymphaea odorata*) along the southwestern shore (Figure 1). Seasonal aggregations of common carp are common and usually related to spawning (Breder and Rosen 1966; Swee and McCrimmon 1966; Johnsen and Hasler 1977; Anderson 1986).

Age and Growth

Green Lake common carp were aged 0+ to 9+ (Tables 10, 11, and 12) and ranged from 87 to 715 mm TL (Table 7; Figures 3 and 5). When compared to other North American common carp populations (Kevern 1966; Swee and McCrimmon 1966; Stucky and Klassen 1971), growth was rapid through age 5+, irrespective of sampling date. From early summer to fall 1999, electrofishing PSD increased (Table 9) as the size structure of the population shifted toward smaller individuals. This reflects a strong year–class similar to that observed by Mueller (1998) during fall 1997. During all sample periods, the 1993 year–class was not observed, which supports the claim by KCM (1995) of a population in decline. However, our results and those of Mueller (1997) show that Green Lake common carp have certainly rebounded, which is no surprise given their reproductive potential and rapid growth.

Table 10. Age and growth of common carp (*Cyprinus carpio*) captured at Green Lake (King County) during fall 1997. Values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993).

		Mean total length (mm) at age						
Year class	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1996	20	137.7						
1995	1	178.7	340.5					
1994	0							
1993	0							
1992	1	143.5	320.4	449.6	483.0	530.9		
1991	3	179.9	286.7	380.4	472.3	522.8	541.6	
1990	1	187.9	350.3	419.3	469.0	504.8	537.9	551.7
Weighted mean		146.3	311.9	402.0	473.8	520.8	540.7	551.7
Ontario, Canada [a]		---	---	---	419.0	475.0	510.0	576.0
Tennessee [b]		211.4	278.0	341.0	402.7	472.1	549.8	628.0
Kansas [c]		129.3	189.0	244.7	297.3	338.4	383.4	441.2

[a] Data from Swee and McCrimmon (1966)
[b] Data from Kevern (1966)
[c] Data from Stucky and Klassen (1971)

Table 11. Age and growth of common carp (*Cyprinus carpio*) captured at Green Lake (King County) during early summer 1999. Values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993).

		Mean total length (mm) at age								
Year class	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1998	6	189.3								
1997	2	137.7	300.7							
1996	3	190.1	319.8	379.4						
1995	0									
1994	2	186.8	291.0	356.3	436.1	476.9				
1993	0									
1992	2	166.9	242.3	329.1	418.4	496.1	534.9	564.1		
1991	1	246.7	362.4	423.3	508.6	557.3	606.0	633.4	657.8	
1990	2	140.7	189.9	268.4	349.7	419.3	458.3	506.5	527.2	544.3
Weighted mean		178.7	280.8	346.9	416.7	477.4	518.5	554.9	570.7	544.3
Ontario, Canada [a]		---	---	---	419.0	475.0	510.0	576.0	613.0	642.0
Tennessee [b]		211.4	278.0	341.0	402.7	472.1	549.8	628.0	---	---
Kansas [c]		129.3	189.0	244.7	297.3	338.4	383.4	441.2	485.3	---

[a] Data from Swee and McCrimmon (1966)
[b] Data from Kevern (1966)
[c] Data from Stucky and Klassen (1971)

Table 12. Age and growth of common carp (*Cyprinus carpio*) captured at Green Lake (King County) during fall 1999. Values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993).

		Mean total length (mm) at age						
Year class	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1998	3	87.1						
1997	6	170.0	328.5					
1996	3	152.1	267.2	370.0				
1995	2	168.1	320.9	412.8	479.8			
1994	4	198.2	404.2	495.5	549.9	582.8		
1993	0							
1992	1	175.5	326.0	436.3	501.6	539.2	576.8	609.4
Weighted mean		160.1	334.8	435.4	523.0	574.1	576.8	609.4
Ontario, Canada [a]		---	---	---	419.0	475.0	510.0	576.0
Tennessee [b]		211.4	278.0	341.0	402.7	472.1	549.8	628.0
Kansas [c]		129.3	189.0	244.7	297.3	338.4	383.4	441.2

[a] Data from Swee and McCrimmon (1966)
[b] Data from Kevern (1966)
[c] Data from Stucky and Klassen (1971)

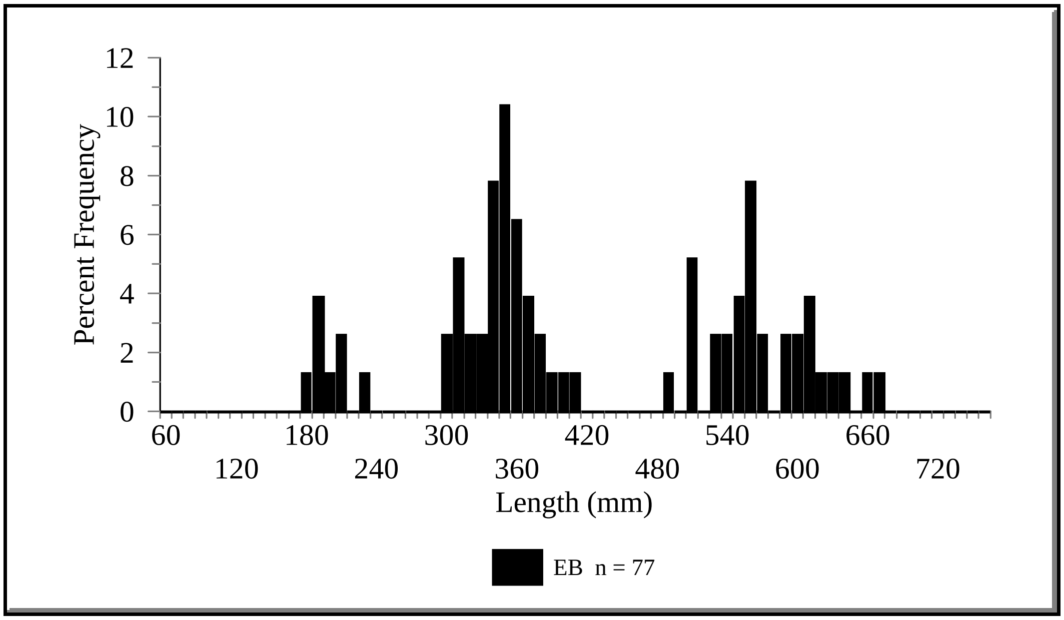

Figure 3. Length frequency histogram of common carp sampled from Green Lake (King County) while electrofishing (EB) in early summer 1999.

Sexual Maturity and Reproduction

In Europe (Hungary), female common carp generally reach sexual maturity at lengths between 300 and 400 mm TL (age 4+ to 5+). Males typically mature at lengths between 250 and 300 mm TL (age 2+ to 3+) (Horváth et al. 1984). In North America (Canada), the minimum size at maturity for female common carp ranges from 381 to 432 mm TL (age 4+ to 5+), whereas males range from 315 to 356 mm TL (age 3+ to 4+) (Swee and McCrimmon 1966). Depending on size and age, female common carp are capable of producing over two million eggs during a single breeding season. Site–specific spawning generally commences at water temperatures above 17°C, in shallow, vegetated areas of the littoral zone. Several males usually accompany a single female followed by much thrashing about as milt and eggs are released into the surrounding vegetation (Breder and Rosen 1966; Swee and McCrimmon 1966; Horváth et al. 1984; Anderson 1986).

According to our analysis, Green Lake common carp reach reproductive sizes (> 250 mm TL) between ages 2+ and 4+ (Tables 10, 11, and 12). In 1998, their spawning activity was observed over a six–month period, from April to September, among the dense stands of white waterlily along the southwestern shore. Peak activity occurred during April and July (Martin Muller, Green Lake Park Alliance, personal communication). During early summer 1999, large aggregations of common carp were also observed along the southeastern shoreline.

Food and Feeding

Common carp are omnivorous, feeding mostly on benthic organisms (e.g., chironomid larvae and pupae), detritus, and algae (Kevern 1966; Eder and Carlson 1977), and may alter their diet depending on prey–densities (Scheffer 1998). For example, high–density, cyprinid populations like Green Lake common carp may switch to feeding on zooplankton when abundant rather than benthos. High–predation pressure on algae-grazing zooplankton ultimately leads to high algal biomass (Scheffer 1998). Not surprisingly, common carp thrive in phytoplankton– and/or nutrient–rich environments such as Green Lake (Haines 1973).

With few exceptions, relative weights of Green Lake common carp were high during 1999 (Figures 4 and 6), which indicates an ample food supply (Blackwell et al. *in press*). The algal and aquatic invertebrate communities of Green Lake were described in some detail by KCM (1995). Besides diatoms (*Asterionella* sp.), Green Lake common carp might feed on zooplankton, such as rotifers (*Keratella* sp. and *Polyarthra* sp.) and cladocerans (*Daphnia* sp. and *Bosmina* sp.), or benthic invertebrates, such as oligochaetes and dipterans (primarily chironomids and *Chaoborus* sp). KCM (1995) noted decreased densities of benthic invertebrates from 1982 (~ 13,000 organisms/m^2) to 1994 (~1,700 organisms/m^2). Temporally, this corresponds well with the expansion of common carp in Green Lake and may be related to predation, but no diet studies were conducted to confirm this hypothesis.

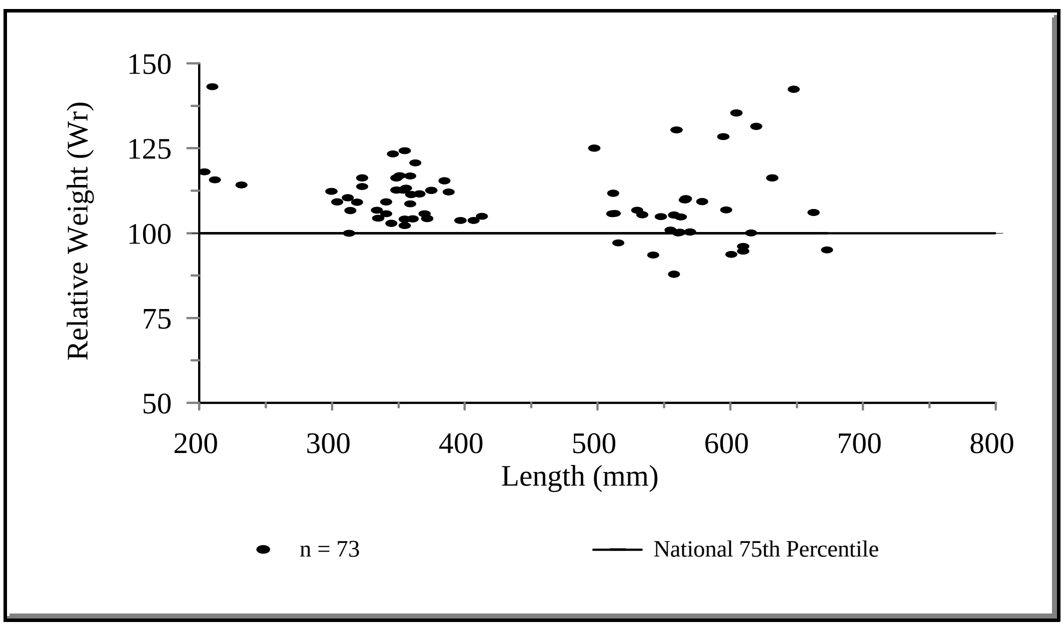

Figure 4. Relationship between total length and relative weight (Wr) of common carp from Green Lake (King County) during early summer 1999 compared with means from up to 25 western Washington lakes and the national 75th percentile.

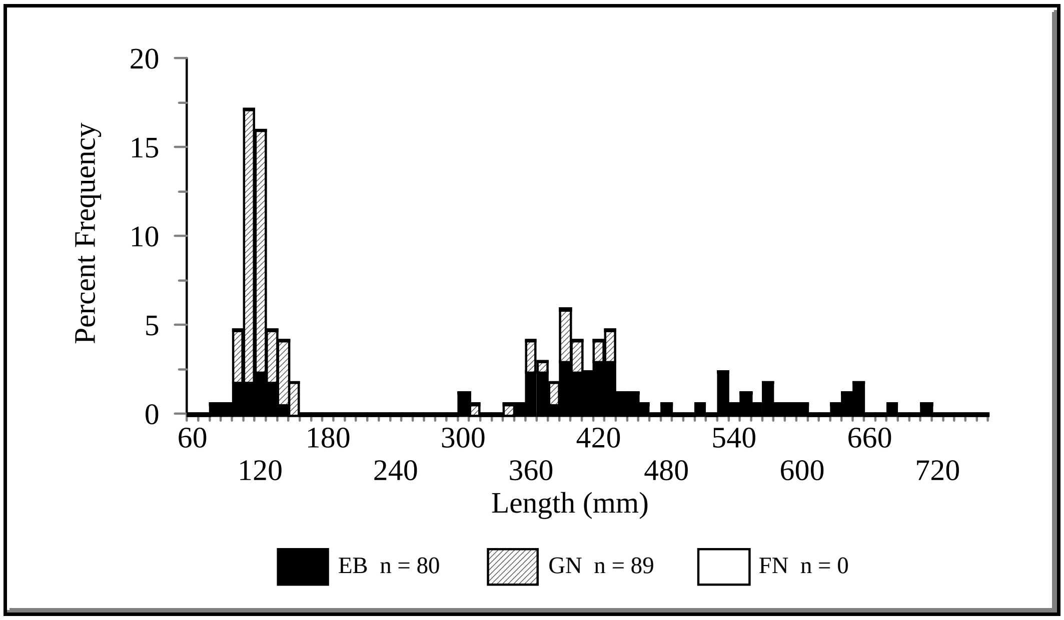

Figure 5. Length frequency histogram of common carp sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

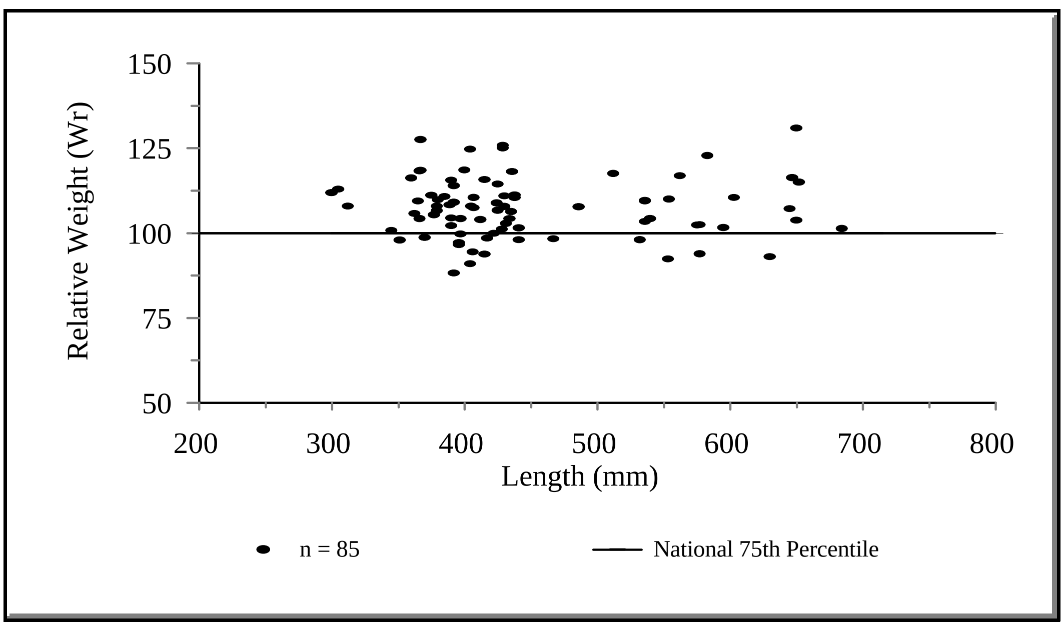

Figure 6. Relationship between total length and relative weight (Wr) of common carp from Green Lake (King County) during fall 1999 compared with means from up to 25 western Washington lakes and the national 75th percentile.

Parasites and Diseases

KCM (1995) surmised that a disease outbreak contributed to the decline of Green Lake common carp in 1994. However, an etiologic agent was never identified nor evidence reported to support this claim. In January 1989, a fish pathology report showed that winter–time aggregations of Green Lake common carp were susceptible to modest infestations (< 10 organisms/gill arch) of flatworms, *Gyrodactulus* sp. (Platyhelminthes: Monogenea) and external, ciliated protozoans, *Epistylis* sp. and *Trichodina* sp. (WDFW, unpublished data). Parasitosis is not unusual for high–density populations of common carp. Although severe infestations may cause considerable damage to skin and gill filaments, they do not ordinarily play an important role in controlling wild populations (Panek 1987).

Brown Bullhead

Eleven brown bullhead were captured during fall 1999. These fish ranged from 164 to 289 mm TL (Table 7). At least two year-classes were evident from the length frequency histogram (Figure 7); however, these fish were not aged. The relative weights of Green Lake brown bullhead were low by national standards (Figure 8).

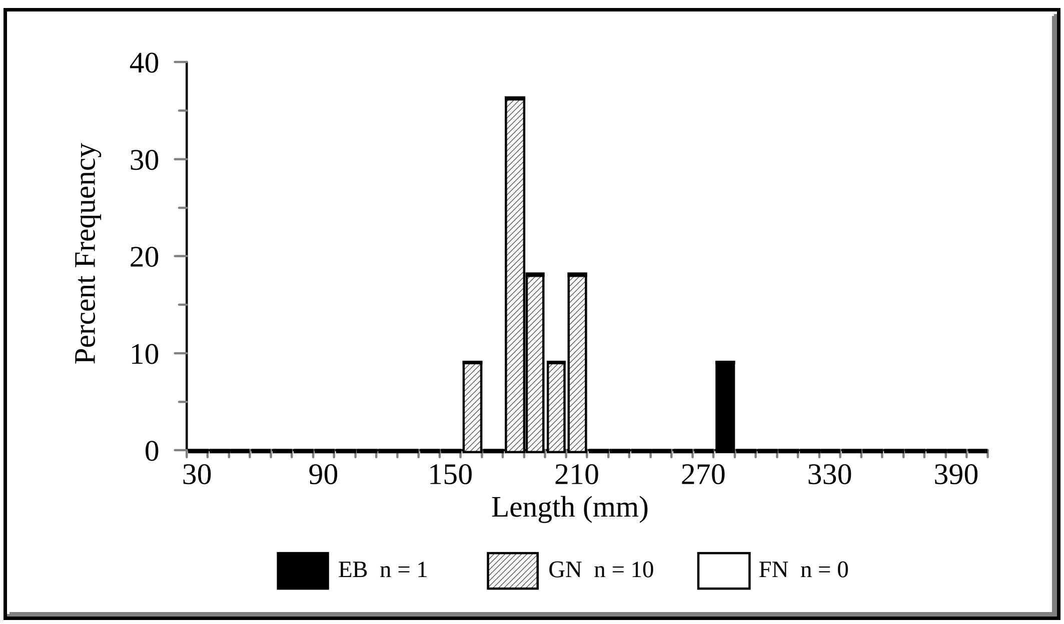

Figure 7. Length frequency histogram of brown bullhead sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

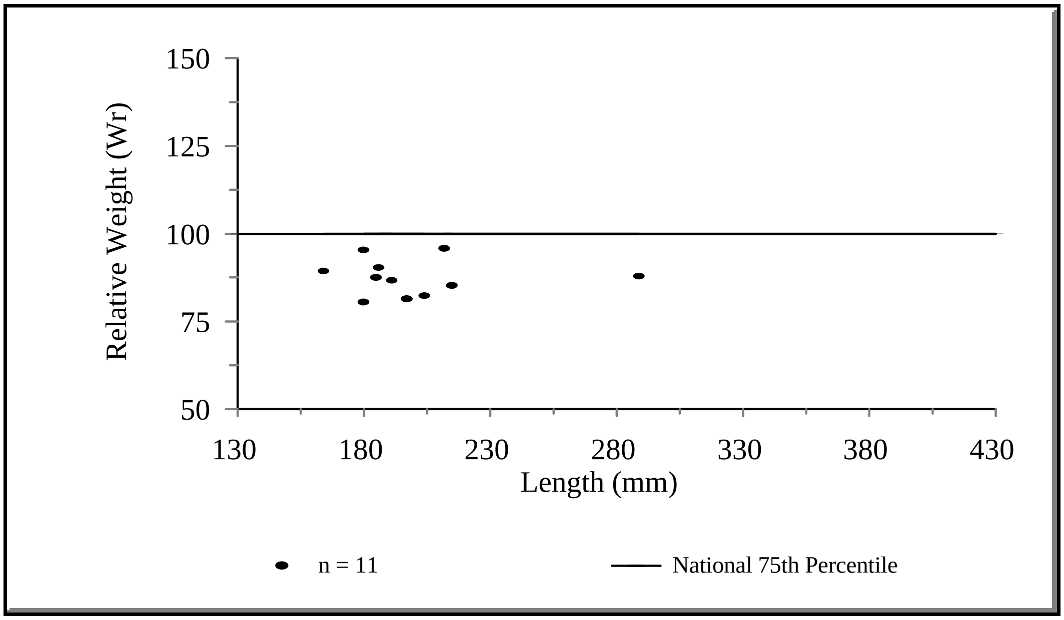

Figure 8. Relationship between total length and relative weight (Wr) of brown bullhead from Green Lake (King County) compared with the national 75th percentile.

Channel Catfish

Two channel catfish were captured during fall 1999. These fish measured 238 and 277 mm TL (Table 7) and weighed 114 and 250 g, respectively. Their relative weights were consistent with the state average, yet above the national standard for the species (Figure 9). Channel catfish are a recent introduction by WDFW to increase warmwater angling opportunities at Green Lake.

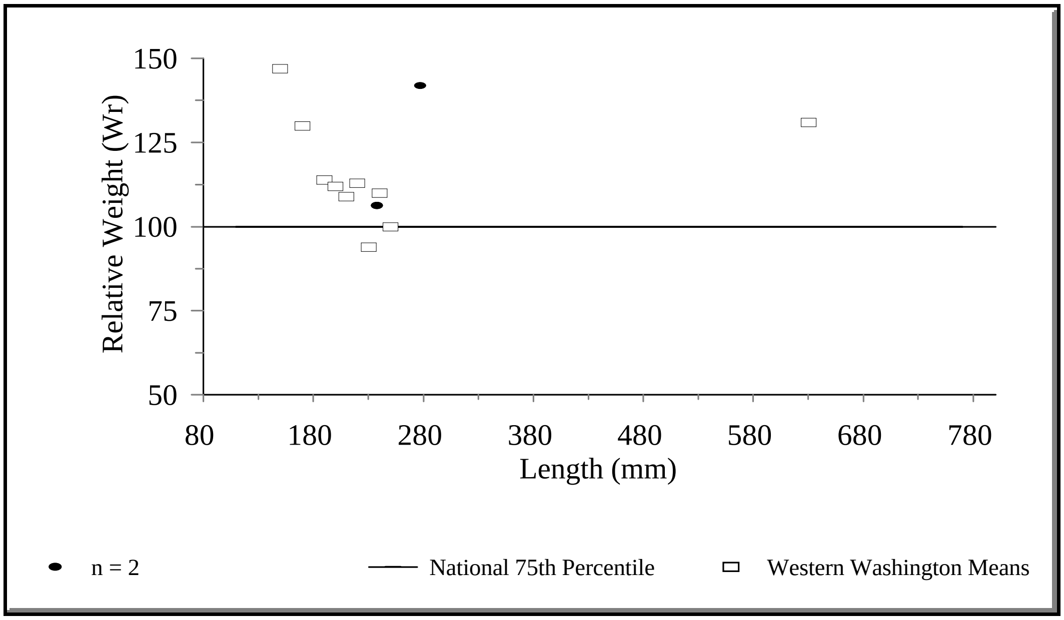

Figure 9. Relationship between total length and relative weight (Wr) of channel catfish from Green Lake (King County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Largemouth Bass

Largemouth bass were reintroduced to Green Lake illegally between 1983 and 1993 after a 25–year absence (Table 1). The four large fish captured during early summer 1999 (Figure 10) displayed phenomenal growth compared to the western Washington average for the species and that reported by Mueller (1998) (Table 13). This strongly suggests the fish originated from someplace other than western Washington and were transplanted into Green Lake. The size structure of largemouth bass observed during fall 1999 (Figure 12) was skewed toward sub–stock size fish consistent with the findings of Mueller (1998). However, 1999 catch rates for stock–size fish were slightly elevated compared to those of 1997 (Table 8), a possible reflection of improved growth in Green Lake largemouth bass since Mueller's (1998) survey (Table 14). PSD and RSD values suggest that the lake is naturally suited for a common carp or panfish fishery rather than a balanced or big bass fishery (Tables 5 and 9) (Gabelhouse 1984; Willis et al. 1993). Still, relative weights of Green Lake largemouth bass were consistent with or greater than the national standard and averages for this species from up to 25 western Washington warmwater lakes (Figures 11 and 13).

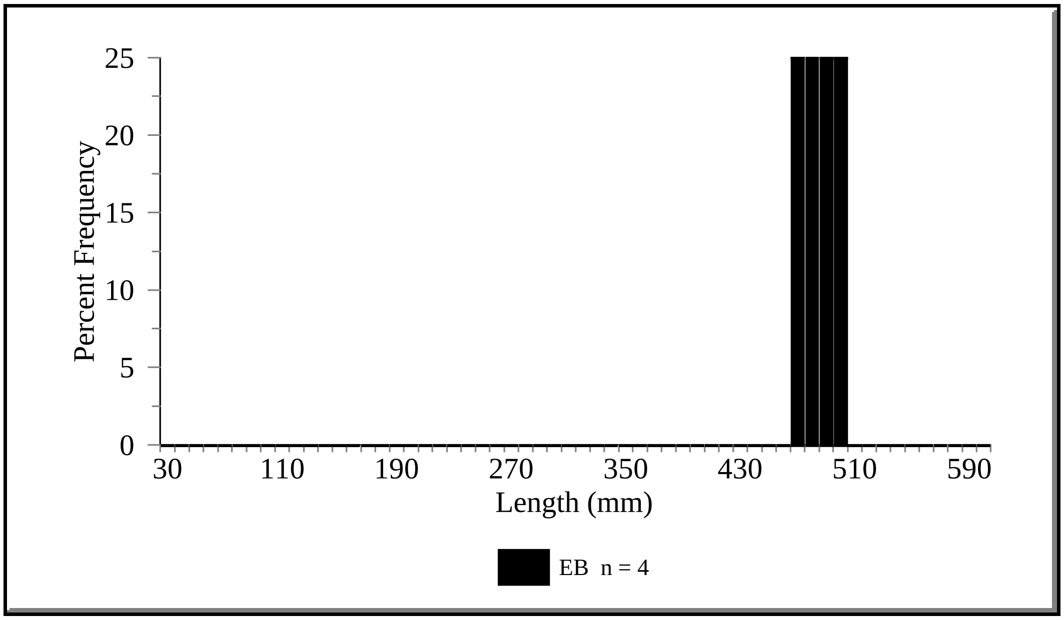

Figure 10. Length frequency histogram of largemouth bass sampled from Green Lake (King County) while electrofishing (EB) in early summer 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type.

Table 13. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Green Lake (King County) during early summer 1999. Unshaded values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back–calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

		Mean total length (mm) at age								
Year class	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1998	0									
1997	0									
1996	0									
1995	0									
1994	0									
1993	1	180.3	239.1	337.1	376.3	415.5	470.3			
		192.9	249.2	343.2	380.8	418.4	471.0			
1992	1	184.0	262.2	332.7	399.2	446.2	473.6	493.2		
		196.6	271.8	339.4	403.3	448.4	474.7	493.5		
1991	1	165.5	259.1	363.4	403.0	428.2	442.6	453.4	464.2	
		178.6	268.2	368.1	406.1	430.2	444.0	454.3	464.7	
1990	1	128.3	224.5	292.6	388.8	424.9	444.9	460.9	473.0	485.0
		143.1	235.3	300.7	393.0	427.6	446.9	462.2	473.8	485.3
Overall mean		164.5	246.2	331.5	391.8	428.7	457.9	469.2	468.6	485.0
Weighted mean		177.8	256.1	337.9	395.8	431.1	459.1	470.0	469.2	485.3
Data from Mueller (1998)		43.9	125.1	156.8	176.8	---	---	---	---	---
Western WA average		60.4	145.5	222.2	261.1	289.3	319	367.8	396	439.9

Table 14. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Green Lake (King County) during fall 1999. Unshaded values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back–calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age 1
1998	4	78.8
		91.2
	Overall mean	78.8
	Weighted mean	91.2
	Data from Mueller (1998)	43.9
	Western WA average	60.4

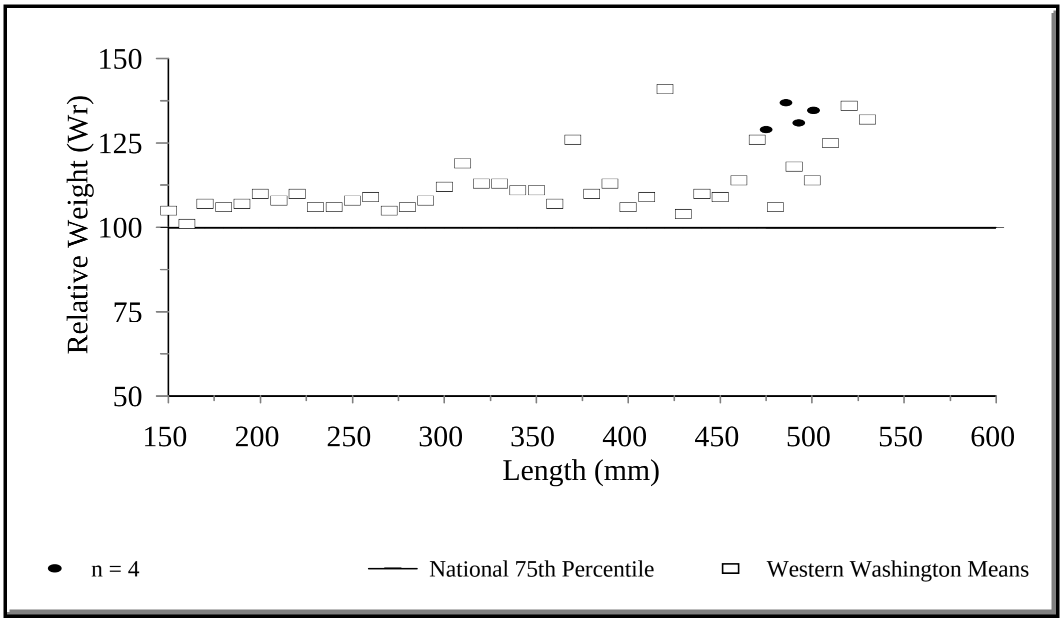

Figure 11. Relationship between total length and relative weight (Wr) of largemouth bass from Green Lake (King County) during early summer 1999 compared with means from up to 25 western Washington lakes and the national 75th percentile.

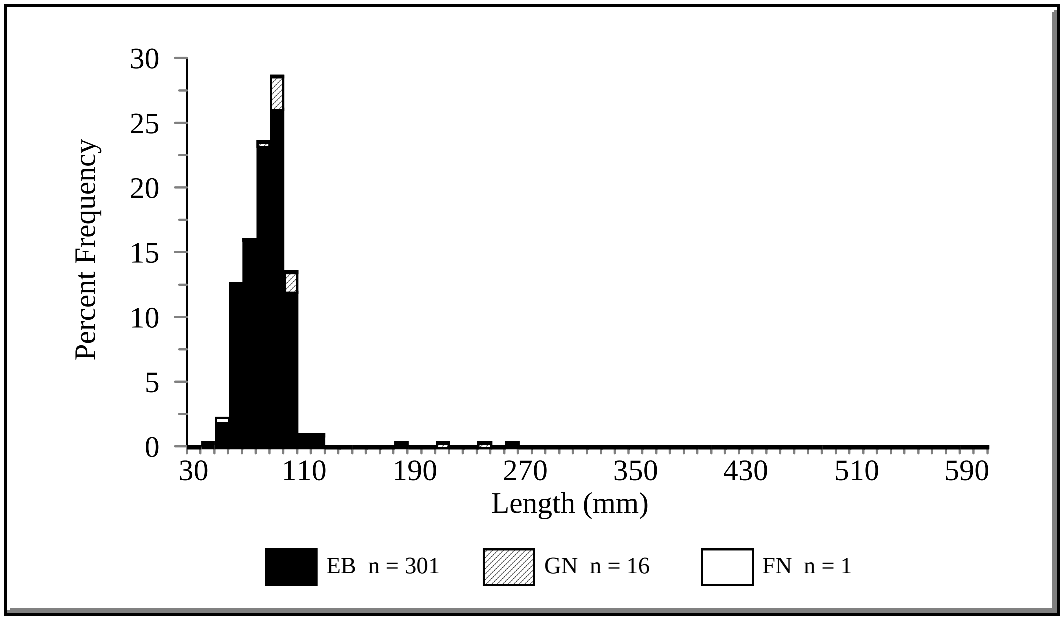

Figure 12. Length frequency histogram of largemouth bass sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

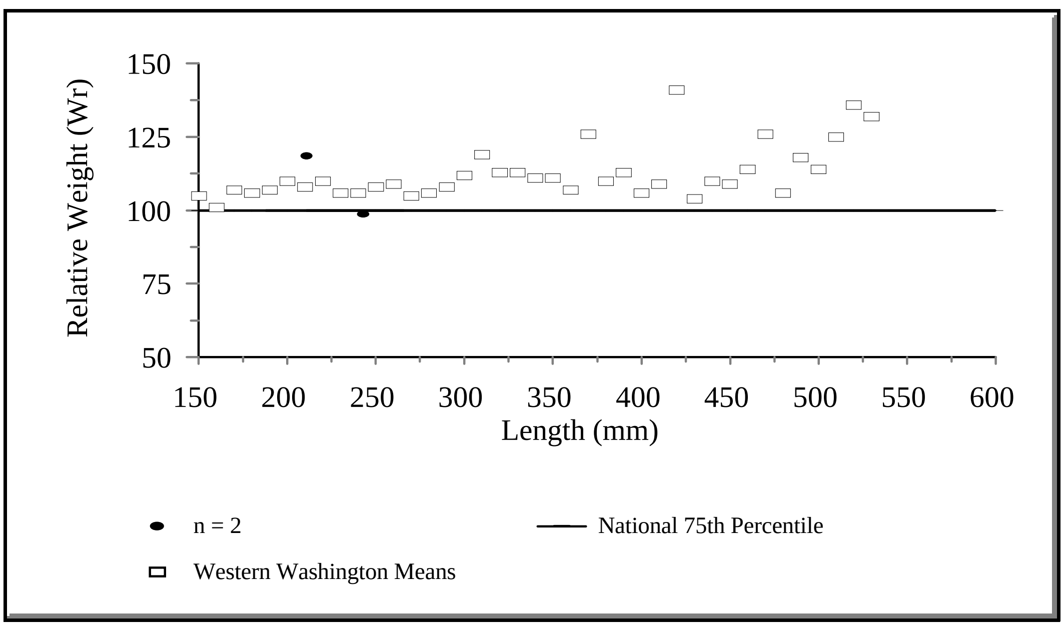

Figure 13. Relationship between total length and relative weight (Wr) of largemouth bass from Green Lake (King County) during fall 1999 compared with means from up to 25 western Washington lakes and the national 75th percentile.

Pumpkinseed

During fall 1999, Green Lake pumpkinseed ranged from 27 to 164 mm TL and were aged 0+ to 3+ (Figure 14; Tables 7 and 15). Like largemouth bass, pumpkinseed size/age structure was skewed toward smaller, younger fish resulting in PSD values that were below average (Tables 6 and 9). Growth of fish older than age 1+ was high when compared to pumpkinseed statewide and the data from Mueller (1998). Improved growth rates might be due to lower population density, as reflected in the decreased catch rate for pumpkinseed (Table 8), or improved foraging opportunities because of the routine mechanical harvest of aquatic vegetation (Olson et al. 1998; Unmuth et al. 1999). With few exceptions, relative weights were above the national standard for the species, consistent with the averages for pumpkinseed from up to 25 western Washington warmwater lakes (Figure 15), and similar to those reported in Mueller (1998).

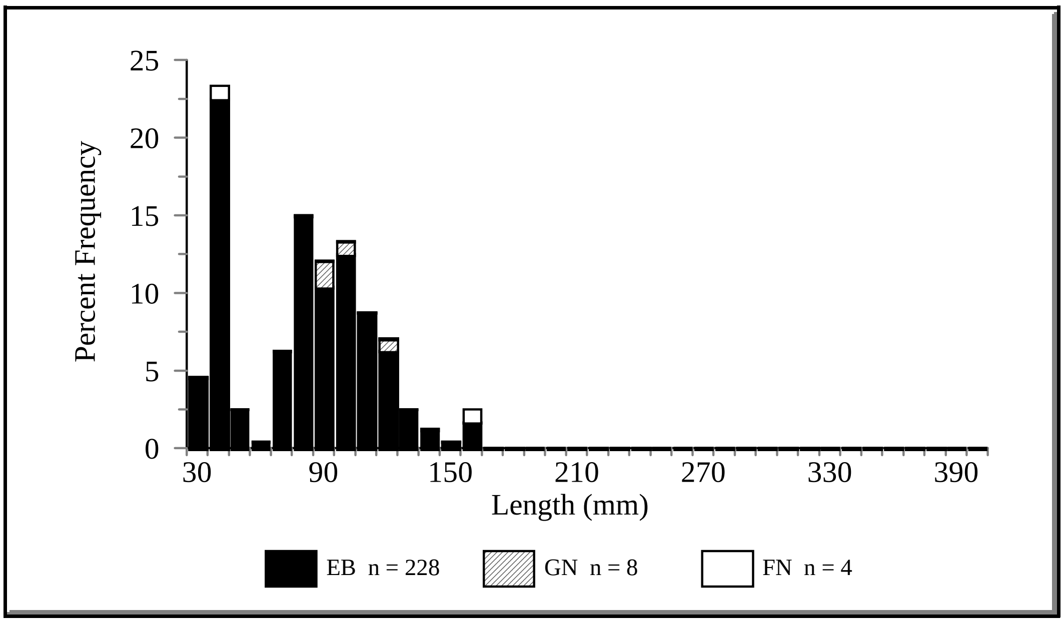

Figure 14. Length frequency histogram of pumpkinseed sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, FN = fyke netting.

Table 15. Age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Green Lake (King County) during fall 1999. Unshaded values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back–calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

		Mean total length (mm) at age		
Year class	**# fish**	**1**	**2**	**3**
1998	36	17.9		
		38.7		
1997	5	22.1	110.5	
		43.4	118.0	
1996	3	20.8	90.1	126.9
		42.5	100.4	131.2
	Overall mean	20.3	100.3	126.9
	Weighted mean	39.5	111.4	131.2
	Data from Mueller (1998)	42.6	87.8	109.8
	State average	23.6	72.1	101.6

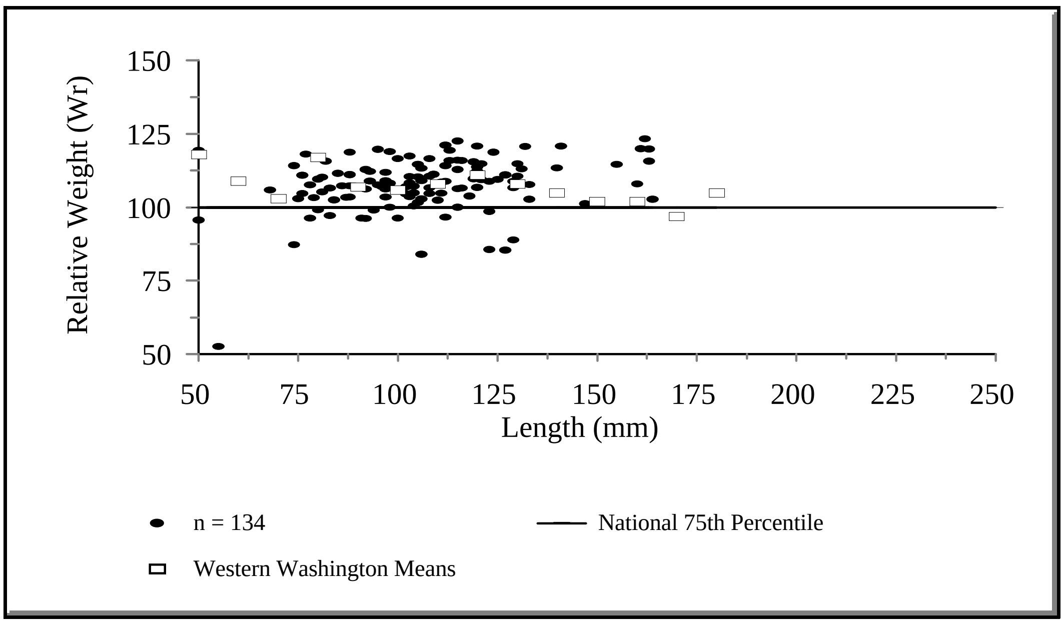

Figure 15. Relationship between total length and relative weight (Wr) of pumpkinseed from Green Lake (King County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Rock Bass

Rock bass are a recent introduction to Green Lake and were first reported by Mueller (1998) (Table 1). During fall 1999, fish ranged from 42 to 215 mm TL and were aged 0+ to 3+ (Figure 16; Tables 7 and 16). Like pumpkinseed, growth of fish older than age 1+ was high when compared to rock bass statewide and the data from Mueller (1998). Relative weights were variable around the national standard for the species, yet mostly high when compared to the averages for rock bass from up to 25 western Washington warmwater lakes (Figure 17).

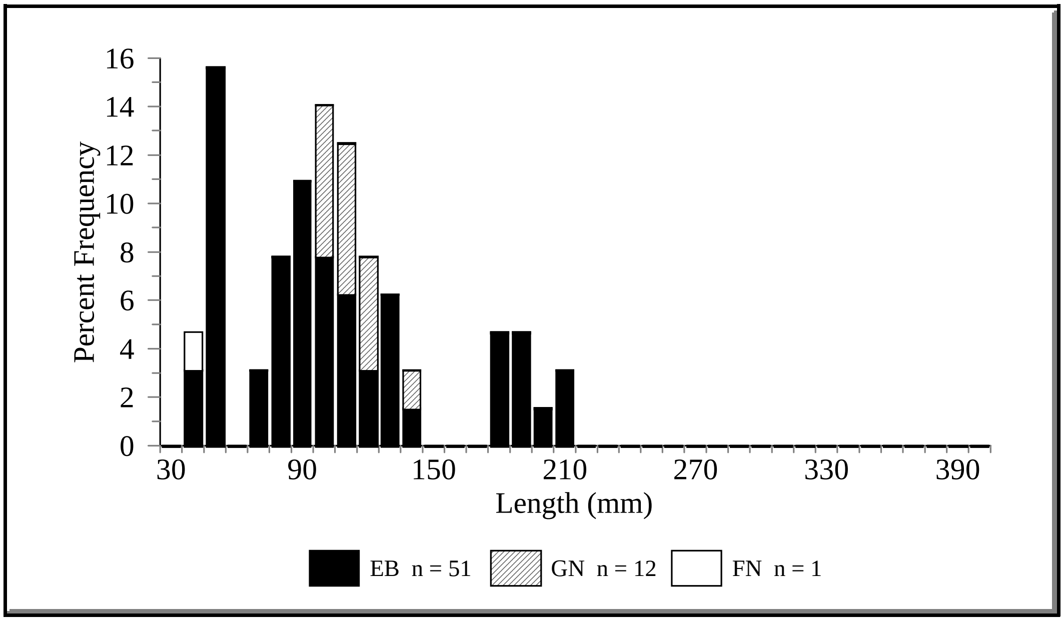

Figure 16. Length frequency histogram of rock bass sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

Table 16. Age and growth of rock bass (*Ambloplites rupestris*) captured at Green Lake (King County) during fall 1999. Unshaded values are mean back–calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back–calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

		Mean total length (mm) at age		
Year class	**# fish**	**1**	**2**	**3**
1998	21	44.8		
		60.1		
1997	7	42.5	129.8	
		61.4	136.3	
1996	3	31.2	100.1	172.6
		52.5	113.2	177.1
	Overall mean	39.5	114.9	172.6
	Weighted mean	59.7	129.4	177.1
	Data from Mueller (1998)	49.3	90.6	117.4
	State average	29	69.6	117.6

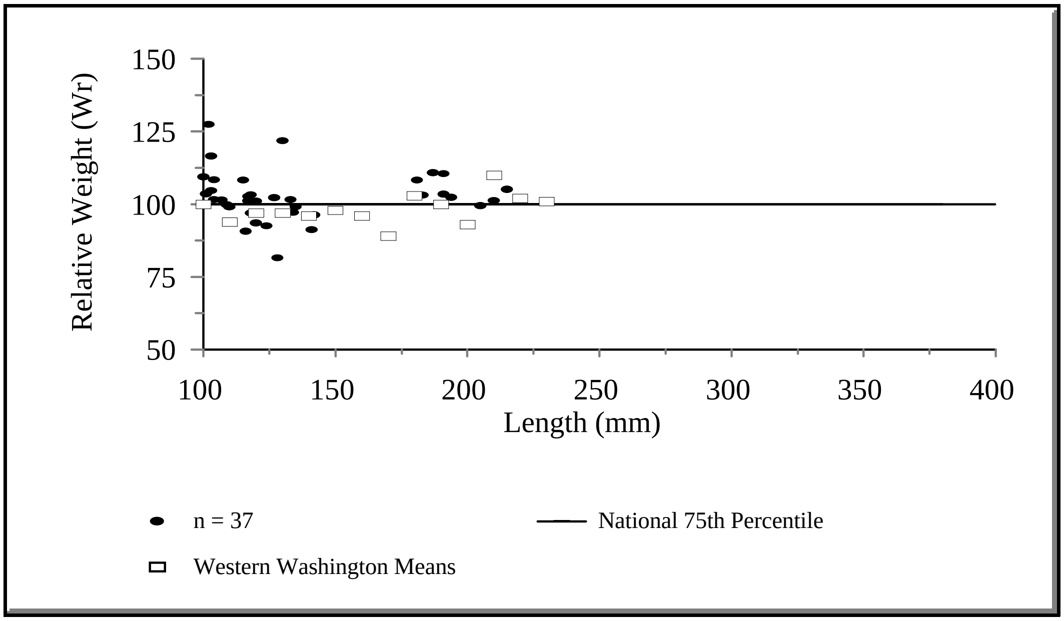

Figure 17. Relationship between total length and relative weight (Wr) of rock bass from Green Lake (King County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Sculpin and Members of the Family Salmonidae

Sculpin comprised less than 0.05% of the biomass and 2% of the number captured, and ranged from 39 to 97 mm TL (Table 7; Figure 18). Catch rates increased two–fold for this species since fall 1997 (Table 8). Several dozen chinook salmon were captured during fall 1999. Considering their size at stocking (~ 60 mm TL), chinook salmon grew rapidly during spring and summer as indicated by their length frequency histogram (Figure 19). As of this writing, anecdotal reports of anglers landing 250 mm FL chinook salmon are common. Rainbow trout ranged from 138 to 290 mm TL (Figure 20) and comprised 1.6% of the biomass captured and 2.8% by number (Table 7). Their relative weights decreased with length and were below the national standard for the species (Figure 21), possibly related to competition with the recently introduced chinook salmon.

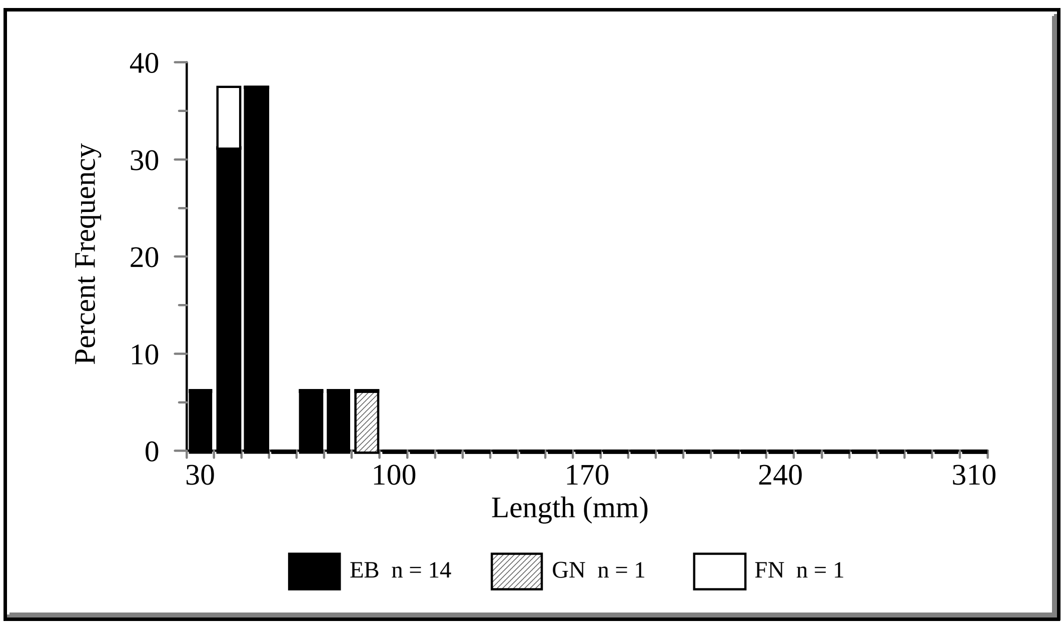

Figure 18. Length frequency histogram of sculpin (*Cottus* sp.) sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

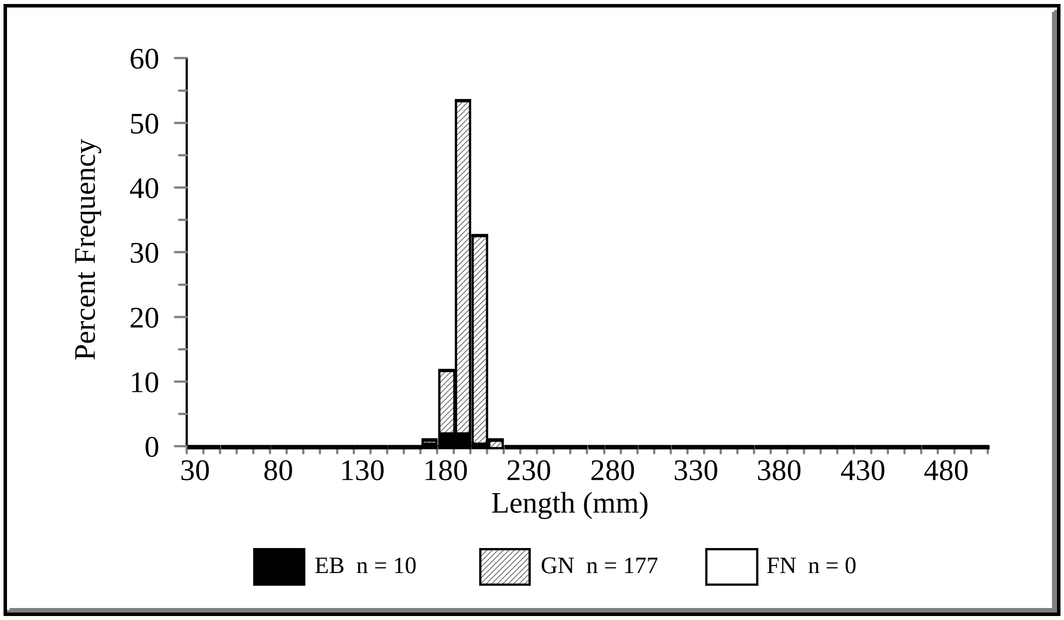

Figure 19. Length frequency histogram of chinook salmon (*Oncorhynchus tshawytscha*) sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

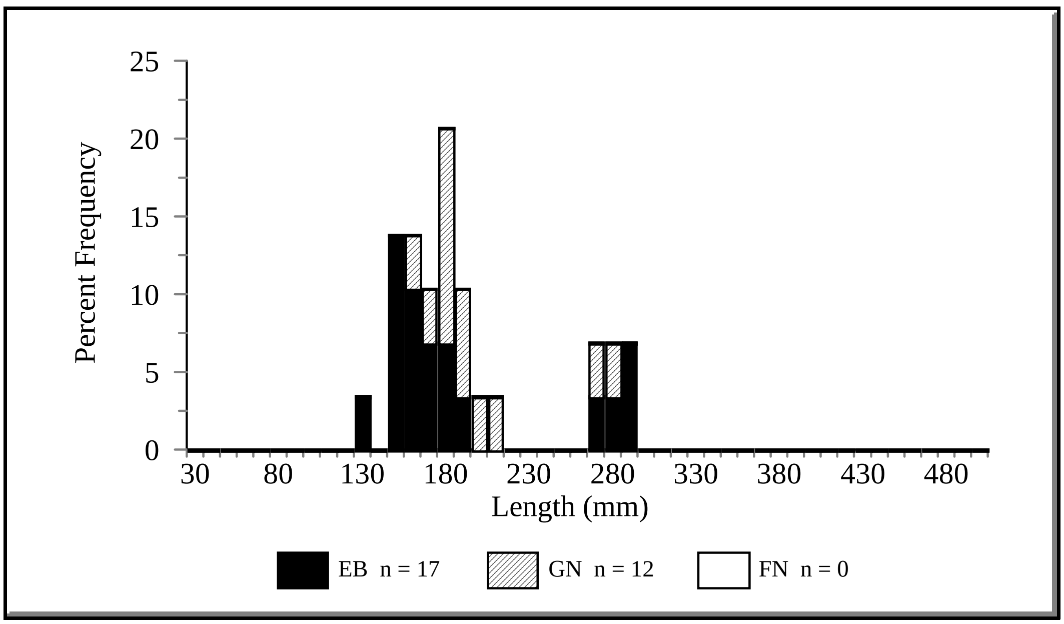

Figure 20. Length frequency histogram of rainbow trout (*Oncorhynchus mykiss*) sampled from Green Lake (King County) in fall 1999. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gill netting, and FN = fyke netting.

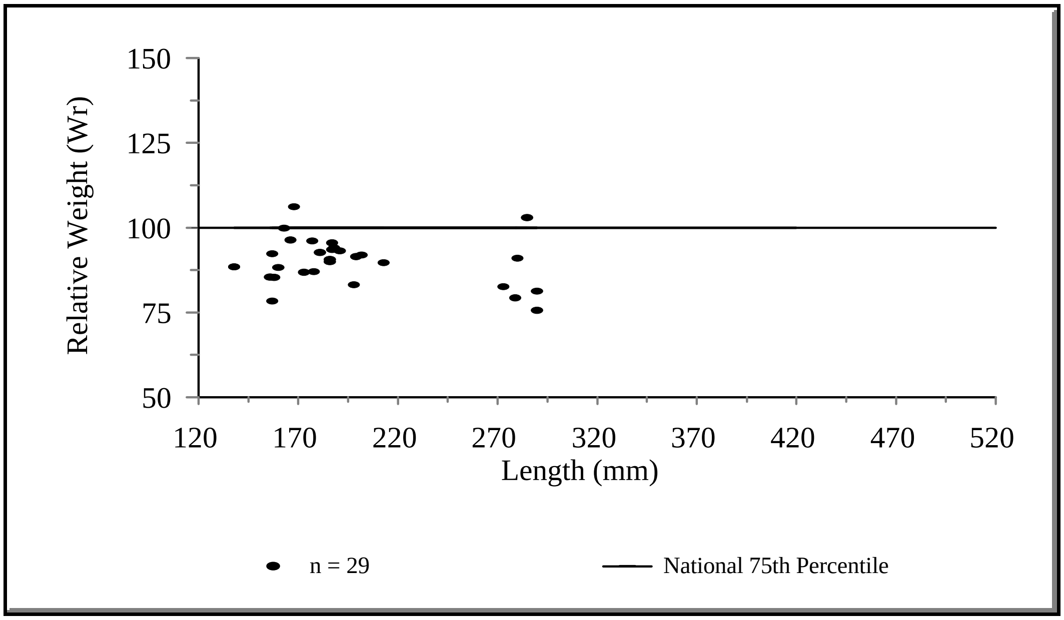

Figure 21. Relationship between total length and relative weight (Wr) of rainbow trout from Green Lake (King County) compared with the national 75th percentile.

Warmwater Enhancement Options

Our results show unequivocally that the common carp population at Green Lake continues to thrive. Growth of fish through age 5+ was rapid; ostensibly, Green Lake common carp reach reproductive sizes sooner than populations elsewhere. Furthermore, the relative weights of individual fish were high, indicating an ample food supply.

Since the last survey of Green Lake's fisheries in fall 1997 (Mueller 1998), growth of largemouth bass, pumpkinseed, and rock bass all improved. This might be related to SDPR's seasonal efforts to mechanically harvest Eurasian watermilfoil. Indeed, recent studies (Olson et al. 1998; Unmuth et al. 1999) showed that mechanical harvesting of aquatic vegetation positively affected growth of largemouth bass and bluegill (*Lepomis macrochirus*), a close relative of pumpkinseed.

In light of SDPR's "zero tolerance" for chemical control measures, the agency should revisit stocking herbivorous grass carp as a cost–effective alternative to chemical control of aquatic vegetation. Irrespective of stocking grass carp, SDPR should maintain its aquatic plant harvest activities to improve water quality, recreational opportunities, and continue the trend of improved growth in Green Lake's warmwater fishes. Other management strategies that might reduce nuisance common carp and improve the warmwater fishery at Green Lake include, but are not limited to, the following:

- Change existing fishing rules to alter size structure of largemouth bass and increase predation of common carp

  Currently, Green Lake anglers are allowed to harvest five largemouth bass daily, including no more than three over 381 mm (15") TL. The PSD and RSD values of largemouth bass suggest that the lake is naturally suited for a panfish fishery rather than a big bass fishery or one balanced between predator and prey fish (Tables 5 and 9) (Gabelhouse 1984; Willis et al. 1993). Changes in the size structure of largemouth bass will require implementing corrective length and bag limits (*sensu* Willis 1989) to improve this fishery and increase predation of nuisance common carp.

  Implementing a 305-432 mm (12-17") slot limit for largemouth bass might succeed where the original rule failed. The main objective of a slot limit is to improve the size structure of largemouth bass. Under this rule, only fish less than 305 or greater than 432 mm TL may be kept. Decreasing the creel limit from three fish over 381 mm TL to one fish over 432 mm TL would stimulate harvest of small fish while still protecting large fish. A reduction of small fish by anglers may improve growth and production of predator and prey species alike (McHugh 1990).

The success of any rule change, though, depends upon angler compliance. Reasons for non–compliance include lack of angler knowledge of the rules for a particular lake, a poor understanding of the purpose of the rules, and inadequate enforcement (Glass 1984). Therefore, clear and concise multilingual posters or signs should be placed at Green Lake describing the fishing rules for the lake. Press releases should be sent to local papers, magazines, and sport fishing groups detailing the changes to, and purpose of, the rules. Furthermore, increasing the presence of WDFW enforcement personnel at Green Lake during peak harvest periods would encourage compliance.

- Selectively remove common carp with electrofishing boat(s) during spawning season

  KCM (1995) and Mueller (1998) described a variety of ways (e.g., commercial fishing, whole–lake rotenone treatment, and toxic fish bait) in which SDPR might sponsor the selective removal of common carp from Green Lake. However, the lake's dense aquatic vegetation precludes the successful use of many fishing gear types, and SDPR's reluctance to use herbi– and piscicides limit these possibilities. Alternatively, SDPR should consider purchasing an electrofishing boat (approximate cost = $50,000) for their own use, or hiring a private contractor, to electrofish the lower half of the lake during the peak spawning period (April to July). During early summer 1999, we found the greatest concentrations of common carp along portions of the southwest and southeast shorelines (Figures 1 and 2). Our results show that a three-person crew is capable of landing over 80 stock–size fish per hour nighttime electrofishing during the spawning season (Table 8). However, given the common carp's growth and reproductive potentials and ability to repopulate Green Lake, an electrofishing 'round–up' of this kind must be repeated every other year to ensure a modicum level of control.

- Promote sport fishery for common carp

  The size structure of Green Lake's common carp population, as indicated by PSD and RSD values (Table 9), suggests that the lake would support a fine sport fishery for this species. Common carp fisheries are popular all over the world, so why not here? Cultural differences and long–held misperceptions top the list (Spitler 1987). Currently, Green Lake anglers are allowed to retain any number and size of common carp year–round (i.e., no season, size, or bag limits). The lake supports a modest, dependable sport fishery (KCM 1995), yet lacks the pressure needed for controlling the nuisance species. For example, a three–month creel survey conducted by (KCM 1995) revealed that successful common carp anglers landed less than one fish per person during spring and early summer (Table 17). Catch rates for the wily prize would likely increase if WDFW permitted chumming at the lake. Chumming takes advantage of the aggregating behavior of common carp and concentrates the fish in an area pre–selected for fishing. Preferably, canned corn or half–boiled potatoes are used to chum an area for three days prior to fishing. Spitler (1987) provides a good review of this and other techniques to catch the all–too–frequently–dismissed common carp.

Table 17. Results of three–month creel census of common carp anglers at Green Lake during spring and early summer 1994 (from KCM 1995).

Month	Number of anglers	Number of fish caught	Catch per angler
May	80	29	0.36
June	62	15	0.24
July	73	28	0.38

- Consider stocking tiger muskellunge to control common carp

  Several years ago, KCM (1995) and WDFW staff proposed stocking sterile, yearling tiger muskellunge (*Esox masquinongy* × *E. lucius*) into Green Lake to reduce the number of common carp through predation. Although mercilessly lampooned by a journalist in the *Seattle Times* (Hannula 1994), stocking apex predators to control undesirable non–game fish, that compete directly or indirectly with sport fish for resources, has been used with varied degrees of success for years and remains a viable option (Wingate 1986; Tipping 1996, 1999). During fall 1999, 80% of the biomass of our catch was comprised of common carp (Table 7). Tiger muskellunge prefer fusiform, soft–rayed prey, such as common carp, over deep–bodied, spiny–rayed prey, such as pumpkinseed, yet generally fare well irrespective of the forage base (Tomcko et al. 1984; Newman and Storck 1986; Wahl and Stein 1988; Kohler and Kelly 1991; Tipping 1996, 1999). Increased predation of common carp should allow more fish to realize their full growth potential. Furthermore, tiger muskellunge grow rapidly in Washington (Hillson and Tipping 1999). Therefore, in addition to improving balance, stocking tiger muskellunge may also provide a trophy fishing opportunity at Green Lake (Adair 1986; Storck and Newman 1992; Tipping 1996).

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