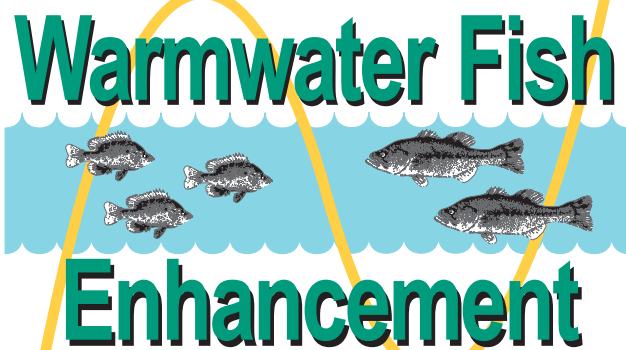


# A Biological Assessment of the Warmwater Fish Community in Lake Washington



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*Washington Department of  
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Yellow perch in Lake Washington, photographed by Don Rothaus.

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# Abstract

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The limnology of Lake Washington has been studied extensively over the past 100 years, and many changes have occurred during that time that have dramatically altered the fish community and fish habitat. In the past two decades, researchers at the University of Washington and U. S. Fish and Wildlife Service have conducted many research projects that broadened our understanding of food web dynamics, trophic relationships, and impacts of predatory fishes on outmigrating salmonids. Although extensive sampling accompanied these research projects, a whole-lake assessment of the warmwater fish community has never been conducted.

To update our knowledge of the warmwater fish community and draw comparisons to prior sampling, we conducted a “standardized warmwater survey” developed by the Warmwater Program (Washington Department of Fish and Wildlife) in 1997. Using electrofishing, gill netting, and fyke netting, we sampled a total of 248 locations and captured 40,894 individuals representing 22 species. Warmwater gamefish comprised 73.7% of the sample by number, but only 33.7% of the sample weight. Collectively, coldwater gamefish species including Northern Pikeminnow *Ptychocheilus oregonensis*, Peamouth Chub *Mylocheilus caurinus*, and Largescale Suckers *Catostomus macrocheilus* accounted for 50.1% of the biomass. Threespine Stickleback *Gasterosteus aculeatus* was by far the most abundant species comprising 70% of the sample by number. Yellow Perch *Perca flavescens* was the most abundant warmwater gamefish species sampled and comprised 19% of the sampled biomass; second to Largescale Suckers (35.3%). Pumpkinseed *Lepomis gibbosus* was the second most abundant warmwater gamefish, followed by Brown Bullhead *Ameiurus nebulosus* and Smallmouth Bass *Micropterus dolomieu*. Other gamefish including Rainbow Trout *Oncorhynchus mykiss*, Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii*, Bluegill *Lepomis macrochirus*, Largemouth Bass *Micropterus salmoides*, and Black Crappie *Pomoxis nigromaculatus* constituted a small portion of the sample. These results suggest that, similar to other Washington lakes, the fish community of Lake Washington is dominated by “coolwater” species that include Yellow Perch, Pumpkinseed, Smallmouth Bass, and Brown Bullhead Catfish. Comparisons to 1982 sampling suggest that Largemouth Bass and Black Crappie have declined in relative abundance over the past 30 years, while the relative abundance of Smallmouth Bass has increased.

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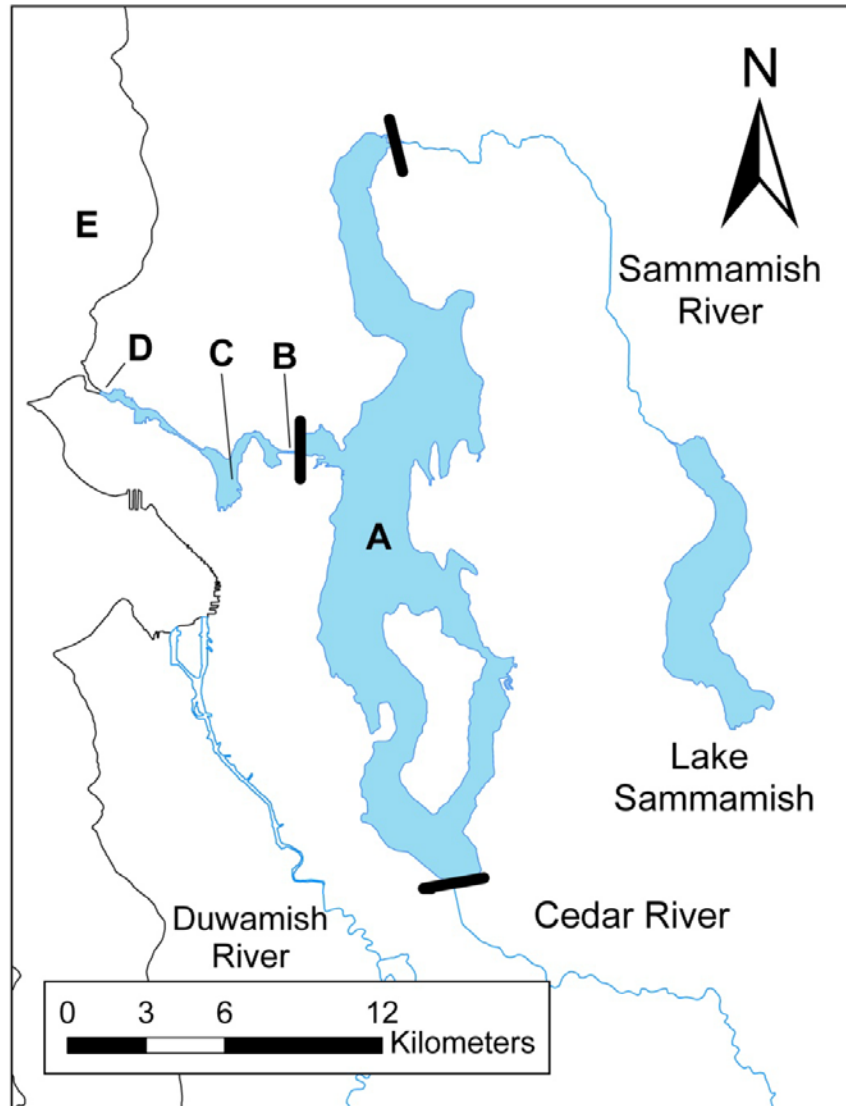
# Introduction

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Covering 22,138 acres and spanning 18.4 miles, Lake Washington is the second largest natural lake in Washington State (Figure 1). Given its size and close proximity to large metropolitan areas, including Seattle and Bellevue, Lake Washington is a popular destination for recreational boaters, water skiers, swimmers, jet skiers, and anglers. Throughout the year, Lake Washington offers some of the State's best recreational fishing opportunities. Popular fisheries in the lake include cutthroat trout, smallmouth bass, yellow perch, and sockeye salmon. In 1981, an estimated 88,500 Lake Washington anglers lived in the greater Seattle area (Bradbury and Pfeifer 1992). From 1981 to 1982, the estimated monetary value of the coldwater and warmwater fisheries in Lake Washington averaged \$1,681,947 and \$812,514, respectively. Arguably, both angler use and the value of the fisheries in Lake Washington have increased over the past 20 years. Proper management of these valuable fisheries is critical to maintaining them for future users.

Although the limnology and food web dynamics of Lake Washington have been studied somewhat intensively (Eggers et al. 1978; Costa 1979; Edmondson 1994; Edmondson and Lehman 1981; Beauchamp et al. 2004; Tabor et al. 2004; McIntyre et al. 2006; Overman et al. 2009), the resident fish community, comprised largely of nonnative species, remains poorly understood. The most recent whole-lake stock assessment survey of the resident fish community in Lake Washington was conducted in 1982 (Pfeifer and Weinheimer 1992). Given that change is a fundamental aspect of fish communities, updating our information on the resident fish community has become increasingly important. For many resident species, information on size structure, age structure, condition, growth, and most importantly, relative abundance is not known. Current data to produce these fishery statistics is useful in guiding management strategies for several species, identifying future research needs, and fulfilling information requests from the public and other governmental natural resource agencies.

At nearly 22,000 acres with an average depth of 33 meters and a heavily urbanized shoreline, Lake Washington is a very difficult lake to sample in its entirety. Consequently, past research conducted on Lake Washington focused on localized areas and extrapolated the data to the entire lake (Pfeifer and Weinheimer 1992). This strategy can produce results that do not represent the entire fish community, especially in large lakes which have an uneven distribution of habitat. Here, we provide a whole-lake assessment of the resident fish communities that use the littoral zone of Lake Washington. Fishery statistics collected include species composition (numerical and biomass), relative abundance (catch per unit effort; CPUE), size and age structure, and relative weight (condition). Catch rate data from specific sites was compared to Pfeifer and Weinheimer (1992) to examine potential changes that have occurred to the fish community. Information collected from this survey may be used by state, tribal, federal and municipal natural resource agencies to guide future management decisions.



**Figure 1** Map showing lower portion of the Cedar River Watershed including Lake Washington (A), the Lake Washington Shipping Canal (B), Lake Union (C), and the Hiram M. Chittenden Locks (Ballard Locks; D). Bold bars delineate lake boundaries, the furthest extent of warmwater sampling conducted in 2005.

## Methods

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During June 26–July 1, 2005, eight 3-person crews from the Washington Department of Fish and Wildlife sampled the shoreline of Lake Washington. We used standardized sampling protocols developed for Washington lakes by Bonar et al. (2000), which incorporate random sampling and multiple gears types to obtain the best representative sample of warmwater species and their respective size classes.

Fish were captured using three sampling techniques: electrofishing, gill netting, and fyke netting. Electrofishing was conducted using four 16-foot and four 18-foot Smith-Root 5.0 GPP electrofishing boats set to a DC current of 60 cycles/second at 4-6 amps. Gill nets (45.7 m long X 2.4 m deep) consisted of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size monofilament mesh (13, 19, 25, and 51 mm stretched). Fyke nets were constructed of a single 30.4-m lead and two 15.2-m wings of 130 mm nylon mesh with the body of the nets stretched around four 1.2-m aluminum rings in each of two section.

Sampling locations were chosen by dividing the shoreline into 400-m sections. Of the 301 sections, 120 were randomly selected for electrofishing, 64 for gill netting, and 64 for fyke netting (Figures 2 and 3). In some cases, multiple gear types were used at the same sampling locations. At each electrofishing section, the boat was maneuvered adjacent to the shoreline (depth range = 0.2 - 2 m) for 600 seconds. Electrofishing was conducted only during evening hours to maximize the size and number of fish captured. Electrofishing is more effective at night because some fish species seek shelter during the day and move freely at night (Reynolds 1996; Dumont and Dennis 1997). The total electrofishing effort (“pedal-down” time) for the lake was 72000 seconds (20 hours). Gill nets were set perpendicular to the shoreline with the small mesh end attached nearshore and the large mesh end anchored offshore. Fyke nets were set perpendicular to the shore with the lead net anchored onshore and the wing nets set at 45-degree angles to the trap. Fyke nets were set so that the trap was no deeper than three meters (Bonar et al. 2000). Both gill nets and fyke nets were set at dusk and retrieved the following day (net-night; 16-20 hours). Total lake effort was 64 net nights for gill nets and 64 net nights for fyke nets.

Catch per unit effort (CPUE) of each sampling gear was determined for each species collected. The CPUE of electrofishing was determined by dividing the number of fish captured by the total amount of “pedal-down” time recorded from the GPP. CPUE of gill netting and fyke netting was determined by dividing the number of fish captured by the total time the nets were deployed (net-night; 16-20 hours).

Relative weight ( $W_r$ ) was used to evaluate the condition of warmwater gamnefish in Lake Washington. As presented by Anderson and Neumann (1996), a  $W_r$  of 100 generally indicates that the fish is in a condition similar to the national average for that species and length. The index is defined 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).  $W_s$  was derived from a standard weight-length (log10) relationship which was defined for each species of interest in Anderson and Neumann (1996). Minimum lengths were used for each species as the variability can be significant for small fish (young-of-the-year).

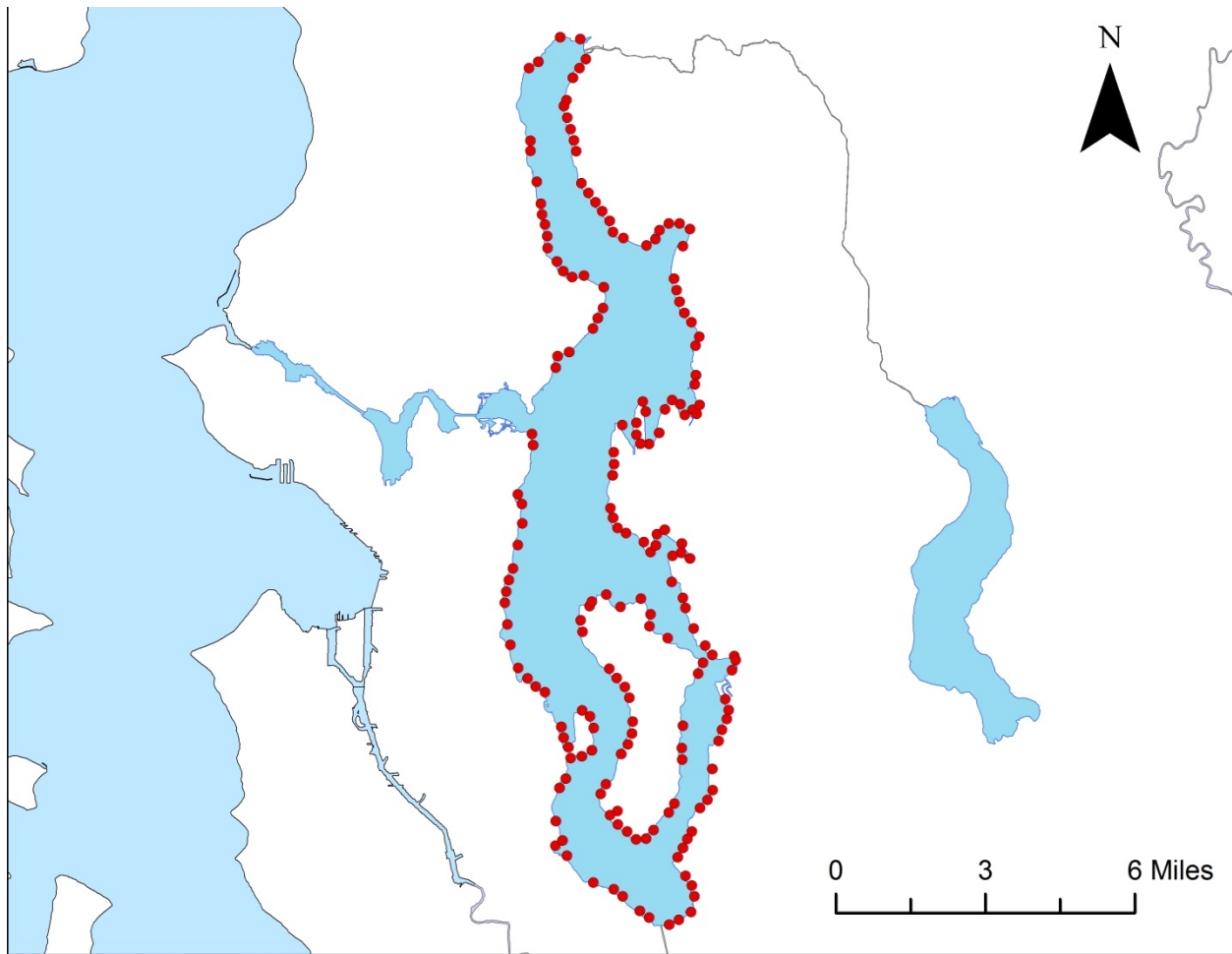
Age and growth of five species (Smallmouth Bass, Largemouth Bass, Yellow Perch, Pumpkinseed, Black Crappie) in Lake Washington were evaluated using procedures described by Fletcher et al. (1993). All samples were evaluated using both the direct proportion method (Fletcher et al. 1993).

The proportional size distributions (PSDs) of six species (Smallmouth Bass, Largemouth Bass, Yellow Perch, Pumpkinseed, Black Crappie, and Common Carp) were determined following procedures outlined in Anderson and Neumann (1996) with terminology refined by Guy et al. (2006; 2007). PSDs use two length measurements to provide information about the proportion of various size fish in a population. PSDs are calculated by using the number of quality-size (PSD), preferred-size (PSD-P), memorable-size (PSD-M), and trophy-size (PSD-T) fish, dividing by the number of stock-size fish, and multiplying by 100. PSD length categories, which vary by species, are based on percentages of world-record lengths: stock (20-26%), quality (36-41%), preferred (45-55%), memorable (59-64%), and trophy (74-80%).

Water chemistry data were collected at 1-meter increments in the east channel of Lake Washington (Lat 47.54972 N, Long 122.20365 W) on August 2, 2005. A Hydrolab<sup>®</sup> was used to collect information on temperature (°C), dissolved oxygen (mg/L), pH, and conductivity (µS/cm). A Secchi disk was used to record Secchi depth, a unit of measure representing water clarity.

The timing of a fishery survey can affect the quality of data collected (Bettross and Willis 1988; Guy and Willis 1991). In Washington, standardized warmwater sampling generally occurs during late May/early June or late September/early October, when water temperatures are between 16–22 °C. However, there is a high risk of encountering ESA-listed juvenile Chinook Salmon and Steelhead during these sampling periods in Lake Washington. As a result, June 23–27 was selected as a compromise between sampling efficiency and risk to ESA-listed species.

Biological information recorded from sampled fishes included identification of species (except Cottidae *spp.*), total length (mm) and weight (g). Ageing structures (scales and otoliths) were collected from a subsample (up to eight per 10-mm size class) of select species. From this data we calculated species composition and relative abundance (by weight and number), catch rates for each species by gear type (CPUE), age and back-calculated length at age, and size structure (i.e., length frequency and proportional stock densities).



**Figure 2. Map showing sampling locations of warmwater survey conducted during June-July, 2005 (N=227). Due to the spatial randomization of sampling within each gear type, some stations were sampled using multiple gear types.**

# Results

## Water Chemistry

Water chemistry data was collected from the east channel of Lake Washington (Lat 47.54972 N, Long 122.20365 W) on August 2, 2005. Water quality parameters included temperature, dissolved oxygen, pH, and conductivity (Table 1). Secchi depth was measured at 6.2 meters.

**Table 1. Water chemistry data collected from Lake Washington, King County, Washington on 2 August 2005. Data were collected in the east channel, south of I-90 (Lat 47.54972 N, Long 122.20365 W).**

Depth (m)	Temperature (°C)	DO (mg/L)	pH	Conductivity (µS/cm)
0	23.3	9.51	7.88	79
1	23.23	9.17	7.92	78.7
2	23.18	9.26	7.96	79.1
3	23.13	9.45	7.97	79
4	23.07	9.27	7.99	78.7
5	23	9.36	7.99	78.7
6	22.99	9.22	8	78.8
7	22.96	9.27	8	78.9
8	22.89	9.24	7.98	78.6
9	19.66	8.97	7.53	76.6
10	17.38	8.14	7.24	75.8
11	16.45	7.8	7.1	75.6
12	15.15	7.25	6.98	75.7
13	14.34	6.69	6.86	75.2
14	13.96	6.6	6.83	75.3
15	13.18	6.04	6.75	75.4
16	12.85	5.55	6.7	75.4
17	12.11	5.8	6.7	75.1
18	11.47	5.75	6.67	74.8
19	11.12	4.53	6.58	75.1

## Species Composition

A total of 21 fish species and one family (Cottidae: Sculpins) were collected during sampling efforts on Lake Washington. Warmwater gamefish comprised 73.7% of the sample by number, but only 33.7% of the sample weight (Table 2). Collectively, coldwater species including Northern Pikeminnow, Peamouth, and Largescale Suckers accounted for a large portion of the biomass sampled, (50.1%). Threespine Stickleback (TSS) was by far the most abundant species comprising 70% of the sample by number (Table 2). Yellow Perch was the

most abundant warmwater gamefish species sampled (50.8% of the sample by number, excluding TSS) and comprised 19% of the sampled biomass; second to Largescale Suckers (35.3%). Pumpkinseed was the second most abundant warmwater gamefish (10.2% of the sample by number, excluding TSS). Smallmouth Bass and Brown Bullhead comprised 5.7% and 6.1% of the biomass of fish sampled, respectively. Other gamefish including Rainbow Trout, Cutthroat Trout, Bluegill, Largemouth Bass, and Black Crappie constituted a small portion of the sample (3.2% by number excluding TSS; 1.2% by weight).

**Table 2. Species composition by weight (kg) and number of fish captured at Lake Washington (King County, WA) during June-July 2005. Percent composition by number is also shown without the Threespine Stickleback (TSS).**

Species	Species Composition					
	By number			By weight		Size range (mm TL)
	(#)	(%)	(% no TSS)	(kg)	(%)	
Threespine Stickleback	28631	70.0%		116.5	5.9%	28-148
Yellow Perch	6,228	15.2%	50.8%	377.2	19.0%	11-353
Sculpin ( <i>Cottidae spp.</i> )	1,296	3.2%	10.6%	29.9	1.5%	6-202
Pumpkinseed	1,242	3.0%	10.2%	31.8	1.6%	11-234
Brown Bullhead	897	2.2%	7.3%	120.9	6.1%	71-338
Largescale Sucker	733	1.8%	6.0%	698.7	35.3%	128-1237
Northern Pikeminnow	649	1.6%	5.3%	238.0	12.0%	25-647
Peamouth Chub	365	0.9%	3.0%	56.4	2.8%	85-347
Smallmouth Bass	284	0.7%	2.3%	113.1	5.7%	78-521
Bluegill	145	0.4%	1.2%	0.8	0.0%	33-143
Cutthroat Trout	136	0.3%	1.1%	10.4	0.5%	21-546
Chinook Salmon	65	0.2%	0.5%	1.3	0.1%	85-227
Largemouth Bass	53	0.1%	0.4%	10.1	0.5%	95-393
Sockeye Salmon	31	0.1%	0.3%	62.8	3.2%	535-665
Black Crappie	29	0.1%	0.2%	1.2	0.1%	86-210
Tench	26	0.1%	0.2%	29.3	1.5%	103-525
Rainbow Trout	25	0.1%	0.2%	2.0	0.1%	147-318
Common Carp	19	0.0%	0.2%	79.4	4.0%	300-785
Coho Salmon	11	0.0%	0.1%	0.2	<0.1%	104-193
Green Sunfish	10	0.0%	0.1%	0.6	<0.1%	65-192
Oriental Weatherfish	10	0.0%	0.1%	0.3	<0.1%	137-190
Salish Sucker	2	0.0%	0.0%	0.2	<0.1%	185-226
Unidentified Salmon <i>spp.</i>	2	0.0%	0.0%	<0.1	<0.1%	94-107
Total:	40,894			1981		
Total w/no TSS:	12,263					

## Catch Per Unit Effort (CPUE)

Fyke netting captured the most fish (n=28,643), though Threespine Stickleback (TSS) comprised the majority of the catch (n=26,155; Table 3). Excluding TSS, gill netting captured the most fish (n=6,693), followed by electrofishing (n=5,555) and fyke netting (n=2,488). Gill netting catch rates were highest for Yellow Perch (60.38 fish/net-night), TSS (22.47 fish/net-night), Northern Pikeminnow (6.89 fish/net-night), and Largescale Sucker (3.86 fish/net-night). Electrofishing catch rates were highest for Yellow Perch (74.55 fish/hour), Sculpin (*Cottidae spp.*; 62.82 fish/hour), TSS (44.04 fish/hour), Largescale Sucker (25.71 fish/hour), Pumpkinseed (21.35 fish/hour), and Brown Bullhead (17.45 fish/hour).

**Table 3. Mean catch per unit effort (number of fish per hour of electrofishing and net night), including 80% confidence intervals, for all fishes (excluding young-of-the-year) collected from Lake Washington during June-July 2005.**

Species	Gear Type		
	Electrofishing (# fish/hr)	Gill Net (# fish/net night)	Fyke Net (# fish/net night)
Yellow Perch	74.55 ± 9.56	60.38 ± 10.29	16.13 ± 5.04
Sculpin ( <i>Cottidae spp.</i> )	62.82 ± 6.43	0.17 ± 0.08	1.37 ± 0.45
Threespine Stickleback	44.04 ± 6.69	22.47 ± 4.99	425.40 ± 144.33
Largescale Sucker	25.71 ± 3.59	3.86 ± 0.69	--
Pumpkinseed	21.35 ± 9.68	1.4 ± 0.47	12.15 ± 3.7
Brown Bullhead	17.45 ± 6.04	1.49 ± 0.59	7.6 ± 7.15
Northern Pikeminnow	10.46 ± 3.15	6.89 ± 1.09	0.26 ± 0.19
Smallmouth Bass	9.8 ± 2.36	1.54 ± 0.31	--
Cutthroat Trout	5.71 ± 1.03	0.43 ± 0.11	--
Chinook Salmon	2.63 ± 0.64	0.14 ± 0.06	0.1 ± 0.08
Peamouth	2.52 ± 0.79	4.97 ± 0.91	0.06 ± 0.07
Largemouth Bass	2.31 ± 1.08	0.14 ± 0.08	--
Rainbow Trout	1.21 ± 0.67	0.03 ± 0.03	--
Black Crappie	0.68 ± 0.3	0.21 ± 0.09	0.05 ± 0.04
Tench	0.37 ± 0.35	0.22 ± 0.11	0.08 ± 0.07
Coho Salmon	0.36 ± 0.2	0.05 ± 0.05	0.02 ± 0.02
Oriental Weatherfish	0.32 ± 0.34	0.03 ± 0.04	0.03 ± 0.03
Bluegill	0.26 ± 0.15	0.05 ± 0.05	2.21 ± 2.48
Common Carp	0.21 ± 0.16	0.24 ± 0.08	--
Green Sunfish	0.16 ± 0.12	0.01 ± 0.09	0.02 ± 0.02
Longnose Sucker	0.11 ± 0.09	--	--
Sockeye Salmon	0.11 ± 0.09	0.46 ± 0.15	--
Unidentified salmonid ( <i>Salmonidae spp.</i> )	0.11 ± 0.13	--	--



## Size Distribution Indices

According to Gustafson (1988), sample sizes of 55 and 120 stock size fish provide proportional size distribution (PSD; Guy et al. 2007) estimates with confidence intervals of  $\pm 10$  at the 80 and 95% confidence limits, respectively. Electrofishing sample sizes for stock-length Brown Bullhead, Yellow Perch, Smallmouth Bass, and Pumpkinseed were high, and permitted the calculation of reliable confidence intervals at the 80% confidence limit (Table 4). Electrofishing and fyke netting produced similar PSD values for Yellow Perch and Pumpkinseed. Gill netting produced considerably higher PSD values for Smallmouth Bass and Yellow Perch than electrofishing and provides additional insight into the true size structure of the population. Although we report size distribution values for Largemouth Bass and Common Carp, these values must be interpreted as representing our sample and not the population given the low sample size (<55 individuals). High size distribution values (>30 PSD) were recorded for Yellow Perch (all gear types), Smallmouth Bass (electrofishing and gill netting), and Brown Bullhead (electrofishing and fyke netting).

**Table 4. Proportional size distribution indices, including 80% confidence intervals, of fish collected from Lake Washington (King County) during June-July 2005, by sampling method. Asterisks denote insufficient sample sizes for calculating reliable confidence intervals. Species with sample sizes of stock size fish <10 are not included.**

Species	Gear Type	# Stock Length Fish	PSD	80% CI	PSD-P	80% CI	PSD-M	80% CI	PSD-T	80% CI
Brown Bullhead	Electrofishing	139	50	5	12	3				
Yellow Perch		98	36	6	4	3				
Smallmouth Bass		77	35	7	18	6	9	4		
Pumpkinseed		76	14	5						
Largemouth Bass		11	27*		9*					
Brown Bullhead	Fyke Netting	109	32	6	3	2				
Yellow Perch		79	35	7	5	3				
Pumpkinseed		71	13	5	1	2				
Yellow Perch	Gill Netting	143	53	5	18	4	1	1		
Smallmouth Bass		75	72	7	56	7	28	7	5	3
Brown Bullhead		49	12	6						
Pumpkinseed		28	4*							
Common Carp		14	93*		57*		50*			

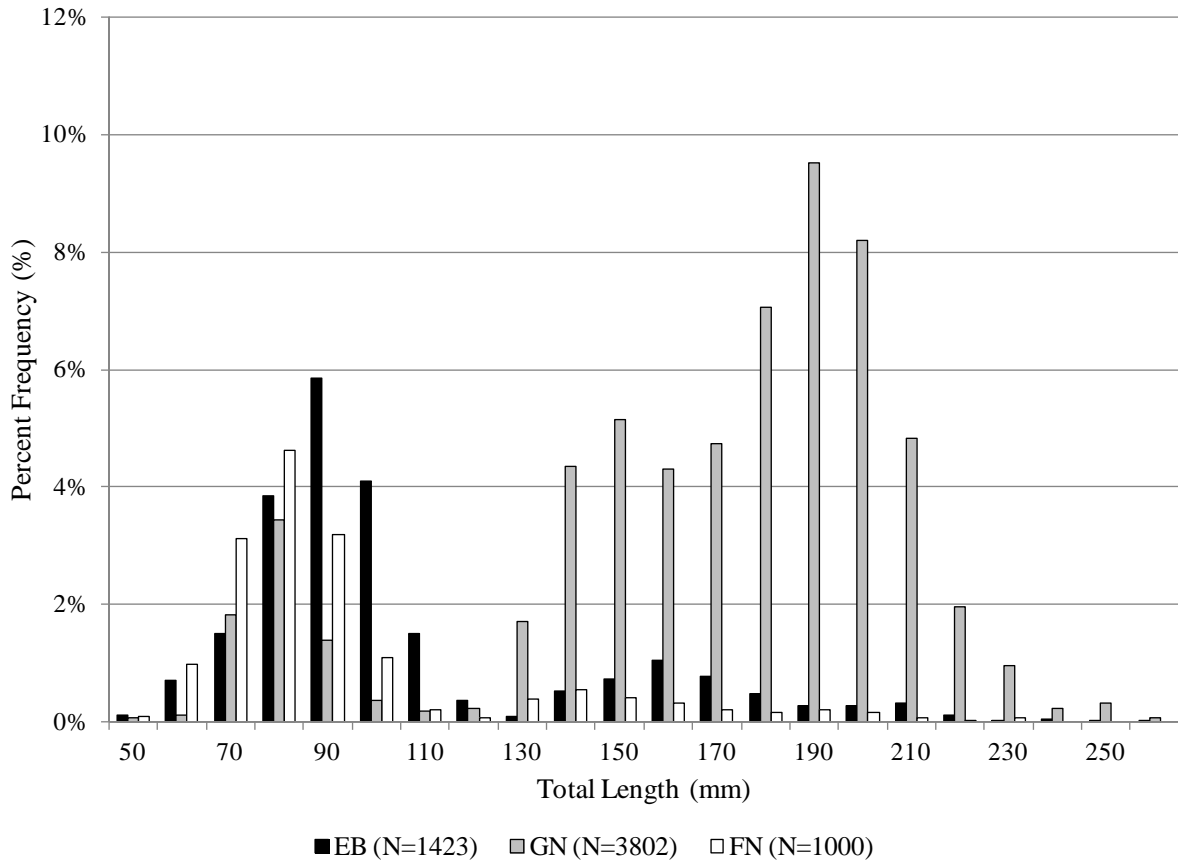
## Yellow Perch

Yellow Perch sampled from Lake Washington ranged from 11 to 353 mm total length (Table 2; Figure 3) and ranged in age from 1 to 6 years (Table 5). The growth of Yellow Perch exceeded the statewide average for all year classes. Relative weights of Yellow Perch less than 140 mm total length were highly variable and clustered around the national average. For Yellow

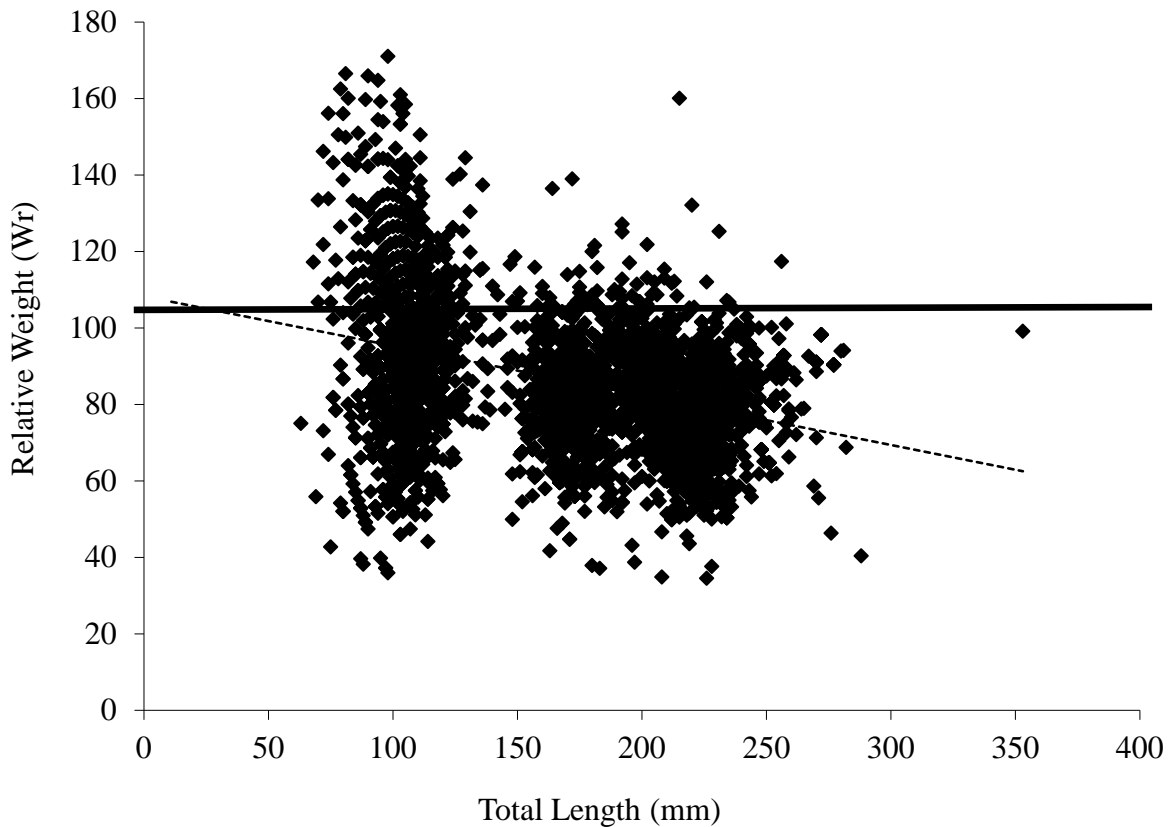
Perch greater than 140 mm total length, relative weights were generally below the national average (Figure 4).

**Table 5. Back calculated mean length at age (mm) of Yellow Perch collected from Lake Washington (King County, WA) during June-July 2005. Values were calculated using the direct proportion method (Fletcher et al. 1993).**

Year Class	# Fish	Mean total length (mm) at age					
		1	2	3	4	5	6
2004	33	85					
2003	43	90	168				
2002	41	82	164	223			
2001	3	120	157	206	241		
2000	14	80	162	209	237	260	
1999	1	107	206	262	302	330	349
Weighted Mean	135	89	165	219	241	265	349
State Average		60	120	152	193	206	



**Figure 3. Length frequency distribution of Yellow Perch (N=6228) sampled by gill netting (GN), fyke netting (FN), and boat electrofishing (EB) at Lake Washington (King County) in early summer 2005.**



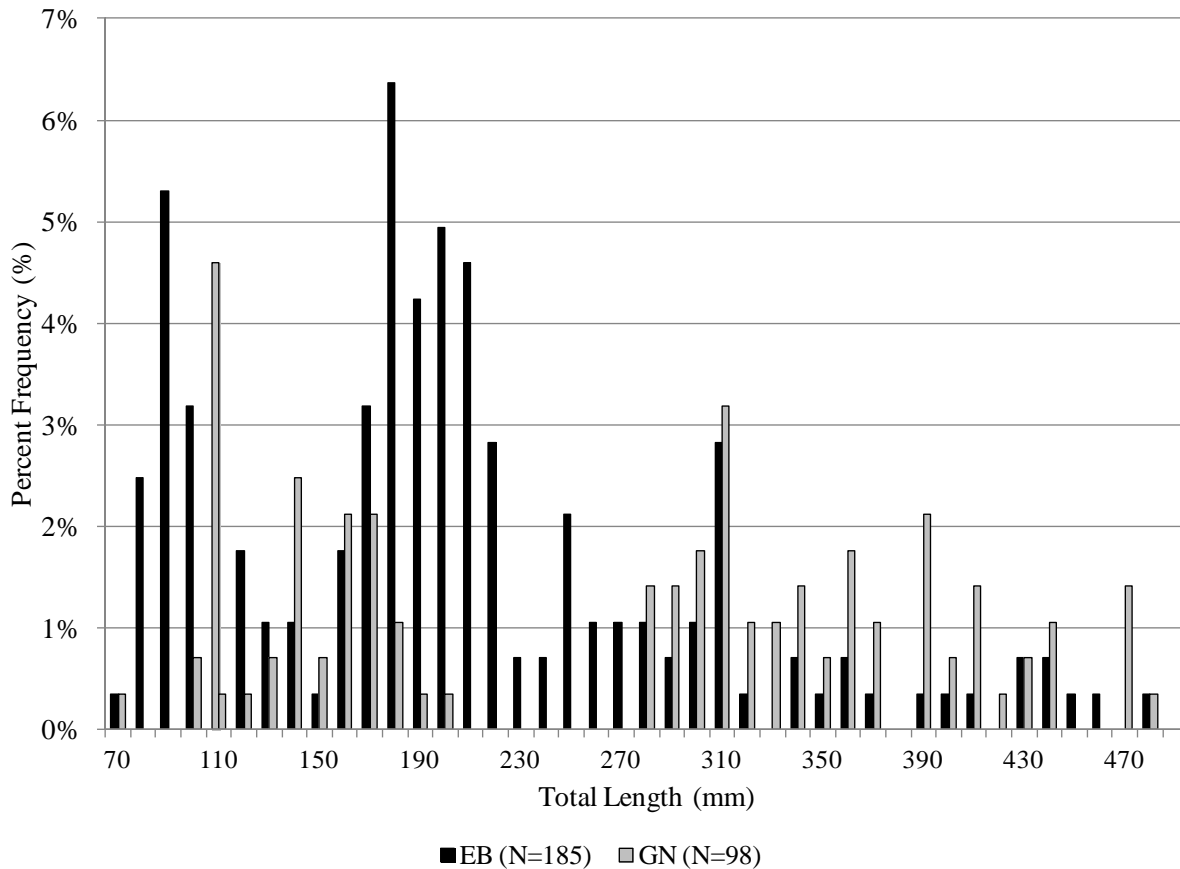
**Figure 4** Relative weights of Yellow Perch (N=3570) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.1374$ ).

## Smallmouth Bass

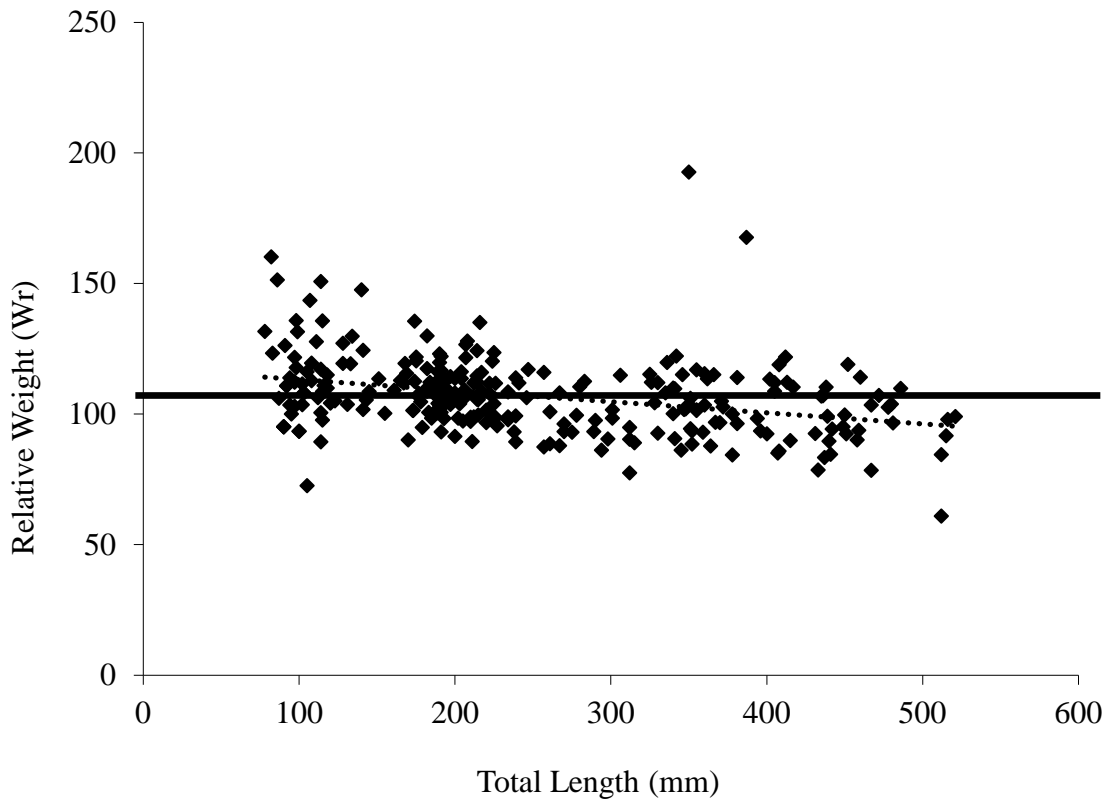
Smallmouth Bass sampled from Lake Washington ranged in length from 78 to 521 mm total length (Table 2; Figure 5) and ranged in age from 1 to 10 years (Table 6). The growth of Smallmouth Bass exceeded the statewide average for year classes 1-7. A reliable length-at-age average for fish older than 7 years has not been developed due to lack of data. The relative weights of Smallmouth Bass varied greatly among individuals (i.e.,  $W_r$  61–168) and were not correlated to fish size (Figure 6).

**Table 6. Back calculated mean length at age (mm) of Smallmouth Bass collected from Lake Washington (King County, WA) during June-July 2005. Values were calculated using the direct proportion method (Fletcher et al. 1993).**

Year Class	# Fish	Mean total length (mm) at age									
		1	2	3	4	5	6	7	8	9	10
2004	19	102									
2003	54	93	188								
2002	27	92	194	306							
2001	8	84	163	260	350						
2000	16	83	146	219	310	378					
1999	4	103	164	238	326	378	410				
1998	8	92	171	254	319	368	412	441			
1997	4	94	174	238	303	359	395	430	455		
1996	6	85	172	261	323	373	409	440	462	483	
1995	7	88	177	254	339	398	428	450	470	483	496
Weighted Mean	153	92	179	264	323	377	412	442	464	483	496
State Average		70	146	212	268	334	356	393			



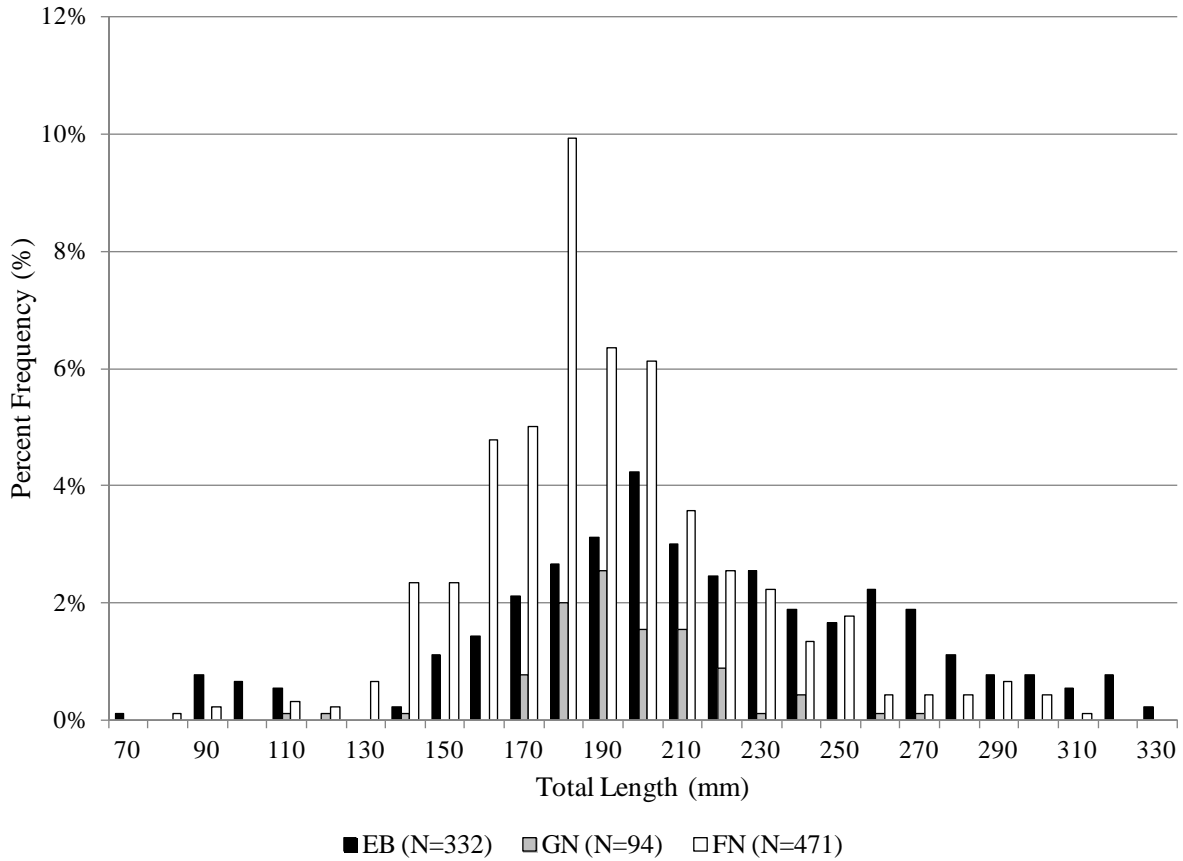
**Figure 5. Length frequency distribution of Smallmouth Bass (N=285) sampled by gill netting (GN) and boat electrofishing (EB) at Lake Washington (King County) in early summer 2005.**



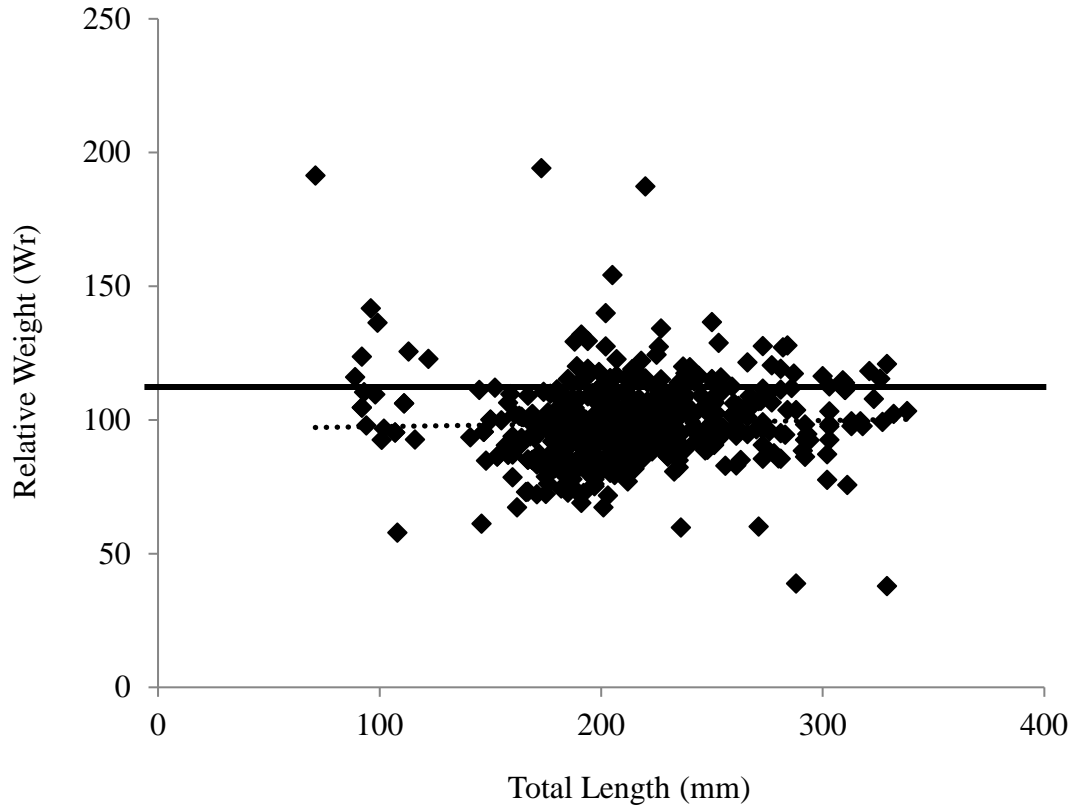
**Figure 6. Relative weights of Smallmouth Bass (N=269) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.1117$ ).**

## **Brown Bullhead**

Brown Bullhead sampled from Lake Washington ranged from 71–338 mm total length (Table 2; Figure 7). Aging structures such as pectoral spines were not collected from Brown Bullhead, so no age data is reported. The condition of Brown Bullhead varied greatly among individuals (i.e.,  $W_r$  38–194) and was not correlated with fish size (Figure 8).



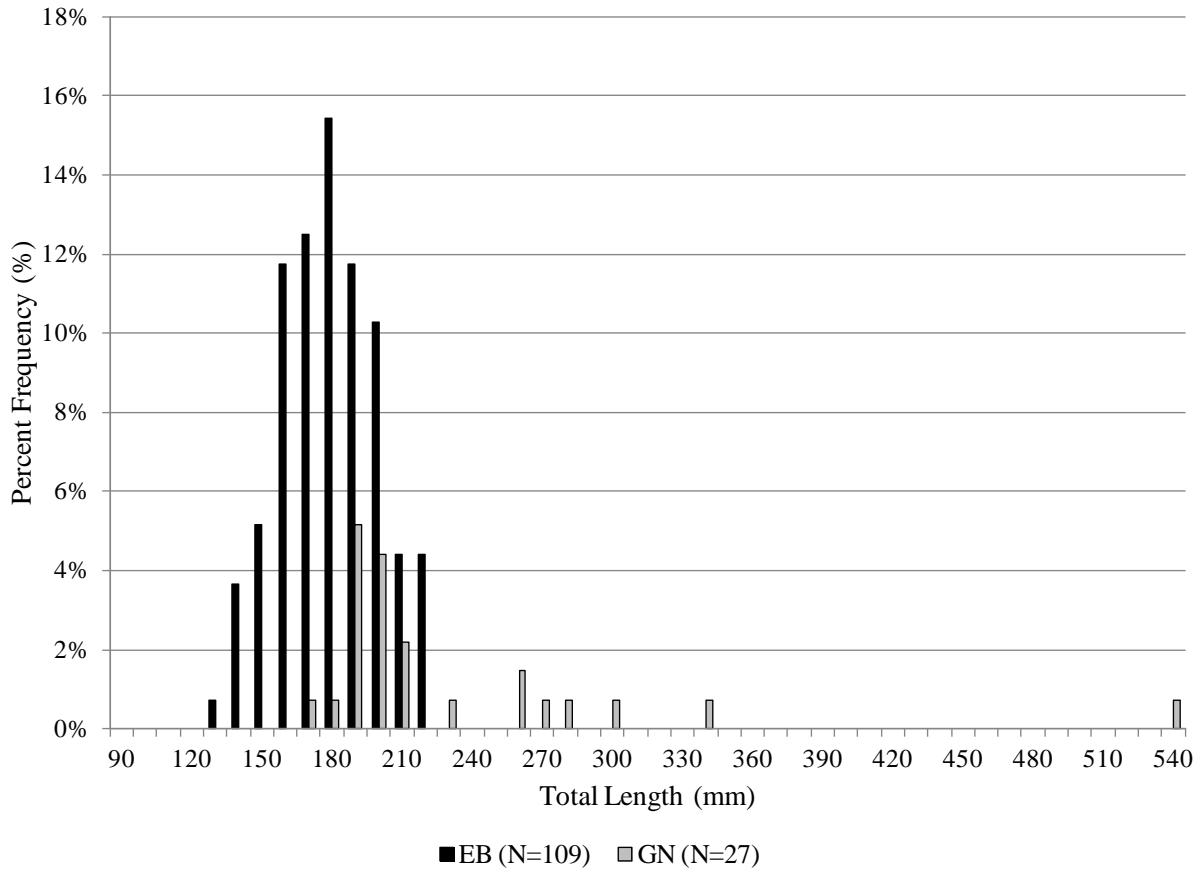
**Figure 7. Length frequency distribution of Brown Bullhead (N=897) sampled by gill netting (GN), fyke netting (FN), and boat electrofishing (EB) at Lake Washington (King County) in early summer 2005.**



**Figure 8. Relative weights of Brown Bullhead (N=507) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.0011$ ).**

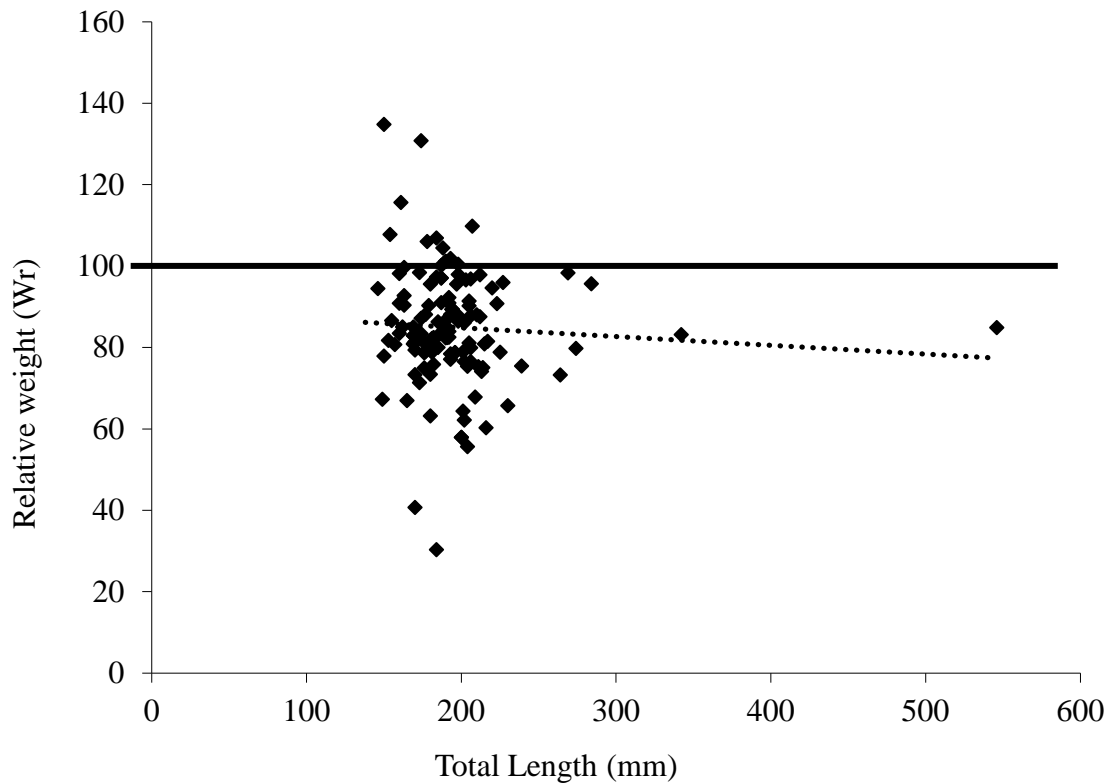
## Cutthroat Trout

Cutthroat Trout sampled from Lake Washington ranged in length from 21 to 546 mm total length (Table 2; Figure 9). Aging structures were not collected from Cutthroat Trout. The condition of Cutthroat Trout varied greatly among individuals (i.e.,  $W_r$  30–135) and was not correlated with fish size (Figure 10).



**Figure 9** Length frequency distribution of Cutthroat Trout (N=136) sampled by boat electrofishing (EB) and gill netting (GN) at Lake Washington (King County) in early summer 2005.





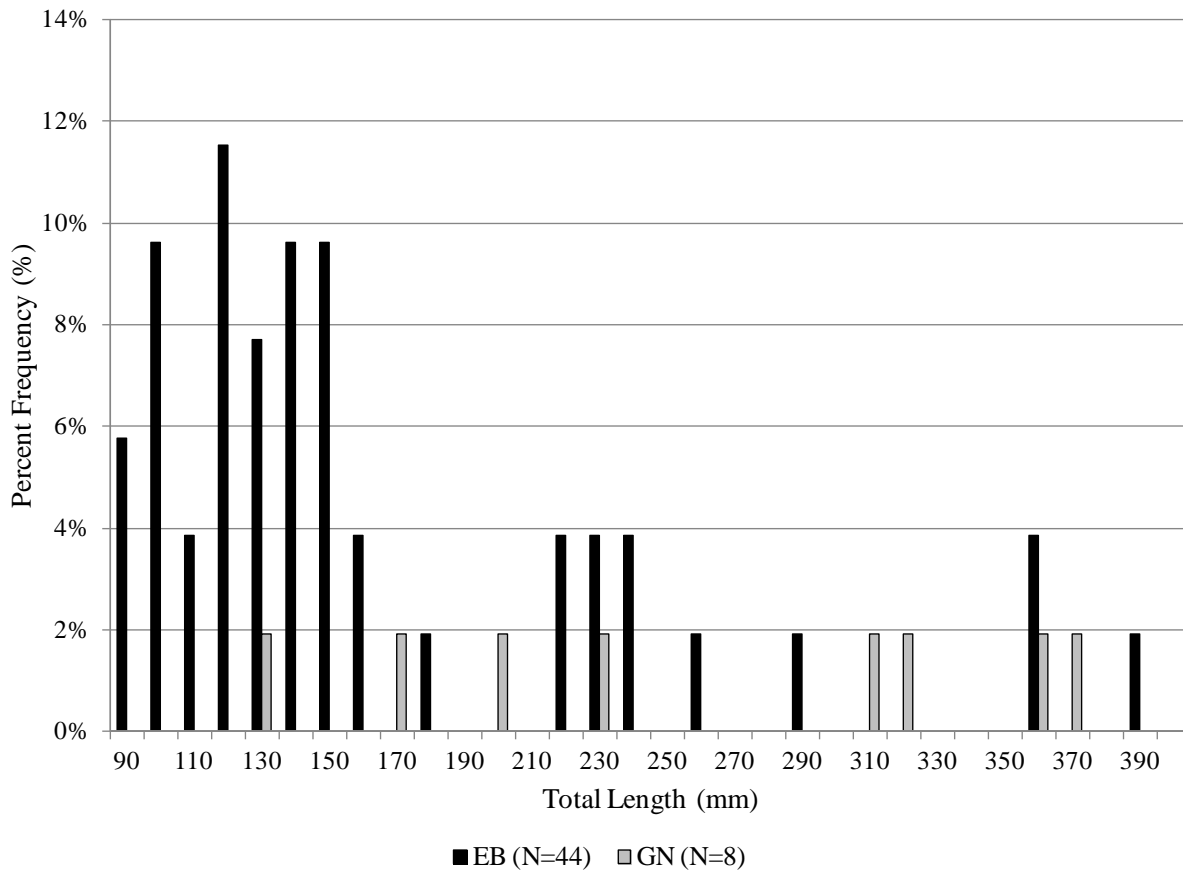
**Figure 10.** Relative weights of Cutthroat Trout (N=122) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.0041$ ).

## Largemouth Bass

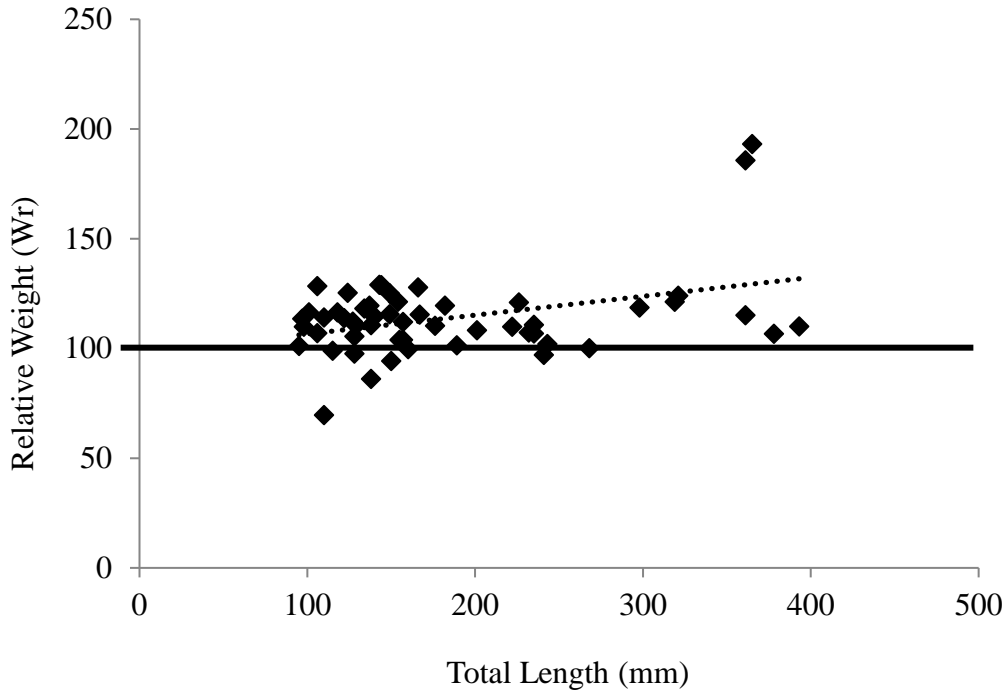
Largemouth Bass sampled from Lake Washington ranged in length from 95 to 393 mm total length (Table 2; Figure 11) and ranged in age from 1 to 3 years (Table 7). The growth of Largemouth Bass exceeded the statewide average for all year classes. The relative weight of Largemouth Bass varied greatly among individuals (i.e.,  $W_r$  82–193) and was not correlated to fish size (Figure 12).

**Table 7. Back calculated mean length at age (mm) of Largemouth Bass collected from Lake Washington (King County, WA) during June-July 2005. Values were calculated using the direct proportion method (Fletcher et al. 1993).**

Year Class	# Fish	Mean total length (mm) at age		
		1	2	3
2004	23	104		
2003	10	100	224	
2002	6	93	238	350
Weighted Mean	39	101	229	350
Western WA average		60	145	222



**Figure 11. Length frequency distribution of Largemouth Bass (N=53) sampled by boat electrofishing (EB) and gill netting (GN) at Lake Washington (King County) in early summer 2005.**



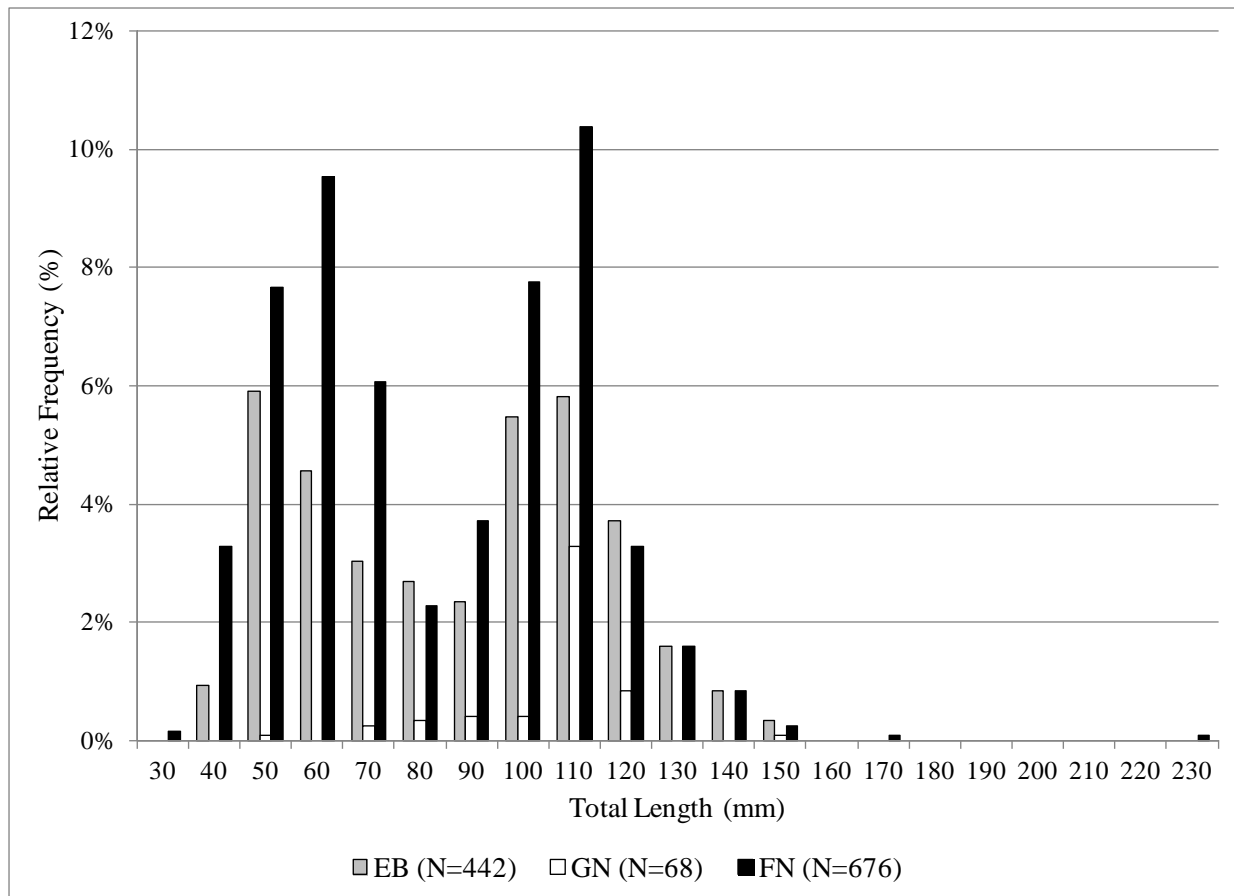
**Figure 12.** Relative weights of Largemouth Bass (N=53) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.1434$ ).

## Pumpkinseed

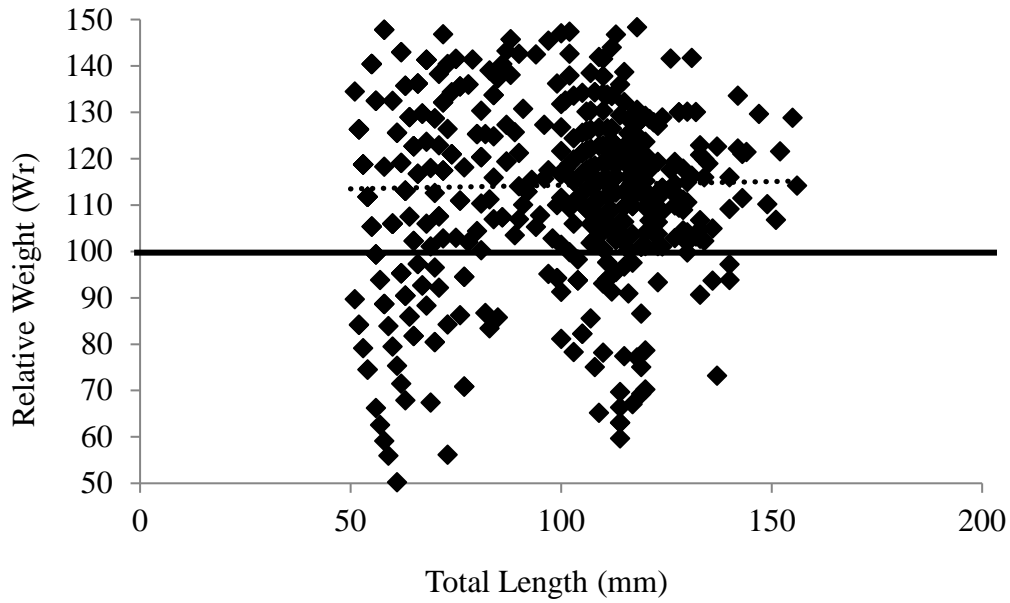
Pumpkinseed sampled from Lake Washington ranged from 11–234 mm total length (Table 2; Figure 13) and ranged in age from 1 to 4 years (Table 8). The growth of Pumpkinseed exceeded the statewide average for all year classes. The condition of Pumpkinseed varied greatly among individuals (i.e.,  $W_r$  50–148) and was not correlated to fish size (Figure 14).

**Table 8. Back calculated mean length at age (mm) of Pumpkinseed collected from Lake Washington (King County, WA) during June-July 2005. Values were calculated using the direct proportion method (Fletcher et al. 1993).**

Year Class	# Fish	Mean total length (mm) at age			
		1	2	3	4
2004	13	51			
2003	27	51	111		
2002	12	49	118	155	
2001	1	35	84	134	160
Weighted Mean	53	50	112.0	153.0	160.0
State Average		24	72	102	122



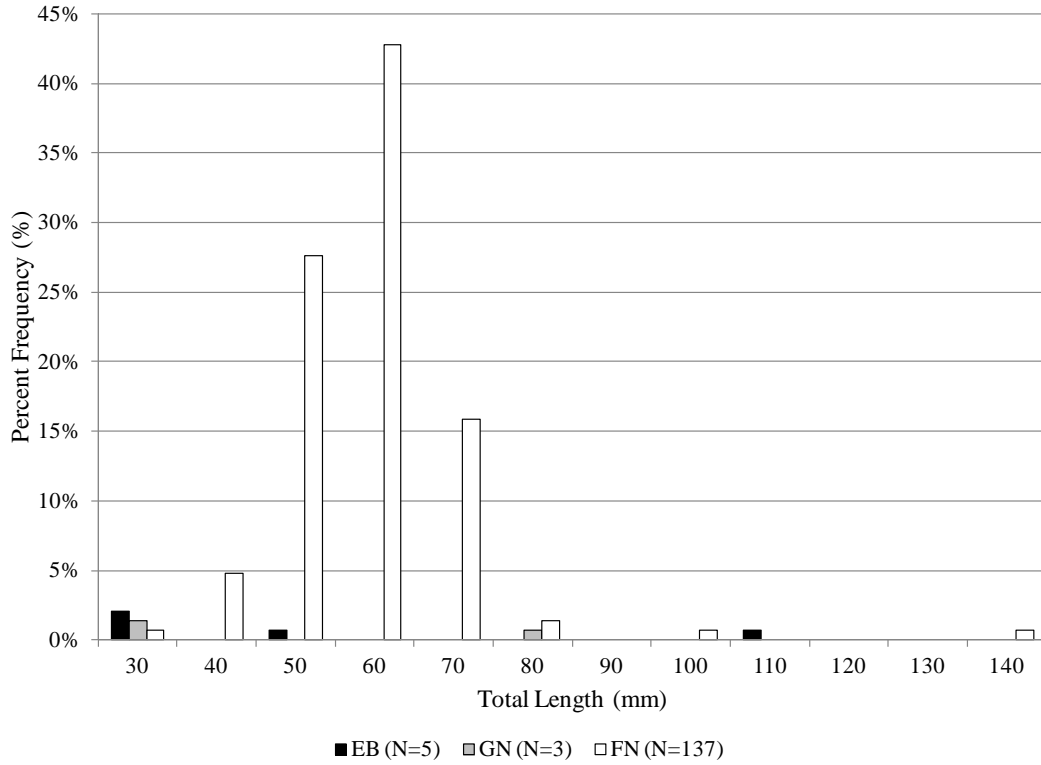
**Figure 13. Length frequency distribution of Pumpkinseed (N=1186) sampled by boat electrofishing (EB), gill netting (GN), and fyke netting (FN) at Lake Washington (King County) during June-July 2005.**



**Figure 14.** Relative weights of Pumpkinseed (N=520) sampled at Lake Washington (King County) during June-July 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.0003$ ).

### Bluegill

Bluegill sampled from Lake Washington ranged from 33–143 mm total length (Table 2; Figure 15). The condition of Bluegill varied greatly among individuals (i.e.,  $W_r$  43–206) and was not correlated to fish size (Figure 16).



**Figure 15. Length frequency distribution of Bluegill (N=145) sampled by boat electrofishing (EB), gill netting (GN), and fyke netting (FN) at Lake Washington (King County) during June-July 2005.**

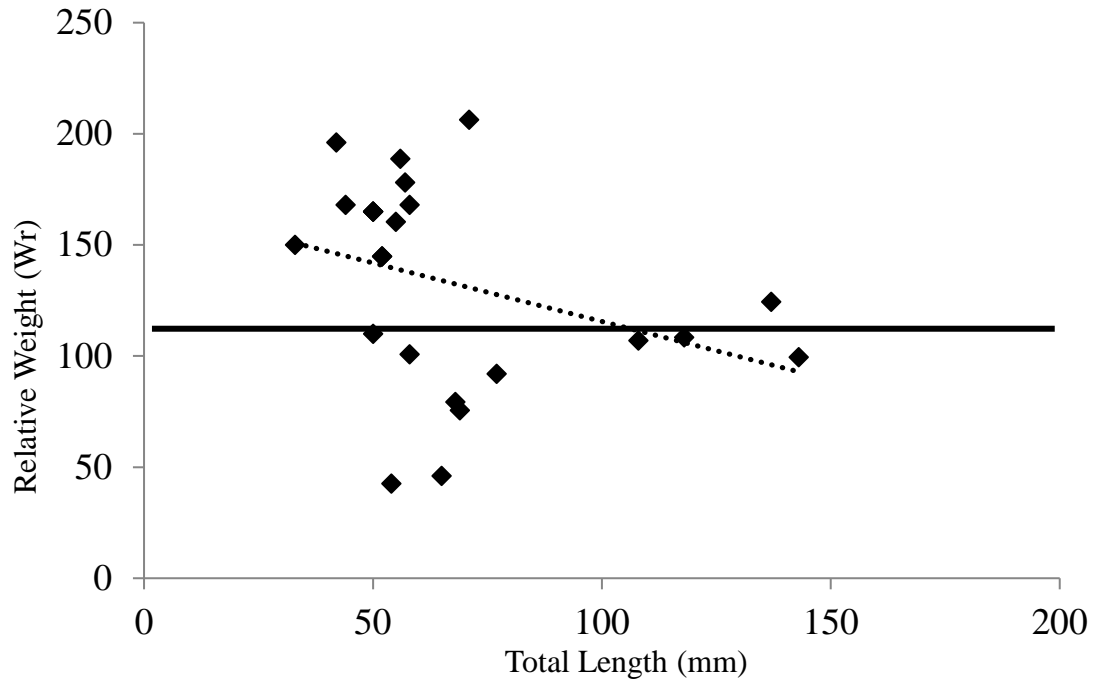
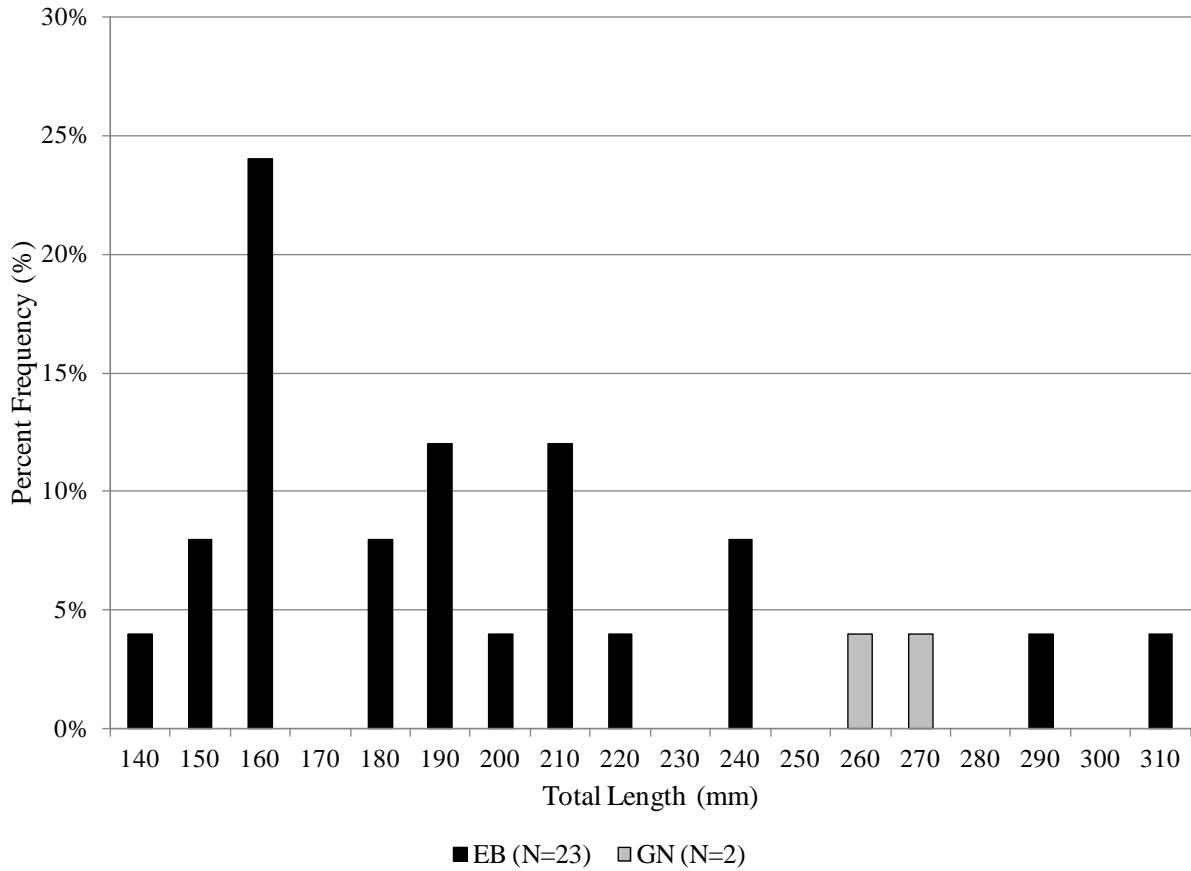


Figure 16. Relative weights of Bluegill (N=24) sampled at Lake Washington (King County) during June-July 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.1117$ ).

### Rainbow Trout

Rainbow Trout sampled from Lake Washington ranged from 147–318 mm total length (Table 2; Figure 17). The condition of all Rainbow Trout was poor (i.e.,  $W_r$  59–78) and was not correlated with fish size (Figure 18).



**Figure 17. Length frequency distribution of Rainbow Trout (N=25) sampled by boat electrofishing (EB) and gill netting (GN) at Lake Washington (King County) in early summer 2005.**



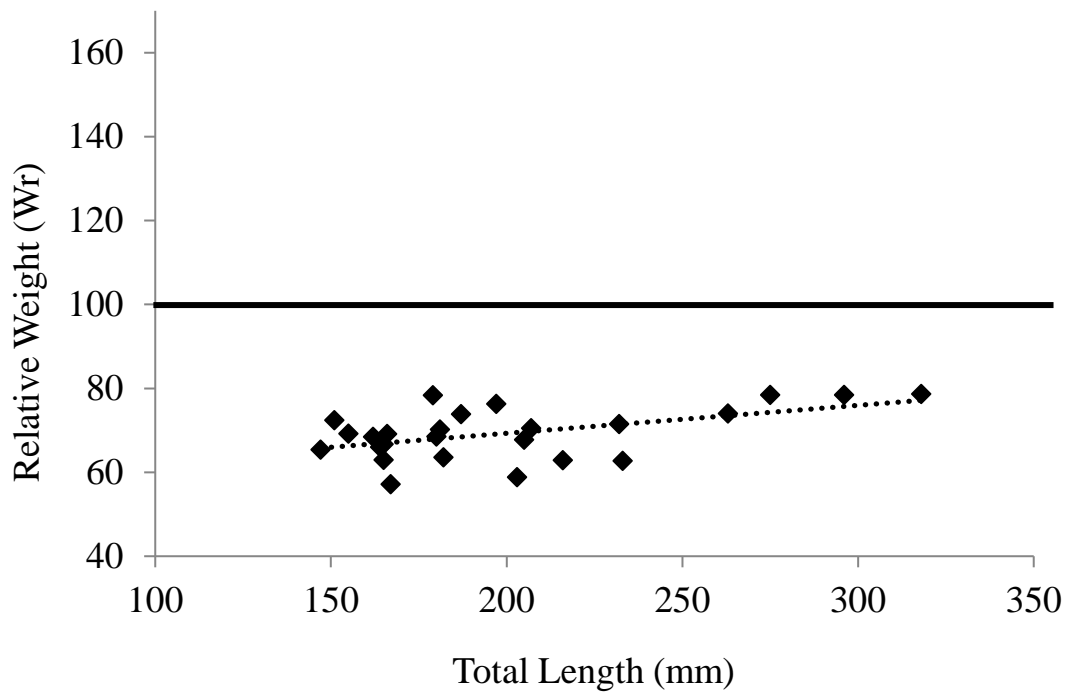


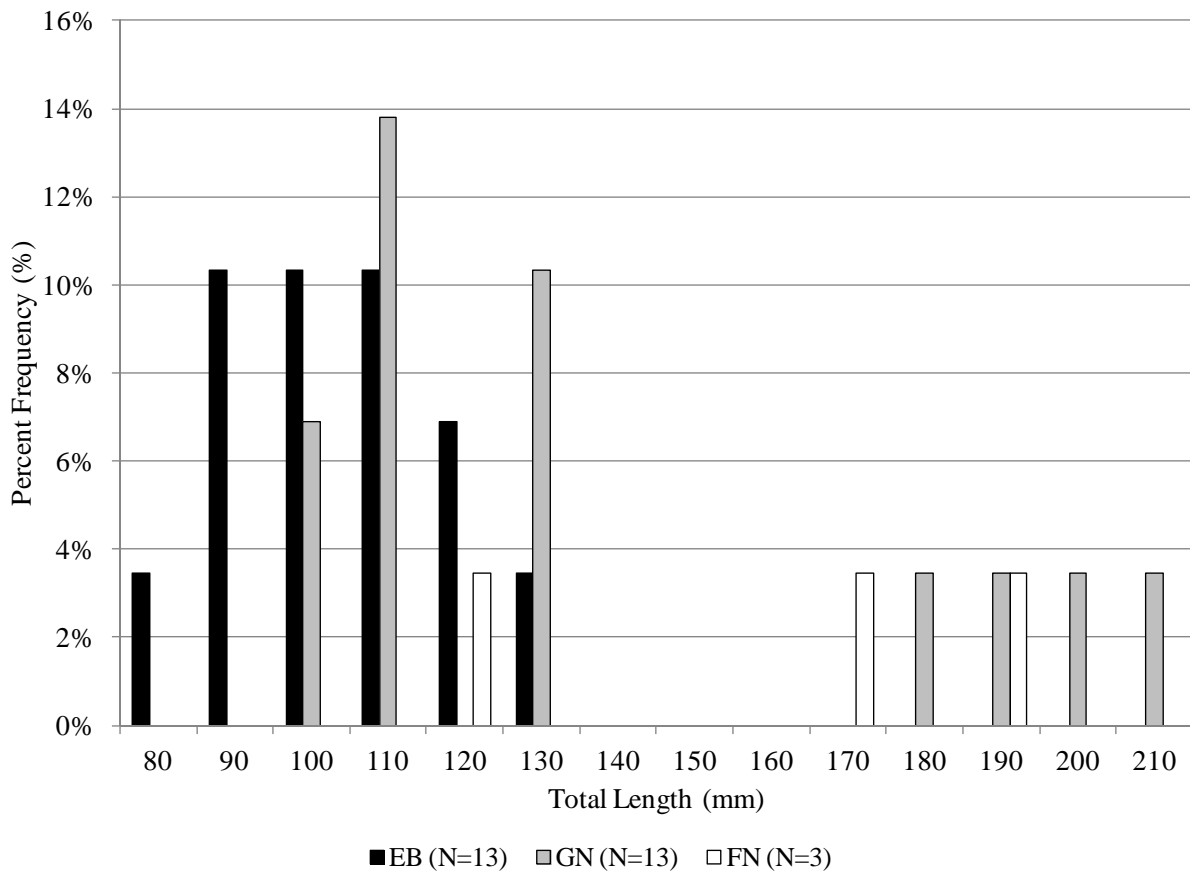
Figure 18. Relative weights of Rainbow Trout (N=25) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.2548$ ).

### Black Crappie

Black Crappie sampled from Lake Washington ranged in length from 86 to 210 mm total length (Table 2; Figure 19) and ranged in age from 1 to 2 years (Table 9). The growth of Black Crappie was similar to the statewide average for all year classes. The condition of Black Crappie varied greatly among individuals (i.e.,  $W_r$  103–166) and did not appear to be related to fish size (Figure 20).

**Table 9. Back calculated mean length at age (mm) of Black Crappie collected from Lake Washington (King County, WA) during June-July 2005. Values were calculated using the direct proportion method (Fletcher et al. 1993).**

Year Class	# Fish	Mean total length	
		1	2
2004	13	86	
2003	5	86	183
Weighted Mean	18	46	111
Western WA average		46	111



**Figure 19. Length frequency distribution of Black Crappie (N=26) sampled by boat electrofishing (EB), gill netting (GN), and fyke netting (FN) at Lake Washington (King County) during June-July 2005.**

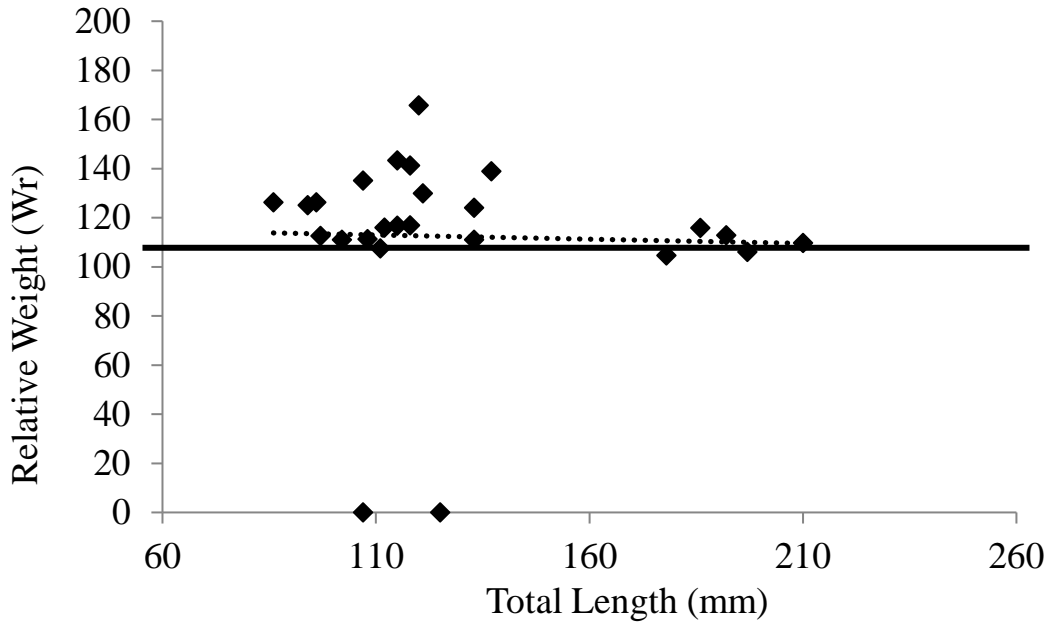
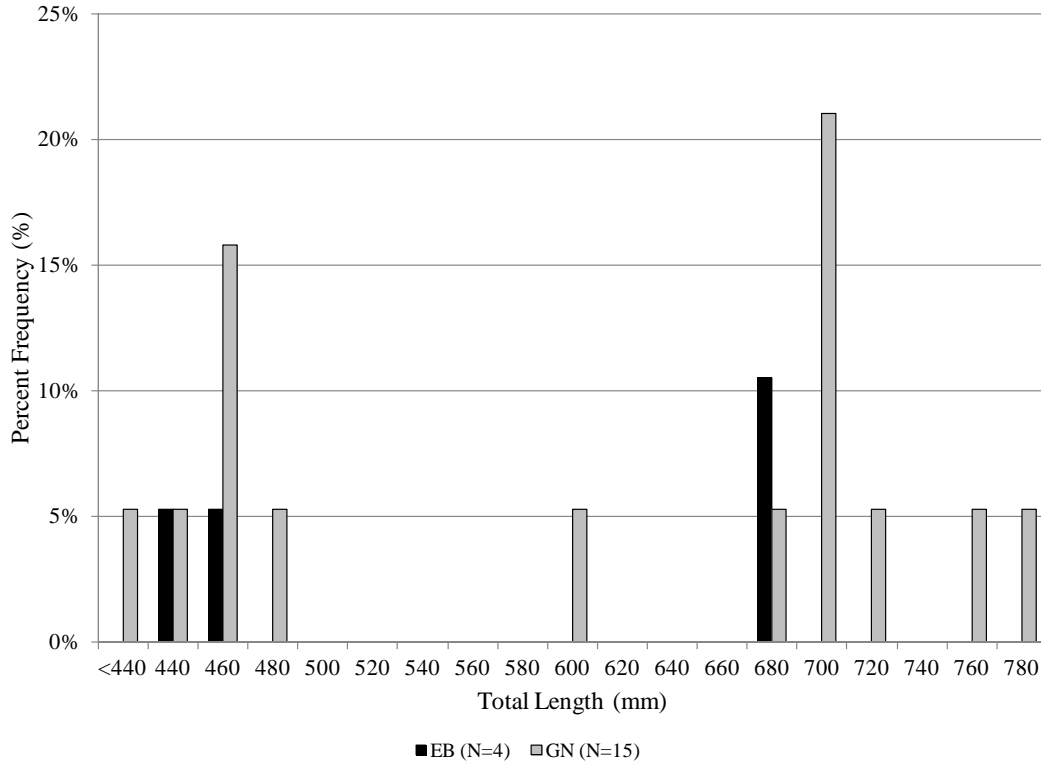


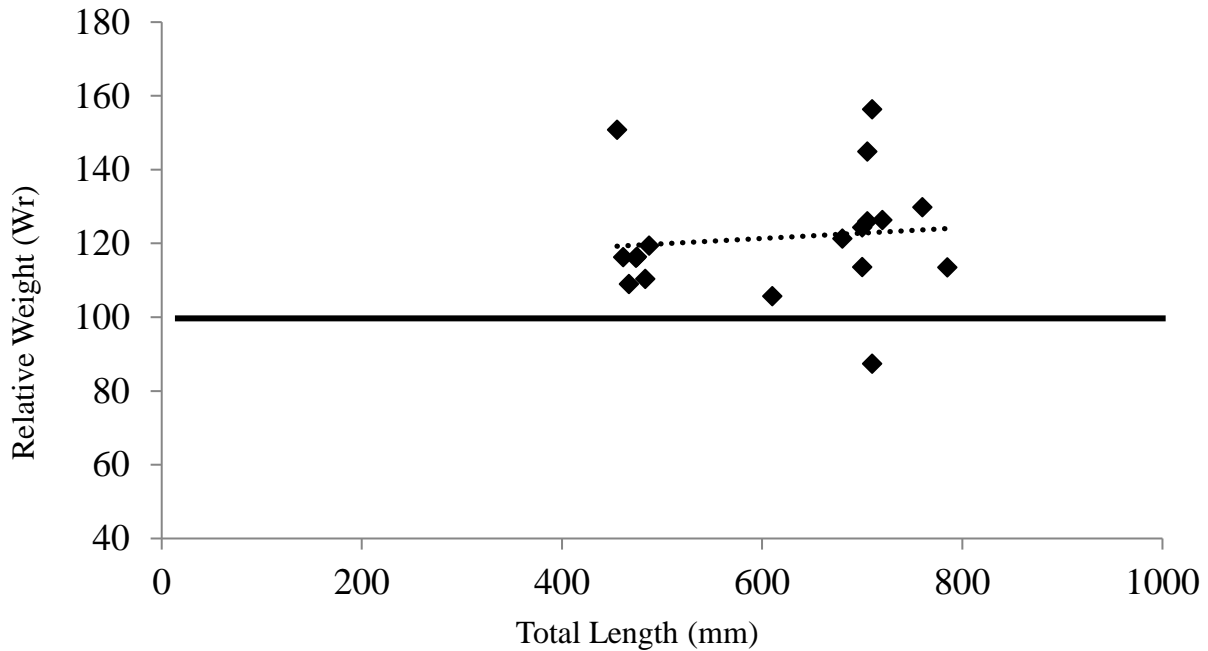
Figure 20. Relative weights of Black Crappie (N=26) sampled at Lake Washington (King County) in early summer 2005, as compared to the national 75th percentile,  $W_r=100$  (Anderson and Neumann 1996). Dashed line denotes the linear regression line ( $R^2=0.0011$ ).

## Common Carp

Common Carp sampled from Lake Washington ranged in length from 300 to 785 mm total length (Table 2; Figure 21). The condition of Common Carp varied greatly among individuals (i.e.,  $W_r$  87–156) and did not appear to be related to fish size (Figure 22).



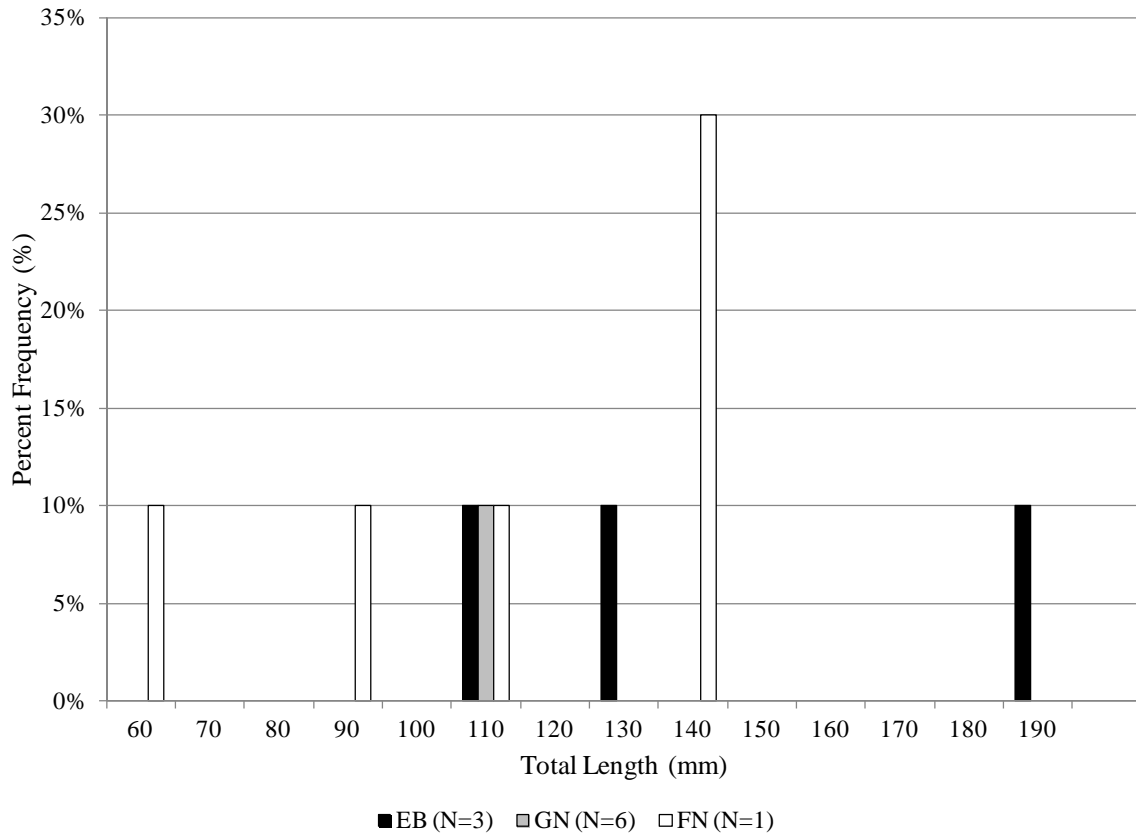
**Figure 21. Length frequency distribution of Common Carp (N=26) sampled by boat electrofishing (EB) and gill netting (GN) at Lake Washington (King County) in early summer 2005.**



**Figure 22. Relative weights of Common Carp (N=26) sampled at Lake Washington (King County) in early summer 2005 as compared to the national 75th percentile,  $Wr=100$  (Bister et al. 2000). Dashed line denotes the linear regression line ( $R^2=0.0117$ ).**

## Green Sunfish

Green Sunfish sampled from Lake Washington ranged in length from 65 to 192 mm total length (Table 2; Figure 23). The condition of Largemouth Bass varied greatly among individuals (i.e.,  $W_r$  79–177) and did not appear to be related to fish size (Figure 24).



**Figure 23. Length frequency distribution of Green Sunfish (N=10) sampled by boat electrofishing (EB), gill netting (GN), and fyke netting (FN) at Lake Washington (King County) in early summer 2005.**

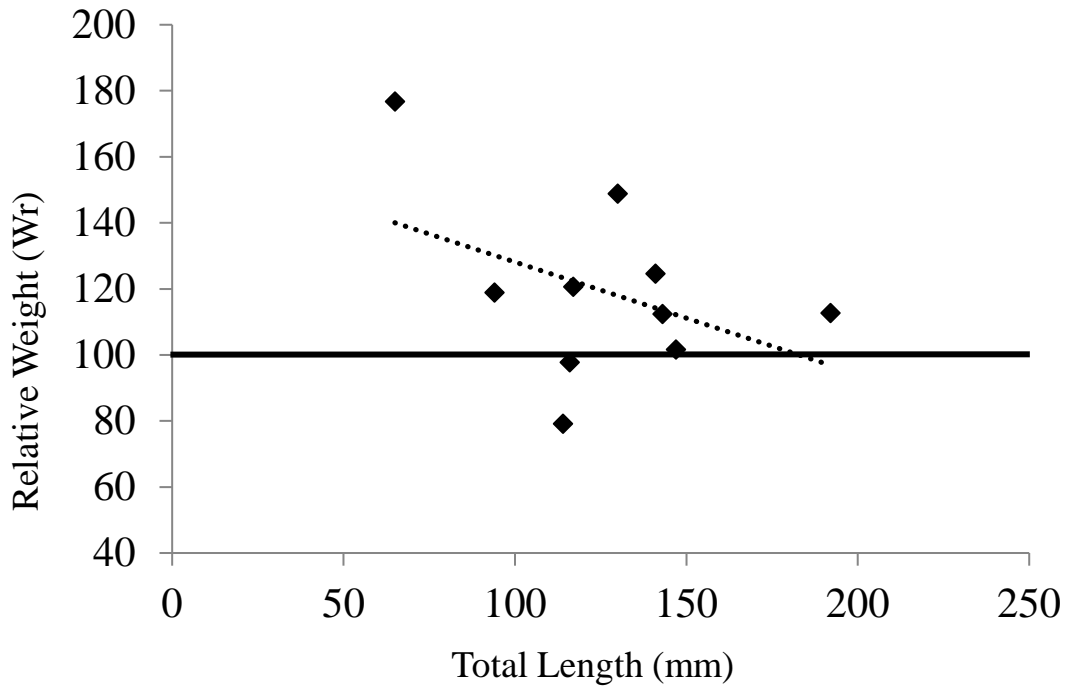


Figure 24. Relative weights of Green Sunfish (N=10) sampled at Lake Washington (King County) in early summer 2005 as compared to the national 75th percentile,  $W_r=100$  (Bister et al. 2000). Dashed line denotes the linear regression line ( $R^2=0.1795$ ).

## Comparisons to Survey Data from 1982

Relative abundance data for warmwater fish species reported by Pfeifer and Weinheimer (1992) are shown in Table 10. Mean electrofishing catch rates for warmwater species from eight locations in Lake Washington are reported for 1982 and 2005 surveys. Mean electrofishing catch rates of Smallmouth Bass, Pumpkinseed, and Brown Bullhead were higher in 2005 across all sampling locations, with the exception of Pumpkinseed at Andrews Bay. Catch rates for Yellow Perch, Largemouth Bass, and Black Crappie varied greatly among surveys and sampling locations.

**Table 10. Relative abundance of gamefish species sampled by electrofishing, gill nets, and trap nets in Lake Washington embayments during August–October 1982 (Pfeifer and Weinheimer 1992).**

Species	Relative Abundance (by number)
Yellow Perch	57.01
Brown Bullhead	15.65
Black Crappie	12.69
Largemouth Bass	10.83
Pumpkinseed	2.58
Rainbow Trout	0.95
Smallmouth Bass	0.29

**Table 11. Mean electrofishing catch rates from 1982 and 2005 surveys, by region. Standard error is reported in parentheses when two or more sites were sampled (Pfeifer and Weineimer 1992).**

Location	# of sites		Effort (hrs)		Yellow Perch		Black Crappie		Brown Bullhead		Largemouth Bass		Smallmouth Bass		Pumpkinseed Sunfish	
	2008	1982	2008	1982	2008	1982	2008	1982	2008	1982	2008	1982	2008	1982	2008	1982
Andrews	2	1	0.33	1.58	6 (4.9)	7.6	0.0	0.0	0.0	0.0	0.0	7.0	6 (4.9)	0.0	0.0	0.6
Cozy Cove	3	1	0.50	0.60	72 (55)	62.1	2 (2)	1.7	148 (148)	0.0	2 (2)	27.6	0.0	0.0	274 (274)	0.0
Juanita Bay	3	2	0.50	2.40	30 (30)	4.5 (0.67)	0.0	6.7 (5.5)	10 (7.2)	0.0	0.0	6 (1.8)	2 (2)	0.0	16 (16)	0.0
Kenmore	3	1	0.50	0.70	72 (27.5)	95.5	2 (2)	0.0	60 (28.4)	3.0	26 (23.1)	10.4	0.0	0.0	28 (22.3)	3.0
Mercer Slough	3	2	0.50	3.50	63.2 (15.4)	13.7 (5.8)	0.0	0.2 (0.2)	27.9 (19.6)	0.9	0.0	0.7 (0.5)	5.8 (5.8)	0.4 (0.4)	23.9 (13.8)	0.2 (0.2)
Meydenbauer Bay	3	1	0.50	1.00	101.7 (38.3)	49.0	0.0	0.0	25.9 (22.9)	0.0	0.0	6.0	0.0	0.0	30 (19.3)	1.0
Sandpoint	3	1	0.50	0.80	78.6 (54.7)	36.0	4 (4)	0.0	27.5 (19.2)	0.0	18 (18)	1.3	17.9 (17.9)	1.3	47.8 (36.7)	0.0
Yarrow Bay	3	2	0.50	3.00	210 (153.5)	43 (35.1)	4 (4)	8.3 (0.9)	108 (55.4)	0.0	4 (4)	17.5 (9.39)	2 (2)	0.0	40 (31.4)	0.0

## Discussion

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The standardized warmwater sampling protocols we used (Bonar et al. 2000) indicate an ideal sampling period for spring (April-mid June) and fall (August-first week in October) surveys. These time periods coincide with peak catch rates for warmwater species (Pope and Willis 1996; Divens et al. 1998). We deviated from this protocol by delaying this survey till late June (June 26-July 1) to minimize take of ESA-listed salmonids during outmigration. Consequently, the data we recorded for certain species may underrepresent the population due to seasonal shifts in habitat use. For example, catch rates and PSD values recorded for Smallmouth Bass may have been higher if sampled in early June when peak spawning occurs.

Lake Washington's Yellow Perch and Smallmouth Bass populations represent the majority of warmwater fishing opportunity in terms of relative abundance and numbers of quality-size fish. Both species exhibited above average growth as compared to the Washington State average and estimates of proportional size distribution (PSD) were high for electrofishing (>30) and gill netting (>50). The higher PSD values for Smallmouth Bass and Yellow Perch from gill netting are not uncommon, and may be attributed to these species commonly occupying deep water habitats that are poorly sampled by electrofishing (Hamley 1975; Osborne et al. 2003). In general, Lake Washington is characterized by a steeply sloped and highly urbanized shoreline, with thousands of docks that are narrowly spaced. These obstructions limit boat maneuverability which ultimately decreases electrofishing efficiency.

The high relative abundance of Yellow Perch was not unexpected. Since their first recorded introductions into places such as the Columbia River and Silver Lake (Cowlitz County) in the 1890s (Lampman 1946; Wydosky and Whitney 2003), Yellow Perch have become one of the most abundant fishes in Washington and often represent the dominant species in the fish community. In the North Puget Sound region, Yellow Perch comprised the majority of fish sampled in Lake Stevens (Snohomish County; Mueller 1999a), Lake Sawyer (King County; Downen and Mueller 2000a), Lake Meridian (King County; Verhey and Mueller 2001); Lake Terrell (Whatcom County; Downen and Mueller 2000b), Big Lake (Skagit County; Mueller and Downen 1999), and Lake Whatcom (Whatcom County; Mueller et al. 1999). Yellow Perch are highly fecund, prolific spawners and in small lakes, they tend to become overabundant and exhibit reduced growth (Wydosky and Whitney 2003), either due to interspecific competition or a lack of larger prey items. In Lake Washington, the diet of Yellow Perch primarily consists of *Cottus spp.* and Longfin Smelt (Costa 1979; Overman et al. 2009), both of which are prevalent in the lake, and presumably, provide a consistent source of food for Yellow Perch after they switch to piscivory at around 200 mm total length (Overman et al. 2009).

Largemouth Bass in Lake Washington represented a small portion of the sample, but exhibited growth and condition above the Washington state average. Although the timing of the survey precludes us from determining young-of-the-year (YOY) abundance, the low relative abundance of Largemouth Bass and size structure coupled with habitat characteristics of the lake suggest low recruitment of age-0 Largemouth Bass. Many researchers have demonstrated that high, size-selective mortality of age-0 Largemouth Bass occurs during the winter (Oliver et al. 1979; Gutreuter and Anderson 1985; Miranda and Hubbard 1994; Garvey et al. 1998). Thus, abiotic factors affecting the duration of first year growth can influence patterns of winter survival and



cohort strength (Garvey et al. 2002). Specifically, low temperatures during the spring and summer can delay hatching and reduce growth rates, resulting in delayed onset of piscivory (Olson 1996). YOY Largemouth Bass that switch to piscivory often have dramatically increased condition and growth (Olson 1996; Ludsin and DeVries 1997). Bowles (1985) found that water temperature and rate of warming (degree-days) affected over-winter survival of YOY in the Coeur d' Alene Lake system by influencing the length and quality of the growing season. He suggested that Largemouth Bass less than 50 mm total length could not survive long winters (Bennett et al. 1991a). In Lake Washington, the growth and condition of adult Largemouth Bass suggests that individuals that survive their first year and switch to piscivory grow quickly, yet high mortality of YOY bass is likely limiting the size of the population.

Tabor et al. (2004) and Tabor et al. (2007) estimated the population of Largemouth Bass and Smallmouth Bass in the Lake Washington Shipping Canal (LWSC; a major migration corridor for salmonids) at 2,500 and 3,400 fish, respectively. In contrast, our relative abundance estimates (Table 2) suggests that Smallmouth Bass greatly outnumber Largemouth Bass in the main lake portion of Lake Washington. The disparity in these results may be attributed to habitat characteristics, e.g., gravel flats, wood cover, vegetation, and warm water, which are largely unavailable to Largemouth Bass in the main lake and restricted to shallow embayments and the LWSC. The amount and arrangement of Largemouth Bass habitat has been shown to regulate population processes at the landscape scale (Irwin et al. 2002). Gravel substratum for spawning, shoreline complexity/morphology, and adequate cover were identified as important landscape features for Largemouth Bass production (Irwin et al. 2002).

Smallmouth and Largemouth Bass have been shown to consume native fishes including juvenile salmonids (Bennett et al. 1991b, Tabor et al. 1993; Fritts and Pearson 2004) and remain controversial for fisheries managers in Lake Washington where ESA-listed stocks of salmon are present. Several studies have been conducted on the predatory impacts of Smallmouth Bass in Lake Washington on outmigrating smolts of Chinook Salmon (Tabor et al. 2004; 2007) and Sockeye Salmon (Fayram and Sibley 2000). Though black bass were shown to prey on salmonids during outmigration, particularly in the Lake Washington Shipping Canal (LWSC), all studies concluded that predation by black bass has a relatively "little" or "minor" impact on salmon abundance (Fayram and Sibley 2000; Tabor et al. 2004; 2007). The primary forage for Smallmouth Bass in Lake Washington is crayfish and sculpin (Overman et al. 2009; Tabor et al. 2004; 2007), both of which are highly abundant.

Although recent creel data is lacking for Lake Washington, the number of recreational bass tournaments held annually strongly suggests that Smallmouth Bass remain the primary driver of warmwater fishing effort. During 2010-2013, angling clubs applied for 13-17 contest permits per year to fish for Smallmouth Bass and Largemouth Bass in Lake Washington. Given that tournaments anglers in Washington are limited to two bass tournaments per month on each water body, anglers are nearly maximizing their opportunities to hold fishing contests every year. Anglers who fish Lake Washington regularly cite the quality of fish and proximity to home as the primary reason for their trip.

Several other warmwater gamefish species occur in Lake Washington, i.e., Pumpkinseed, Bluegill, Black Crappie, and Green Sunfish, that collectively made up a small portion of the total

biomass (11.7%; excluding Threespine Sticklebacks). Similar to Largemouth Bass, these species spawn when water temperatures reach approximately 16-18 °C. In contrast, Yellow Perch comprised the majority of the biomass (50.8%) and spawn at much lower temperatures (7-11 °C). This pattern of fish abundance is common throughout Washington lakes, suggesting that fishes belonging to cold- and coolwater guilds are more physiologically well-adapted to the thermal regime of Washington lakes, e. g., degree days of warming. Temperature can influence the relative abundance of species because the effects of temperature on year-class strength, recruitment, growth, and survival affect each species differently depending on thermal requirements (Shuter and Post 1990; Tonn 1990; Casselman 2002). Although the growth of Largemouth Bass and Pumpkinseed were above the Washington average, the low relative abundance of these species suggests that one or more abiotic or biotic factors is limiting population growth.

Largescale Suckers and Northern Pikeminnow comprised nearly half of the biomass sampled indicating robust populations of both species. Although the sampling methods were specifically designed to estimate the relative abundance of warmwater fish species (Bonar et al. 2000), the 80% confidence interval around catch rates for Northern Pikeminnow and Largescale Sucker (Table 3) suggests that comparisons of relative abundance are valid. High relative abundance of these two species has been documented in several lakes in Washington, including Lake Spokane (Osborne and Divens 2003), Palmer Lake (Osborne et al. 2003), and Mason Lake (Mueller 1999b), and may be linked to the simplicity of their spawning requirements and the plasticity of their feeding ecology. Both species broadcast spawn adhesive eggs over sand, gravel, or cobble bottom in slow to moderate currents, habitats that are widely available in Washington's rivers and streams (Wydosky and Whitney 2003). The feeding ecology of both species is also highly conducive for lacustrine environments. Largescale Suckers and Northern Pikeminnow attain large sizes relative to most species and exploit a wide variety of food items as adults such as snails, crawfish, and sculpins. Largescale suckers can exploit many food items that other species cannot, including periphyton algae, filamentous algae, and detritus (Wydosky and Whitney 2003). Overman et al. (2009) found the diet of adult Northern Pikeminnow across all seasons in Lake Washington varied widely, but primarily consisted of Longfin Smelt and Sockeye Salmon.

Electrofishing catch rate data collected from 11 locations in 1982 and 2005 was reported to investigate potential changes to the Lake Washington fish community (Table 11). The high variability associated with catch rates, i.e., standard error, suggests that a larger sample size is needed to make statistical comparisons among these locations in Lake Washington. Without statistical rigor, we can only hypothesize that observed increases in catch rates of Smallmouth Bass, Pumpkinseed Sunfish and Brown Bullhead reflect actual changes to the fish community. During the 1980s and 1990s, anglers reported catching fewer Largemouth Bass and Black Crappie while encountering an increasing number of Smallmouth Bass (Kurt Kraemer, Washington Department of Fish and Wildlife, personal communication). A possible shift in the fish community may be linked to limnological changes that occurred during the 1970s. With the exception of combined sewer flows, sewage effluent was completely diverted from the lake by 1968 and the lake subsequently reverted to a mesotrophic state (Cooke et al. 1993). Although many changes occurred during this time and have been elaborated by Edmondson (1994), the most notable changes were decreases in phosphorus loading and phytoplankton abundance. This shift from eutrophy to mesotrophy and associated changes to the plankton community may be

correlated with a reduction of Largemouth Bass and Black Crappie and an increase in Smallmouth Bass during the 1980s and 1990s.

Similar to other north temperate lakes, Lake Washington is composed of many species with distinct temperature preferences (i.e., warm-, cool-, and coldwater species). The size, morphometry, and thermal-stratification of Lake Washington provides habitat for all three thermal guilds, though changes in species distribution and abundance are likely to occur in coming decades. Climate change, which results in a change in water temperature over time, is becoming increasingly recognized as a factor that influences fish and aquatic communities (Casselman 2002; Robillard and Fox 2006). Many studies that project the effects of climate change in lake fishes have predicted declines in coldwater species (Mackenzie-Grieve and Post 2006; Jacobson et al. 2010; Herb et al. 2014). Other studies have shown positive associations between water temperature and warmwater fish populations (Robillard and Fox 2006; Hansen et al. 2016). In Lake Washington, current environmental conditions appear to favor coolwater species such as Yellow Perch and Smallmouth Bass. Whether these species will continue to thrive, or be gradually supplanted by other warmwater species, i.e., Largemouth Bass, Rock Bass, Black Crappie, or Bluegill, will depend on the rate and degree of regional temperature changes. Future research may focus on monitoring long-term trends in fish abundances as they relate to changing water temperatures to better understand the relationship among abiotic and biotic factors that continue to shape the Lake Washington fish community.

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