1998 Lake Whatcom Survey: The Warmwater Fish Community 15 Years after the Introduction of Smallmouth Bass

by

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Introduction and Background

Lake Whatcom is a large body of water (surface area = 2,030 ha; volume = 936,651,000 m^3) located directly east of the City of Bellingham in Whatcom County. The lake consists of three basins separated by distinct glacial sills. The northern and middle basins (Basin 1 and Basin 2, respectively) are relatively small and shallow (20 to 25 m maximum depth), whereas the southern basin (Basin 3) is considerably larger and deeper (85 to 100 m maximum depth) (Figure 1). Lake Whatcom is fed by Silver Beach, Carpenter, Olson and Smith Creeks from the east, Anderson, Fir and Brannian Creeks from the south, and Austin/Beaver Creeks from the west. Several unnamed, intermittent creeks discharge into each basin, whereas water from the middle fork of the Nooksak River is occasionally diverted to Basin 3 via Anderson Creek. Surface water exits the lake from the north, through Whatcom Creek, eventually discharging into Bellingham Bay.

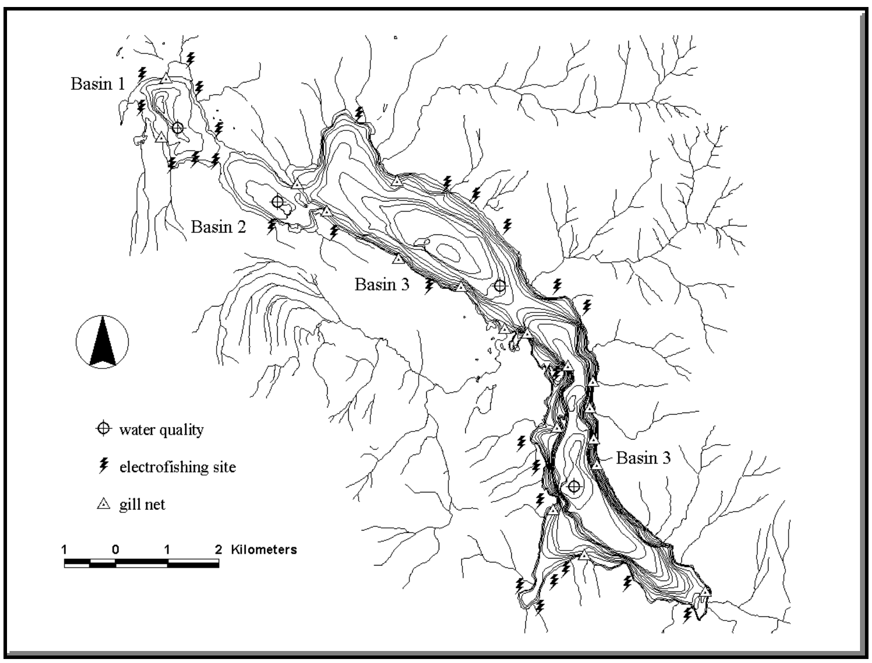

Figure 1. Map of Lake Whatcom (Whatcom County) showing sampling locations. Bolts indicate sections of shoreline where electrofishing occurred. Triangles extending into the lake indicate placement of gill nets whereas compass roses indicate water quality stations.

The near-shore habitat of Basin 1 is comprised mostly of gravel, sand, and mud. Basin 2 is comprised mostly of gravel, sand, and exposed bedrock. Much of Basin 3 is comprised of exposed bedrock and gravel. Low to moderate amounts of coarse woody debris can be found in the shallows of all three basins (Table 1). The aquatic plant community consists of a variety of pondweeds (*Potamogeton* sp.), waterweed (*Elodea* sp.), stonewort (*Nitella* sp.), common naiad (*Najas flexilis*), and the exotic Eurasian watermilfoil (*Myriophyllum spicatum*) [Jenifer Parsons, Washington Department of Ecology (WDE), unpublished data]. Emergent and submersed aquatic vegetation covers up to 33% of the littoral zone of all three basins (Table 1).

Land use around Basins 1 and 2 is primarily high-density residential. Up to 30% of the shoreline is bulkheaded within these basins and the mean number of docks ranges from 2 to 3 per 100 m shoreline (Table 1). Timber and undeveloped lands comprise the dominant uses of Basin 3; however, some high-density residential areas occur as well. Less than five percent of the shoreline in Basin 3 is bulkheaded, with an average of less than 1 dock per 100 m shoreline (Table 1).

Table 1. Nearshore habitat characteristics of three basins of Lake Whatcom during late summer 1998. Values were derived from visual estimates made from the surface while traveling along 46 sections (500 m each) of shoreline.

Basin	# Sections	Development	% Bulkhead	Mean # docks/100 m	% Emergent Vegetation	% Submerged Vegetation	Coarse Woody Debris	% Mud	% Sand	% Gravel	% Cobble	% Bedrock
1	10	High	30	3	7	26	Low to Moderate	19	25	37	13	6
2	3	Moderate to High	25	2	7	23	Low	20	22	26	5	27
3	33	None to Moderate	4	<1	3	19	Low to Moderate	9	18	27	13	33

Surrounding land uses in the Lake Whatcom watershed affect its water quality (Matthews et al. 1999; Serdar et al. 1999). High development adversely affects water quality in Basin 1, which stratifies with regard to temperature and oxygen during summer and fall (Matthews et al. 1999; Table 2). Water quality in Basin 2 has demonstrated a trend towards increased eutrophication in recent years, but is currently less anoxic in the hypolimnion than Basin 1 during summer and fall (Matthews et al. 1999; Table 2). The hypoxic conditions of Basins 1 and 2 have led the Environmental Protection Agency (EPA) to consider the lake degraded based on the work of Matthews et al. (1999) [BPWD 1999]. In Basin 3, water quality is generally good with respect to hypolimnetic oxygen (Matthews et al. 1999; Table 2).

Table 2. Water quality from three locations (basin 1, basin 2 and basin 3) at Lake Whatcom (Whatcom County). Samples were collected midday on August 17, 1998. DO = dissolved oxygen, TDS = total dissolved solids.

		Parameter				
Location	Depth (m)	DO	Temp (°C)	pH	Spec. conductance	TDS
Basin 1	1	9.19	21.43	8.60	58.3	0.037
	3	9.13	21.42	8.44	58.1	0.037
	5	8.88	21.41	8.39	58.1	0.037
	7	8.75	20.74	8.25	57.9	0.037
	9	8.42	16.07	7.73	59.4	0.038
	11	1.19	12.04	7.12	61.5	0.039
	13	0.14	11.09	6.85	63.9	0.041
Basin 2	1	8.85	21.03	8.31	57.7	0.037
	3	9.04	21.01	8.22	57.4	0.037
	5	8.89	21.02	8.19	57.4	0.037
	7	8.67	20.87	8.14	57.3	0.037
	9	8.75	20.76	8.07	57.3	0.037
	11	8.59	20.71	8.01	57.3	0.037
	13	8.15	18.72	7.75	56.4	0.036
	15	4.11	12.11	7.17	57.9	0.037
	17	1.44	11.02	6.89	60.0	0.038
Basin 3	1	9.09	20.67	8.21	57.7	0.037
	3	8.91	20.67	8.17	57.6	0.037
	5	8.84	20.68	8.13	57.7	0.037
	7	8.75	20.68	8.11	57.4	0.037
	9	8.76	20.61	8.09	57.4	0.037
	11	8.72	20.57	8.09	57.4	0.037
	13	8.72	17.93	7.87	56.7	0.036
	15	8.77	15.69	7.65	57.0	0.036
	17	8.97	12.4	7.45	56.1	0.036
	19	9.16	10.78	7.39	56.0	0.036

Lake Whatcom is the primary source of drinking water for approximately 66,000 Whatcom County residents. However, a recent study by Washington Department of Ecology (Serdar et al. 1999) indicated that several contaminants of concern were detected in water, sediment, and fish tissue samples from the lake and its tributaries during 1998. Fecal coliform bacteria (FCB) was the most common contaminant found in creeks surrounding Lake Whatcom. Levels of FCB exceeded Washington State water quality standards wherever water was sampled. Other contaminants included a variety of metals and pesticides, most notably polychlorobiphenyls (PCBs). For example, elevated levels of mercury were detected in smallmouth bass (*Micropterus dolomieu*). Furthermore, levels of dieldrin, PCB-1254, and PCB-1260 detected in smallmouth bass, kokanee (*Oncorhynchus nerka*), and longnose sucker (*Catostomus catostomus*) exceeded the EPA's National Toxics Rule (NTR) edible fish tissue criteria to protect human health (Serdar et al. 1999).

Recreational activities at the lake include swimming, water skiing, sailing, and fishing. Historically, the sport fish community comprised of kokanee and resident cutthroat trout

(*Oncorhynchus clarki*). Rainbow trout (*Oncorhynchus mykiss*) and lake trout (*Salvelinus namaycush*) were introduced early in the 20th century. Largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), brown bullhead (*Ameiurus nebulosus*), and pumpkinseed (*Lepomis gibbosus*) were illegally introduced in later decades. In addition to sport fish, crayfish (*Pacifastacus leniusculus*) occur abundantly in the lake and are harvested commercially on occasion (Fletcher 1982; Looff 1994; Jim Johnston, WDFW, personal communication).

Given the prevalence of gravel and exposed bedrock habitats throughout Lake Whatcom (Table 1), the minimal angling pressure, and the presence of a large crayfish population as a possible forage base, Fletcher (1982) proposed the introduction of a new sport fish into the lake. Subsequently, during late summer 1983 and 1984, smallmouth bass were released into Basin 1 by the WDFW, formerly the Washington Department of Game (Jim Johnston, WDFW, personal communication). Although records of Lake Whatcom's native, resident fishes have been compiled for years (Looff 1994; Jim Johnston, WDFW, unpublished data; Paul Mongillo, WDFW, unpublished data), no recent information exists concerning the warmwater fish community at the lake, especially since the introduction of smallmouth bass. Therefore, in an effort to evaluate the status of the smallmouth bass population and to gather baseline information on other warmwater fishes, personnel from WDFW's Warmwater Enhancement Program conducted a fisheries survey at Lake Whatcom in late summer 1998.

Materials and Methods

Lake Whatcom was surveyed during August 12 to September 3, 1998 by a three-person team consisting of two biologists and one scientific technician. Fish were captured using two sampling techniques: electrofishing and gill netting. The electrofishing unit consisted of a 4.9 m Smith-Root 5.0 GPP 'shock boat' set to 250 volts of 6 amp pulsed DC (120 cycles/sec). 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.

Sampling locations were selected by dividing the shoreline into 83 consecutively numbered sections of about 500 m each (determined visually from a map). Using the random numbers table from Zar (1984), 46 of these sections were then randomly selected as sampling locations. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of 18.3 m/minute. Gill nets were set perpendicular to the shoreline. The small-mesh end was attached onshore while the large-mesh end was anchored offshore. Sampling occurred during evening hours to maximize the type and number of fish captured. Nighttime electrofishing occurred along 33.7% (~ 14 km) of the available shoreline. Gill nets were set overnight at 18 locations (= 18 'net nights') (Figure 1).

With the exception of sculpin (family Cottidae), all fish captured were identified to the species level. Each fish was measured to the nearest 1 mm and assigned to a 10-mm size class based on 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 sub-sample ($n \geq 100$ fish) was measured and weighed while the remainder was counted overboard. The length frequency distribution of the sub-sample 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 sub-sample. Scales were removed from up to 10 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, because the focus of our study was the characteristics of the warmwater fish community, salmonid and non-game fish were not aged.

Shoreline development and near-shore habitat were evaluated on September 4, 1998. The number of docks were recorded and visual estimates made of percent bulkheading, aquatic vegetation cover, and composition of substrate for each of the 500 m sections of shoreline sampled. Shoreline development and submersed coarse woody debris were rated low, moderate, or high (Figure1, Table 1). Using a Hydrolab® probe and digital recorder, water quality data was collected during midday from four locations on August 17, 1998 (Figure 1). Table 2 summarizes the information gathered on dissolved oxygen, total dissolved solids, temperature, pH, and specific conductance from three of these locations.

Data Analysis

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.

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).

Catch per unit effort (CPUE) by gear type was determined for all species (number of fish/hour electrofishing and number of fish/net night). Only stock size fish and larger were used to determine CPUE for the warmwater species, whereas CPUE for salmonids and non-game fish were calculated for all sizes. 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 $\pm\ t_{(\alpha,\ N\text{-}1)} \times SE$, 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 proportional stock density (PSD) of each warmwater fish 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, 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 warmwater fish 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 ≥ specified length/number of fish ≥ stock length × 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. Eighty-percent confidence intervals for PSD and RSD were selected from tables in Gustafson (1988).

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 Lake Whatcom (Whatcom County) during late summer 1998. Measurements are minimum total lengths (mm) for each category (Anderson and Neumann 1996).

	Size				
Type of fish	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
Brown bullhead [a]	130	200	280	360	430
Cutthroat trout	200	350	450	600	750
Largemouth bass	200	300	380	510	630
Pumpkinseed	80	150	200	250	300
Rainbow trout	250	400	500	650	800
Smallmouth bass	180	280	350	430	510
Yellow perch	130	200	250	300	380

[a] T. J. Bister and D. W. Willis, South Dakota State University, unpublished data.

Age and growth of warmwater fishes in Lake Whatcom 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 Lake Whatcom 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 non-game fish and kokanee. 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). 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 of the W_s equations for many cold- and warmwater fish species, including the minimum length recommendations for their application, have been compiled by Anderson and Neumann (1996) as well as Timothy J. Bister and David W. Willis (South Dakota State University, unpublished data). With the exception of non-game fish and kokanee, 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

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 and 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 the adequacy of the food supply (Kohler and Kelly 1991), as well as the balance and productivity of the community (Swingle 1950; Bennett 1962).

Species Composition

In terms of biomass, smallmouth bass and peamouth (*Mylocheilus caurinus*) were dominant in our catch during late summer 1998. However, in terms of abundance, our catch was comprised mostly of yellow perch (32.1%) followed by smallmouth bass (23.9%) then peamouth (22.2%) (Table 4). This differs from a previous survey (Fletcher 1982) which showed peamouth were the most abundant fish (60.5%) followed by kokanee (11.5%) then yellow perch (10.8%). In terms of abundance, the percentages of brown bullhead, cutthroat trout, largemouth bass, and sculpin were consistent with Fletcher's (1982) findings. However, Fletcher (1982) did not capture longnose sucker, pumpkinseed, rainbow trout, or three-spine stickleback (*Gasterosteus aculeatus*). Seasonal influences and gear-related biases can be attributed to the disparate catches of these fishes as well as kokanee (Pope and Willis 1996), whereas the shift in species composition favoring smallmouth bass over peamouth is probably related to predation on the latter (Fletcher 1991).

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). However, we chose to include them since their relative contribution to the total biomass captured was small (Table 4). The overall length frequency distribution of fish species may also suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes (e.g., Figure 7). Although many of these fish would be subject to natural attrition during their first winter (Chew 1974), resulting in a different size distribution by the following year, their presence in the system relates directly to fecundity and interspecific and intraspecific competition at lower trophic levels (Olson et al. 1995).

Table 4. Species composition by weight (kg) and number of fish captured at Lake Whatcom (Whatcom County) during a late summer 1998 survey of warmwater fish.

Type of fish	Species composition by weight (kg)	by weight (%)	by number (#)	by number (%)	Size range (mm TL)
Brown bullhead (*Ameiurus nebulosus*)	0.807	0.487	12	0.488	145 - 226
Cutthroat trout (*Oncorhynchus clarki*)	8.201	4.951	86	3.500	102 - 440
Kokanee (*Oncorhynchus nerka*)	0.057	0.034	1	0.041	195
Largemouth bass (*Micropterus salmoides*)	0.070	0.043	15	0.611	38 - 81
Longnose sucker (*Catostomus catostomus*)	6.962	4.203	48	1.954	51 - 270
Peamouth (*Mylocheilus caurinus*)	34.151	20.618	546	22.222	42 - 262
Pumpkinseed (*Lepomis gibbosus*)	2.119	1.279	78	3.175	36 - 155
Rainbow trout (*Oncorhynchus mykiss*)	0.388	0.234	2	0.081	202 - 328
Sculpin (*Cottus* sp.)	3.534	2.133	285	11.581	45 - 200
Smallmouth bass (*Micropterus dolomieu*)	93.355	56.362	588	23.932	41 - 483
Three-spine stickleback (*Gasterosteus aculeatus*)	0.006	0.004	6	0.244	37 - 49
Yellow perch (*Perca flavescens*)	15.986	9.651	790	32.153	36 - 273
Total	165.635		2,457		

C P U E

While electrofishing, catch rates were highest for stock-size yellow perch, smallmouth bass, and pumpkinseed. For species other than the warmwater variety, electrofishing catch rates were highest for peamouth and sculpin (Table 5). Conversely, while gill netting, catch rates were highest for stock-size smallmouth bass and yellow perch. For species other than the warmwater variety, gill netting catch rates were highest for peamouth and longnose sucker (Table 5).

Table 5. Mean catch per unit effort (number of fish/hour electrofishing and number of fish/net night), including 80% confidence intervals, for stock-size warmwater fish, salmonids, and non-game fish collected from Lake Whatcom (Whatcom County) while electrofishing and gill netting during late summer 1998.

	Gear type			
Type of fish	**Electrofishing (# fish/hour)**	**Shock sites**	**Gill netting (# fish/net night)**	**Net nights**
Brown bullhead	2.14 ± 1.59	28	0.06 [a]	18
Cutthroat trout	1.70 ± 0.95	28	1.06 ± 0.46	18
Kokanee	0.21 [a]	28	None captured	18
Largemouth bass	None captured	28	None captured	18
Longnose sucker	0.85 [a]	28	2.44 ± 2.08	18
Peamouth	57.16 ± 20.43	28	15.44 ± 4.11	18
Pumpkinseed	10.87 ± 4.59	28	0.67 [a]	18
Rainbow trout	0.21 [a]	28	None captured	18
Sculpin	56.96 ± 14.14	28	1.00 ± 0.78	18
Smallmouth bass	12.38 ± 5.31	28	4.11 ± 1.25	18
Three-spine stickleback	1.28 ± 0.82	28	None captured	18
Yellow perch	29.45 ± 8.44	28	2.28 ± 1.16	18

[a] Sample size was insufficient to calculate confidence intervals

Stock Density Indices

Except for smallmouth bass and yellow perch, few quality or preferred size fish were captured (Table 6). The electrofishing PSD and RSD values for smallmouth bass (Table 6) were within the stock density index ranges for a body of water managed for a balance between predator and prey species. For predators such as smallmouth bass, the generally accepted stock density index ranges for balanced fish populations are PSD values of 40 to 70, RSD-P values of 10 to 40, and RSD-M values of 0 to 10 (Gabelhouse 1984; Willis et al. 1993). No trophy length fish were captured; yet the gill netting PSD and RSD values for smallmouth bass (Table 6) were close to the stock density index ranges for a body of water managed for large predators. The generally accepted stock density index ranges for fish populations managed for ‘big bass’ are PSD values of 50 to 80, RSD-P values of 30 to 60, and RSD-M values of 10 to 25 (Gabelhouse 1984; Willis et al. 1993). The PSD and RSD values for brown bullhead and cutthroat trout (Table 6) should be viewed with caution, especially given the low catch rates for stock-size fish and small sample sizes used to determine these indices (Divens et al. 1998).

Table 6. Traditional stock density indices, including 80% confidence intervals, for cold- and warmwater fishes collected from Lake Whatcom (Whatcom County) while electrofishing and gill netting during late summer 1998. 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, GN = gill netting.

Type of fish	Gear type	# Stock length fish	PSD	RSD-P	RSD-M	RSD-T
Brown bullhead	EB	10	0	0	0	0
	GN	1	0	0	0	0
Cutthroat trout	EB	5	0	0	0	0
	GN	22	18 ± 11	0	0	0
Pumpkinseed	EB	61	7 ± 4	0	0	0
	GN	2	0	0	0	0
Smallmouth bass	EB	66	42 ± 8	18 ± 6	6 ± 4	0
	GN	66	89 ± 5	86 ± 5	9 ± 5	0
Yellow perch	EB	155	7 ± 3	1 [a]	0	0
	GN	24	79 ± 11	4 [a]	0	0

[a] Sample size was insufficient to calculate confidence intervals

Size Structure

Length frequencies are generally reported by gear type because selectivity of gear types biases species catch based on body form and behavior, and size classes within species (Willis et al. 1993). However, 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, which can be interpreted independently.

Brown Bullhead

Lake Whatcom brown bullhead ranged from 145 to 226 mm TL; all but one were captured in Basin 1. The dominant size classes were between 140 and 170 mm TL (Figure 2). These fish were smaller than the individual captured by Fletcher (1982) that measured 235 mm TL. The relative weights of brown bullhead were somewhat low, which is consistent with Fletcher's (1982) results, and decreased with size (Figure 3).

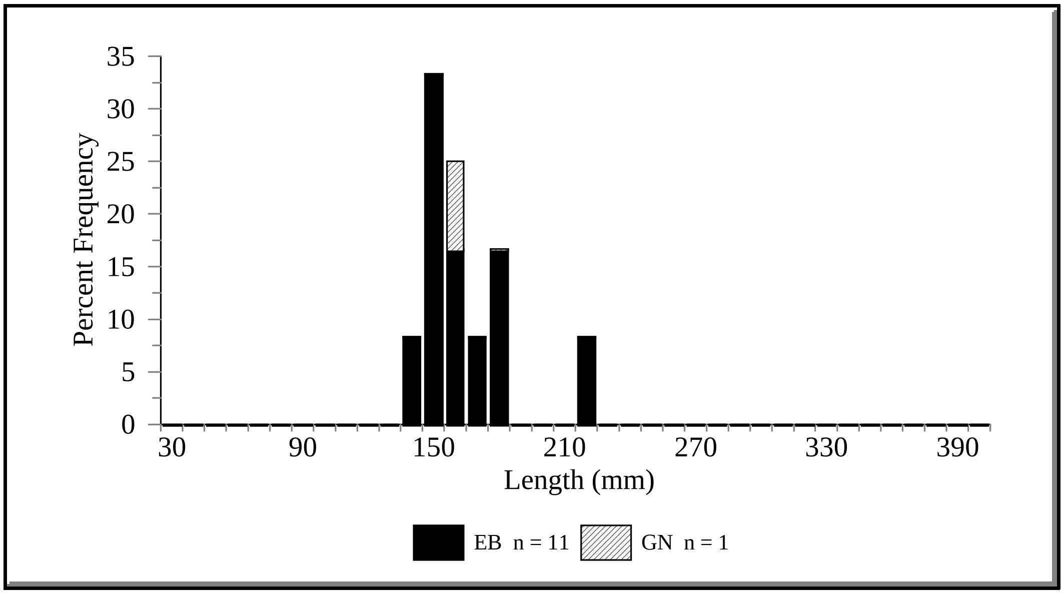

Figure 2. Length frequency histogram of brown bullhead sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

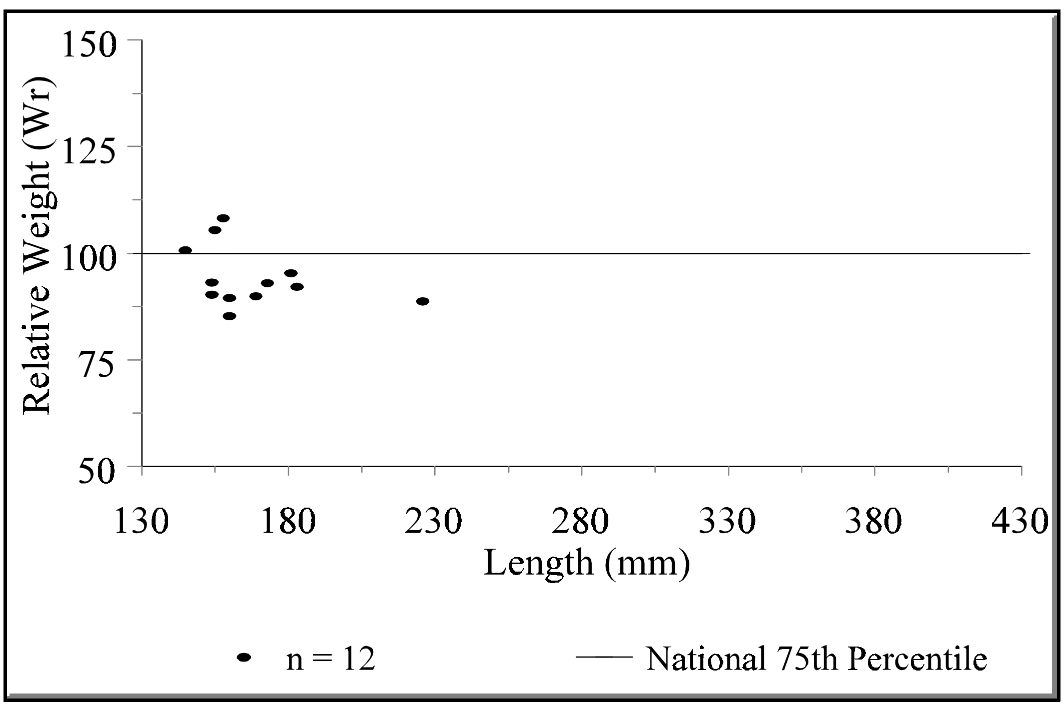

Figure 3. Relationship between total length and relative weight (Wr) of brown bullhead from Lake Whatcom (Whatcom County) compared with the national 75th percentile.

Largemouth Bass

Only 15 largemouth bass were captured in Lake Whatcom during late summer 1998; all but four came from shallow, vegetated habitats in Basin 1. Of the remainder, two were sampled from similar habitats in Basins 2 and 3, one from steep, rocky shoreline in Basin 3, and one from a sandy, shallow cove in Agate Bay (Basin 3). No stock-length fish were captured. All fish were young-of-year (age 0+) and ranged from 38 to 81 mm TL (Figure 4). Fletcher (1982) reported low numbers of largemouth bass as well, but cited personal observations of individual fish weighing in excess of 4.5 kg! The two fish that Fletcher (1982) captured measured 127 and 152 mm TL. Both fish were aged 2+ and displayed below average growth and condition.

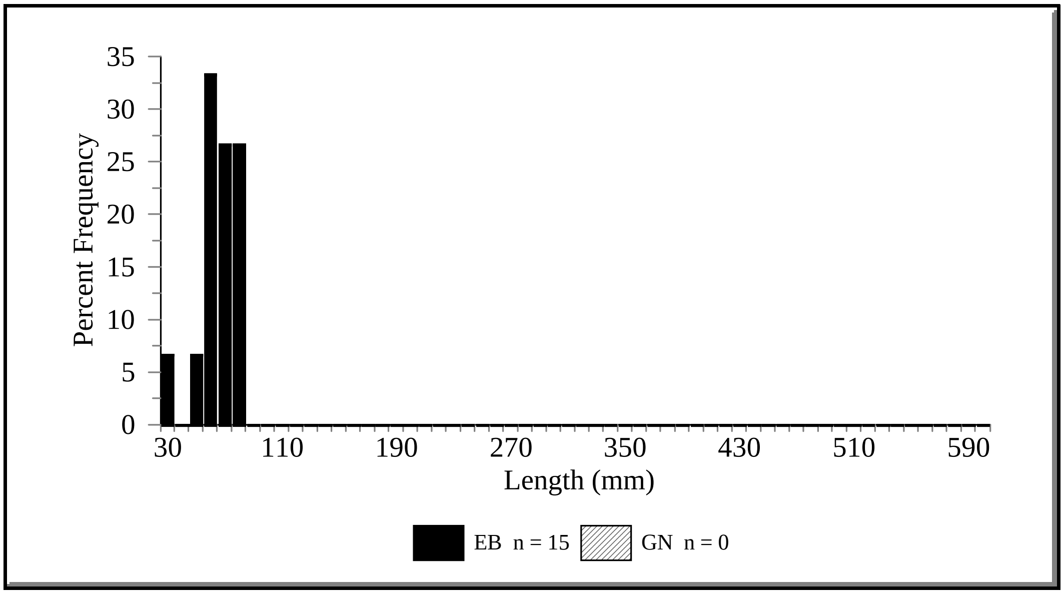

Figure 4. Length frequency histogram of largemouth bass sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

Pumpkinseed

Lake Whatcom pumpkinseed ranged from 36 to 155 mm TL (age 1+ to 4+). The 1997 year class was dominant (Table 6, Figure 5). Using the direct proportion method (Fletcher et al. 1993), age and growth of the Lake Whatcom fish were consistent with pumpkinseed statewide (Table 7). Relative weights were consistent with or slightly below average (Figure 6). That Fletcher (1982) did not capture pumpkinseed suggests that the fish might be a relatively new introduction into the lake. However, it should be noted that pumpkinseed were captured in the shallow, vegetated habitats of all three basins.

Table 7. Age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Lake Whatcom (Whatcom County) during late summer 1998. 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**
1997	25	23.2			
		41.6			
1996	10	20.1	90.3		
		41.3	98.4		
1995	7	24.2	86.9	113.9	
		44.5	95.0	116.6	
1994	1	35.5	60.8	76.0	126.7
		54.6	75.7	88.4	130.7
	Overall mean	25.7	79.4	94.9	126.7
	Weighted mean	42.3	95.8	113.0	130.7
	State average	23.6	72.1	101.6	122.7

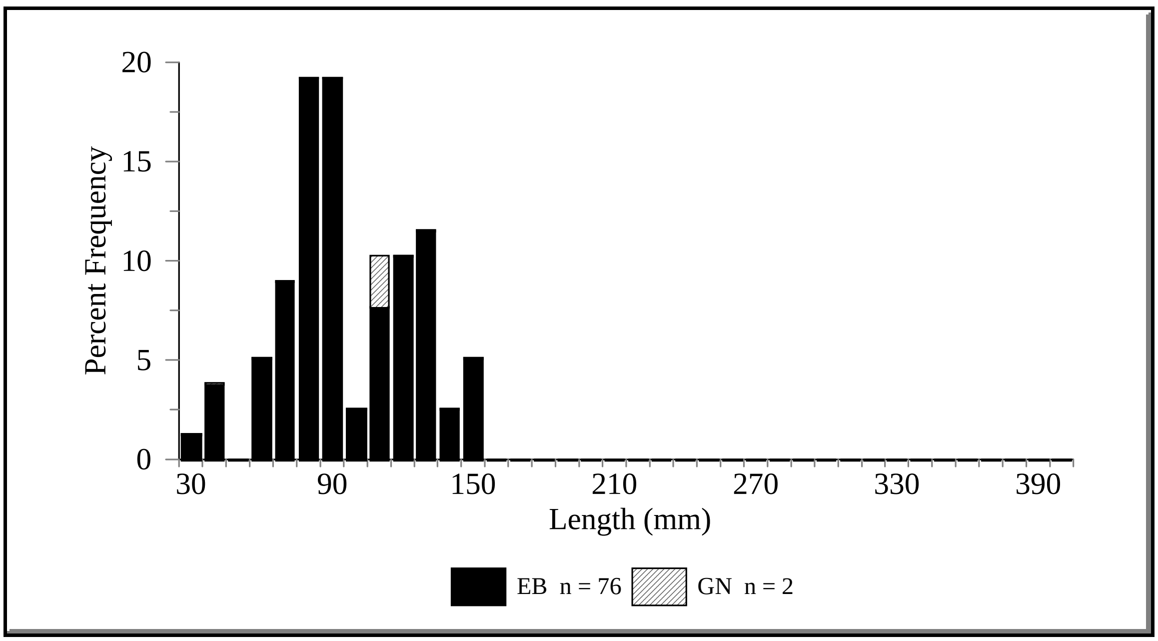

Figure 5. Length frequency histogram of pumpkinseed sunfish sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

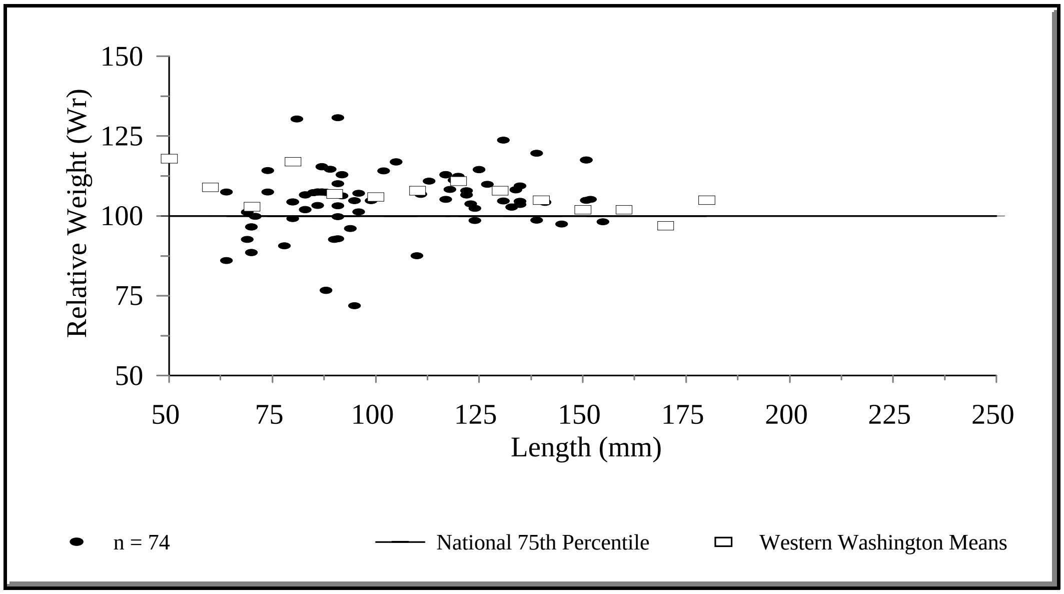

Figure 6. Relationship between total length and relative weight (Wr) of pumpkinseed from Lake Whatcom (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Smallmouth Bass

Smallmouth bass were sampled from all three basins and ranged from 41 to 483 mm TL (age 0+ to 8+). The stock density indices (Table 6) and length frequency histogram (Figure 7) suggest that a thriving population has evolved since their introduction in late summer 1983 and 1984. Except for small (< 160 mm TL), young (< age 3+) fish, growth of Lake Whatcom smallmouth bass was high when compared to smallmouth bass statewide (Table 7). Relative weights were generally consistent with, or above, the mean values from up to 25 western Washington warmwater lakes (Figure 8).

Concentrations of contaminants in the tissues of Lake Whatcom smallmouth bass increased with size or age (Serdar et al. 1999). For example, 0.504 mg/kg of mercury was detected in a composite sample (n = 8 fish) of large (mean length = 393 ± 6 mm TL), old (~ age 6) fish from Basin 3, whereas 0.145 mg/kg was detected in a composite sample (n = 8 fish) of smaller (mean length = 246 ± 32 mm TL), younger (~ age 3) fish from Basin 1. Likewise, two- and three-fold increases in PCB-1254 and PCB-1260 were detected in the large, old smallmouth bass from Basin 3 compared to the small, young smallmouth bass from Basin 1 (Serdar et al. 1999). Bioaccumulation of contaminants with age is a well-known phenomenon in apex predators such as smallmouth bass (Ward and Neumann 1999, and references therein). Although the concentration of mercury in the sample of large, old fish from Lake Whatcom is disturbing, it is below the EPA's NTR criterion (0.825 mg/kg) for safe human consumption (Serdar et al. 1999).

Table 8. Age and growth of smallmouth bass (*Micropterus dolomieu*) captured at Lake Whatcom (Whatcom County) during late summer 1998. 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	1	2	3	4	5	6	7	8
1997	43	79.1							
		96.4							
1996	17	53.6	150.6						
		80.5	162.5						
1995	21	52.9	119.9	203.6					
		81.0	139.3	212.2					
1994	13	61.3	146.2	229.2	297.6				
		90.2	166.5	241.0	302.5				
1993	15	57.0	135.1	215.0	293.1	342.6			
		86.8	157.9	230.5	301.5	346.5			
1992	26	61.5	138.1	214.6	286.6	340.2	384.5		
		91.3	161.4	231.4	297.3	346.3	386.8		
1991	6	54.9	126.1	193.6	275.0	332.0	372.8	402.5	
		85.3	150.7	212.6	287.3	339.5	377.0	404.2	
1990	1	38.8	145.2	226.3	324.3	376.6	422.2	447.5	459.4
		71.0	169.7	244.9	335.8	384.3	426.6	450.1	461.1
Overall mean		57.4	137.3	213.7	295.3	347.9	393.2	425.0	459.4
Weighted mean		89.0	156.5	226.6	299.1	346.3	386.3	410.8	461.1
State average		70.4	146.3	211.8	268	334	356.1	392.7	

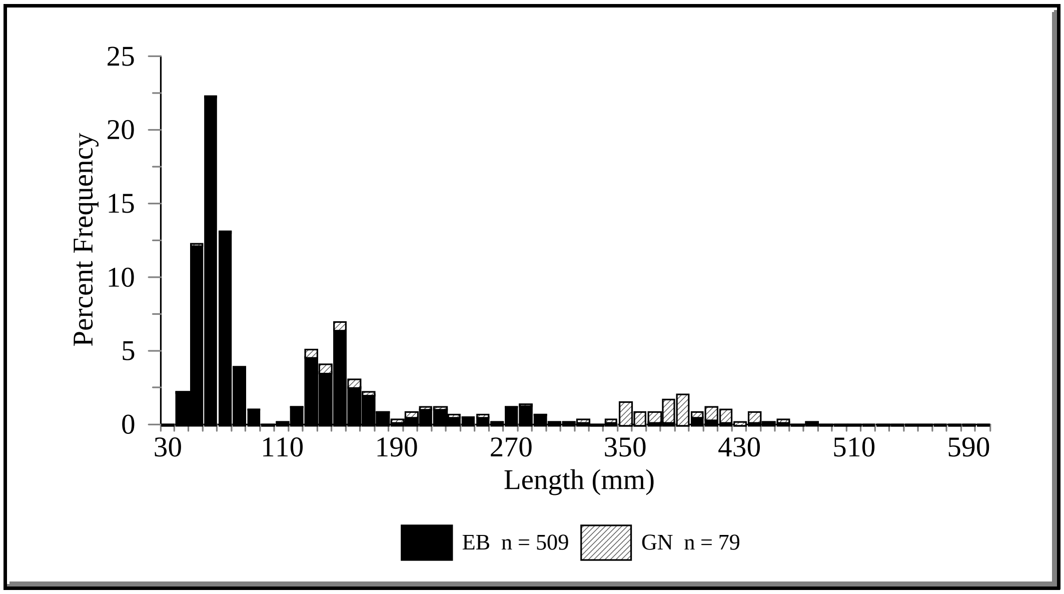

Figure 7. Length frequency histogram of smallmouth bass sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

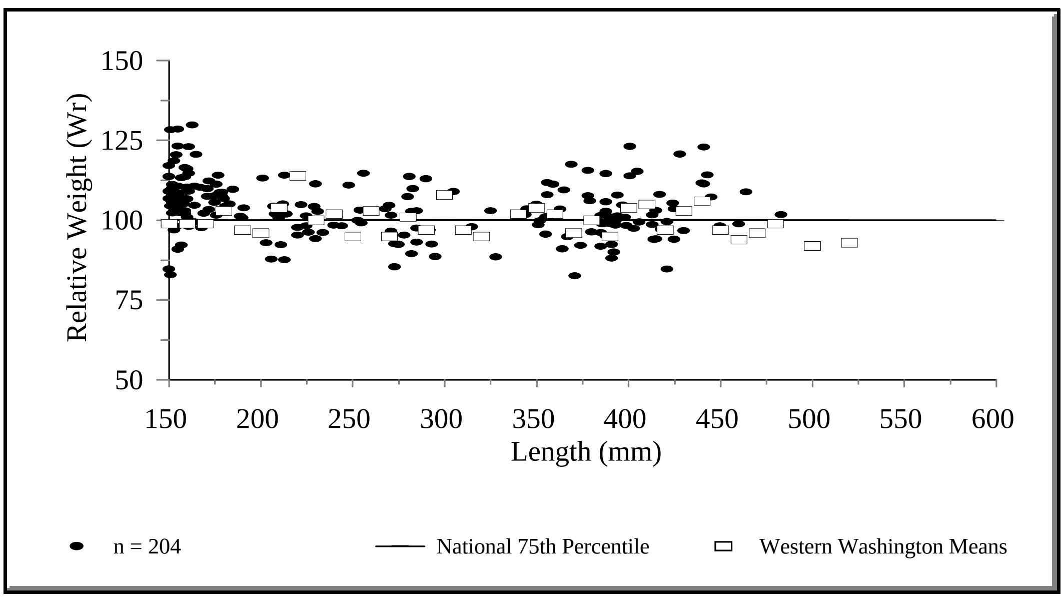

Figure 8. Relationship between total length and relative weight (W_r) of smallmouth bass from Lake Whatcom (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Yellow Perch

Lake Whatcom yellow perch ranged from 36 to 273 mm TL (age 0+ to 5+). Small (< 150 mm TL), young (< age 3) fish were dominant (Table 9, Figure 9), whereas few quality or preferred size fish were captured (Table 6). Growth was high when compared to yellow perch statewide. This differs markedly from Fletcher's (1982) findings, which showed below average growth in yellow perch (Table 9), and may be due to the introduction of smallmouth bass. By stocking the predator into the lake, the expanding yellow perch population was probably 'thinned out' enough to allow fish to reach their full growth potential. Indeed, on a small spatial (4.3 ha pond) and temporal (< 3 years) scale, Bolding et al. (1997) showed that yellow perch growth rates were improved by stocking an apex predator.

Table 9. Age and growth of yellow perch (*Perca flavescens*) captured at Lake Whatcom (Whatcom County) during late summer 1998. 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	1	2	3	4	5
1997	43	64.1				
		79.4				
1996	4	43.7	122.4			
		65.7	130.0			
1995	26	43.6	105.1	170.5		
		67.5	120.2	176.5		
1994	3	54.0	115.6	162.9	188.2	
		76.5	129.5	170.0	191.8	
1993	1	67.4	169.3	219.4	243.6	260.9
		90.0	180.7	225.3	246.9	262.2
Overall mean		54.6	128.1	184.3	215.9	260.9
Weighted mean		74.7	124.0	177.5	205.6	262.2
Data from Fletcher (1982)		51.3	106.7	142.5	166.1	
State average		59.7	119.9	152.1	192.5	206

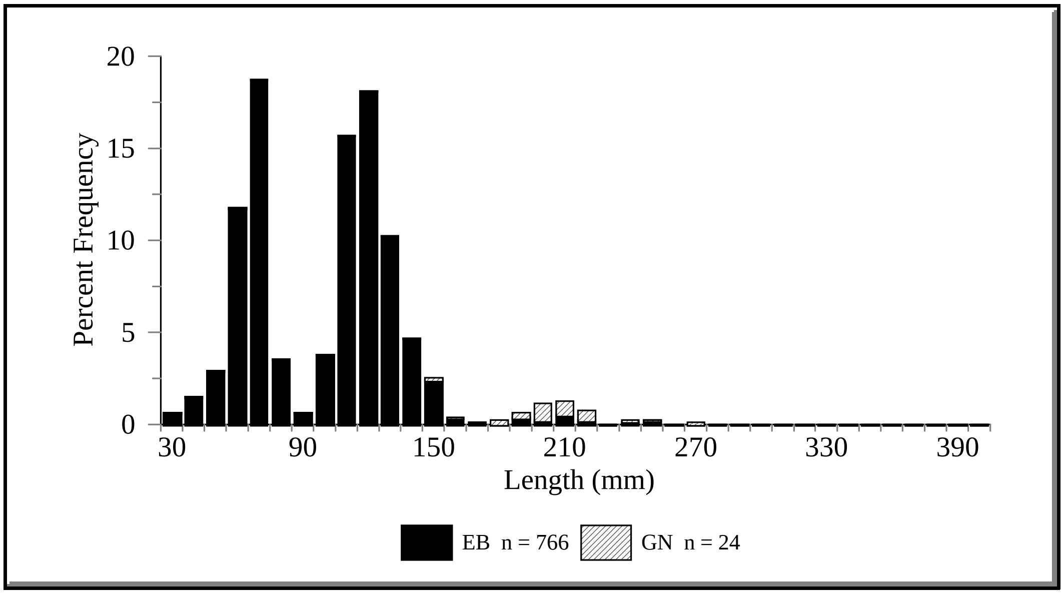

Figure 9. Length frequency histogram of yellow perch sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

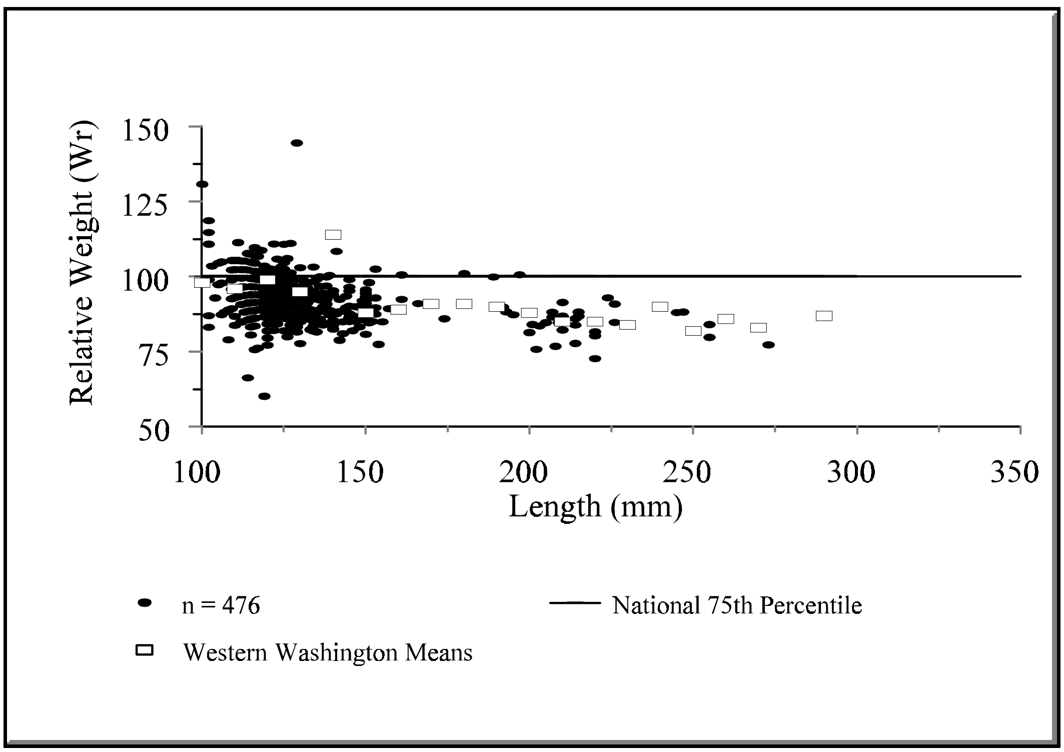

Figure 10. Relationship between total length and relative weight (Wr) of yellow perch form Lake Whatcom (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Non-game Fish and Members of the Family Salmonidae

During late summer 1998, peamouth comprised 20.6% of our catch by weight and 22.2% by number. Conversely, peamouth dominated the catch of Fletcher (1982). Peamouth ranged from 42 to 262 mm TL. The length frequency histogram revealed at least four year-classes, but these fish were not aged. Nearly half of the peamouth captured were between 150 and 210 mm TL (Figure 11). This prolific fish was ubiquitous throughout the lake.

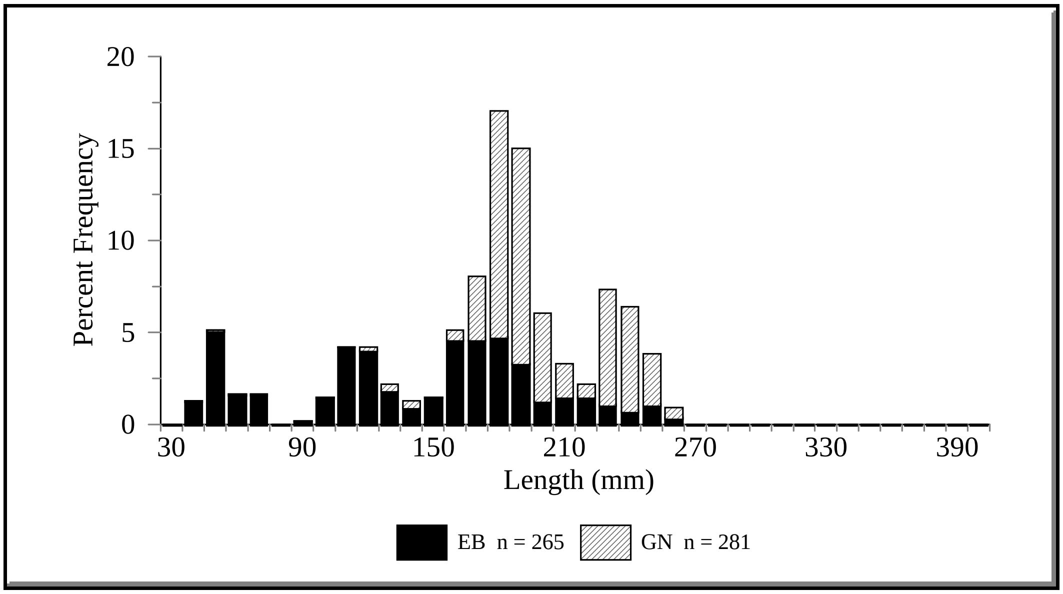

Figure 11. Length frequency histogram of peamouth (*Mylocheilus caurinus*) sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

Longnose suckers were captured only in the southern half of Basin 3, mostly on the steep, rocky drop-offs of the east shore. These fish ranged from 51 to 270 mm TL (Figure 12) and comprised less than 5% of our catch by weight and number (Table 4). A composite sample (n = 7) of longnose sucker had levels of PCB-1254 and PCB-1260 that exceeded EPA's NTR (Serdar et al. 1999). Sculpin ranged from 45 to 200 mm TL (Figure 13) and comprised about 12% of our catch by number (Table 4). Six three-spine stickleback were captured while electrofishing the shallows at the extreme south end of the lake and ranged from 37 to 49 mm TL (Figure 14).

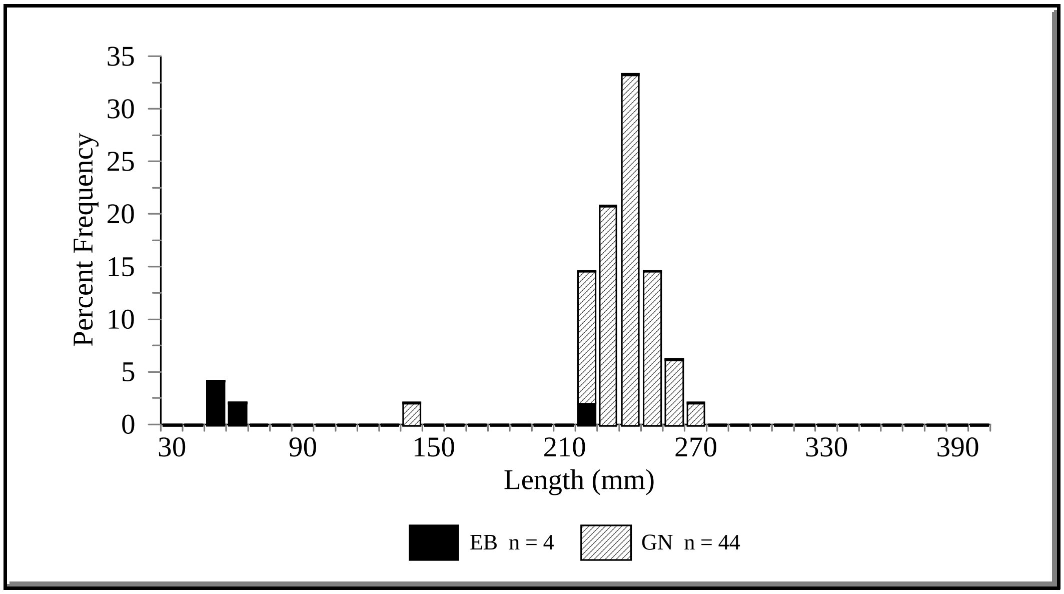

Figure 12. Length frequency histogram of longnose sucker (*Catostomus catostomus*) sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

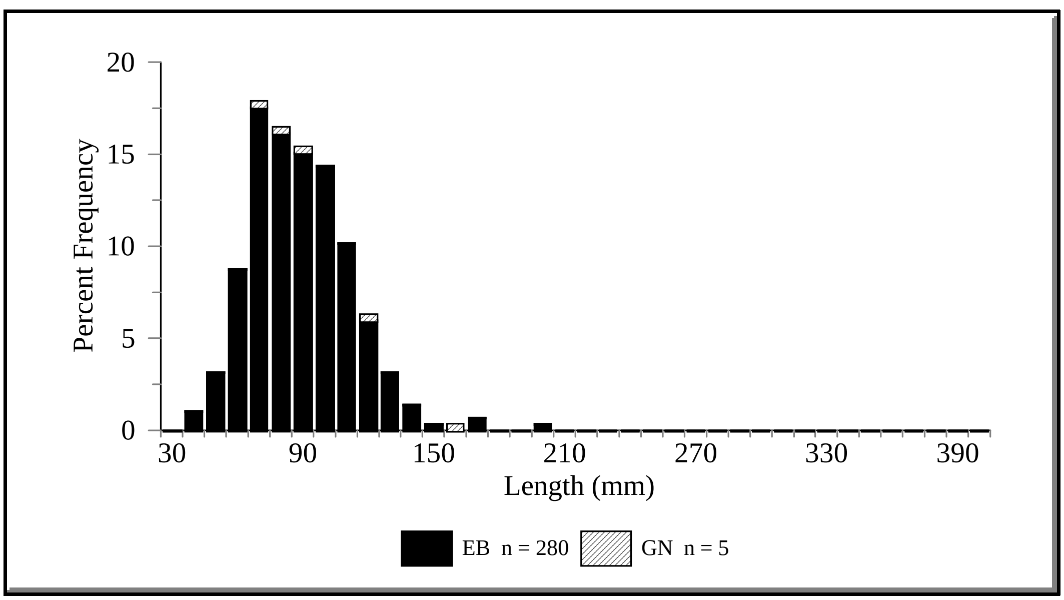

Figure 13. Length frequency histogram of sculpin (*Cottus* sp.) sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

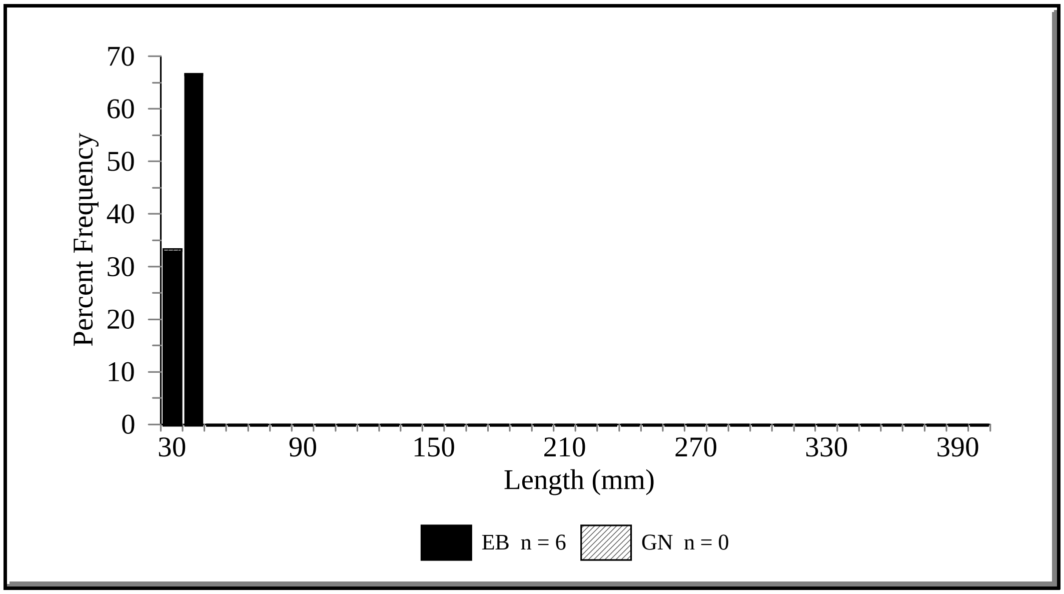

Figure 14. Length frequency histogram of three-spine stickleback (*Gasterosteus aculeatus*) sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

During late summer 1988, we captured only one kokanee while electrofishing Basin 1. The fish measured 195 mm TL and weighed 57 g. This differs from other surveys (Fletcher 1982; Serdar et al. 1999) which indicated better catch rates for Lake Whatcom kokanee during fall. Thus, seasonal influences and gear-related biases (Pope and Willis 1996) can probably be attributed to the disparate catches between our survey and earlier efforts. For instance, Serdar et al. (1999) captured several (n = 15) kokanee in Basin 3 using two variable mesh (31 to 76 mm stretched) mid-water gill nets (3.7 x 60.9 m) set overnight on September 29, 1998. The mean total length of these fish was 233 mm (range = 210 – 251 mm TL). The ratio of males to females was 1:1. All of the females were gravid. All of the fish had levels of PCB-1254 and PCB-1260 that exceeded EPA's NTR (Serdar et al. 1999).

Cutthroat trout were ubiquitous throughout the lake, ranged from 102 to 440 mm TL, yet comprised less than 5% of the biomass and number of fish captured during late summer 1998 (Table 4, Figure 15). The relative weights of cutthroat trout were variable, below the national standard, and decreased with size (Figure 16). Only two rainbow trout were observed (Figure 17). One (202 mm TL @ 80 g) was captured in Basin 1, the other (328 mm TL @ 308 g), Basin 2. The relative weights of these fish were below the national standard and decreased with size (Figure 18). Like kokanee, low catch rates for cutthroat and rainbow trout may be attributed to seasonal influences and gear-related biases (Pope and Willis 1996); however, long-term records of cutthroat trout spawning activity around Lake Whatcom indicate dramatic declines in this species in recent years (Jim Johnston, WDFW, unpublished data).

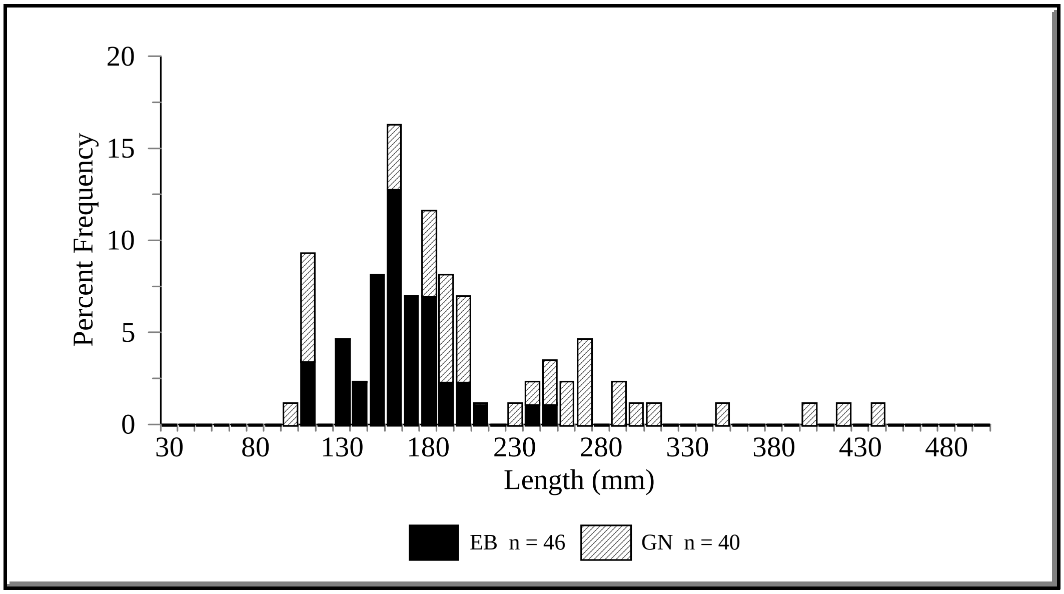

Figure 15. Length frequency histogram of cutthroat trout sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

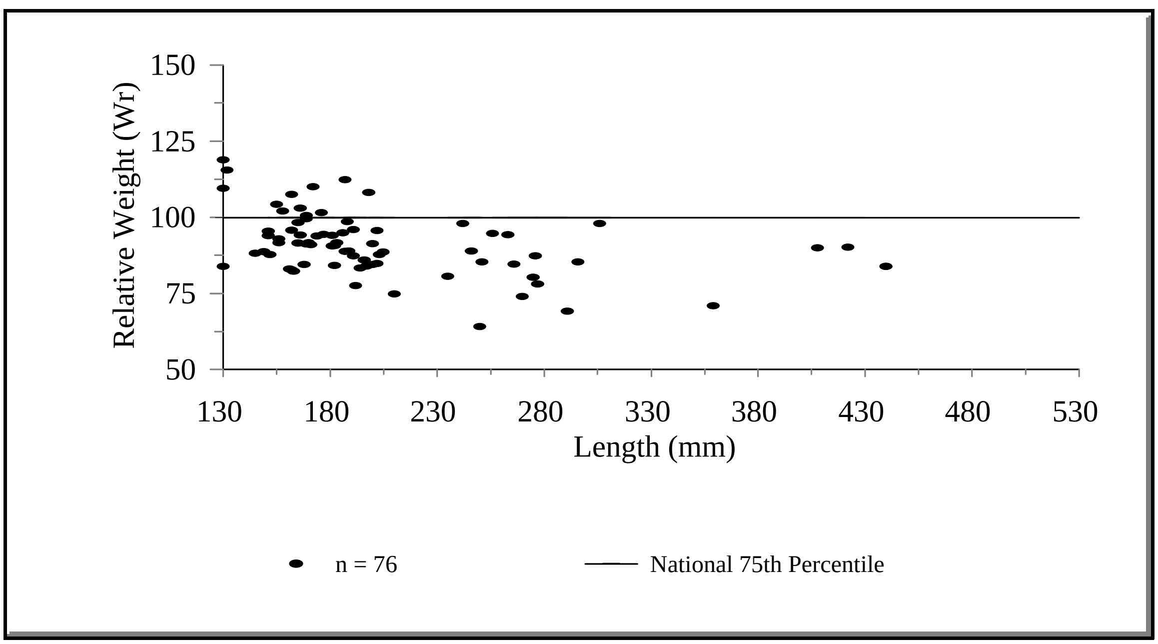

Figure 16. Relationship between total length and relative weight (W_r) of cutthroat trout from Lake Whatcom (Whatcom County) compared with the national 75^{th} percentile.

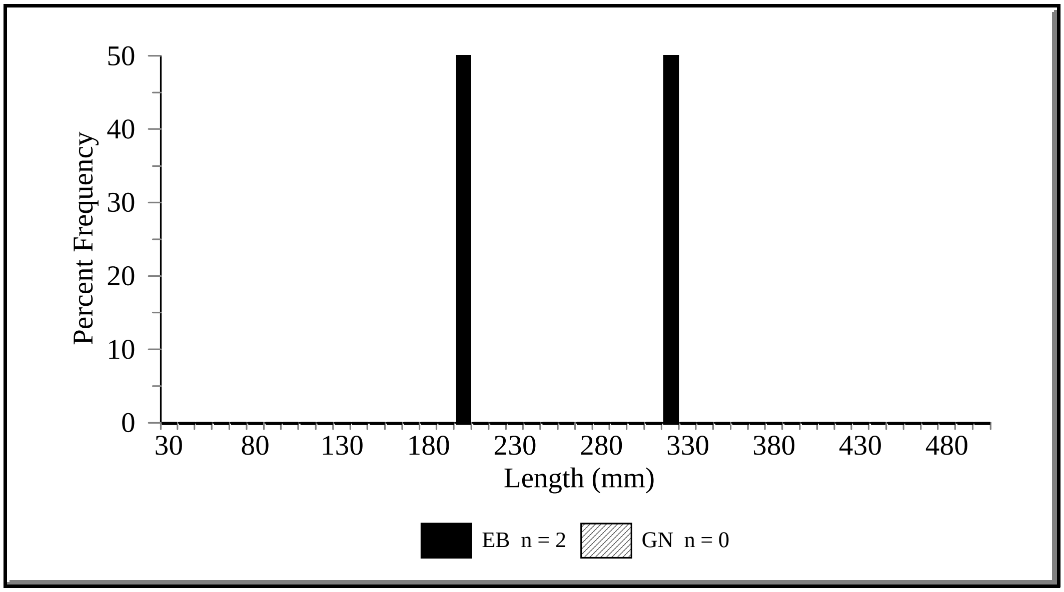

Figure 17. Length frequency histogram of rainbow trout sampled from Lake Whatcom (Whatcom County) in late summer 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting.

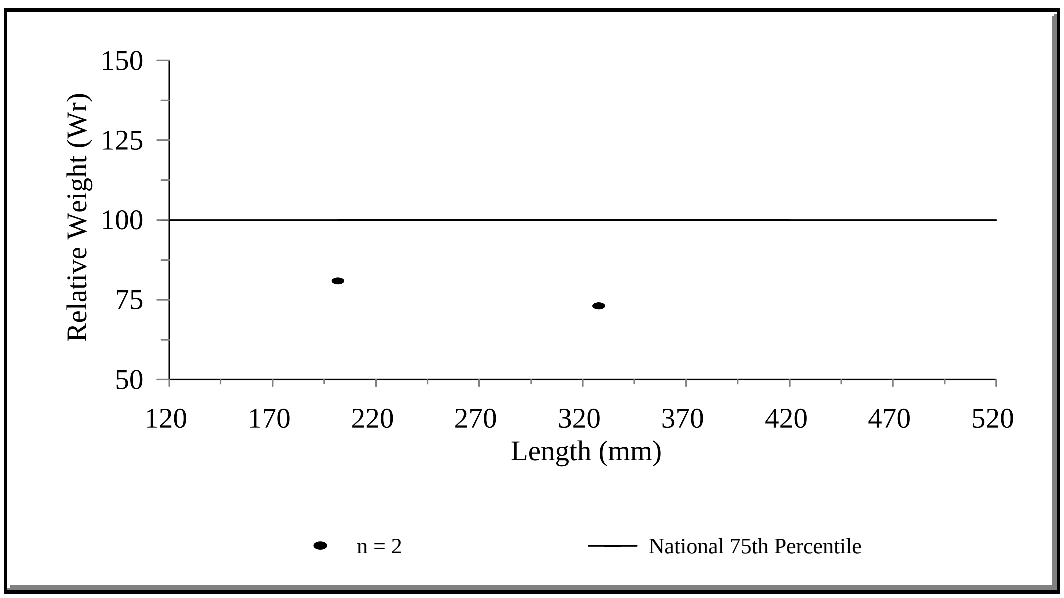

Figure 18. Relationship between total length and relative weight (W_r) of rainbow trout from Lake Whatcom (Whatcom County) compared with the national 75th percentile.

Warmwater Enhancement Options

The warmwater fishery at Lake Whatcom is very popular (Hawley 1999). However, evidence exists that, to some extent, smallmouth bass prey on the lake's native salmonids (Downen 1999). Therefore, the clear potential for warmwater species impacting the native anadromous fishes limits the scope of warmwater enhancement activities at the lake (WDFW 1999), especially given the historical importance of the salmonid fisheries (Fletcher 1982; Looff 1994; Jim Johnston, WDFW, personal communication). Management strategies that might improve Lake Whatcom's warmwater fishery without impacting native salmonid fisheries include:

Change Existing Fishing Rules to Protect Smallmouth and Largemouth Bass

Currently, Lake Whatcom anglers are allowed to retain five fish daily of any combination of smallmouth and largemouth bass. Although there is no minimum size limit, no more than three fish can measure over 381 mm (15") TL. During late summer 1998, the electrofishing PSD and RSD values for Lake Whatcom smallmouth bass were within the stock density index ranges necessary for a balanced population. Gill netting PSD and RSD values suggest that a trophy fishery is evolving for the predator (Gabelhouse 1984; Willis et al. 1993). One way of protecting and enhancing a trophy fishery is implementing a minimum length limit (Cornelius and Margenau 1999). Under this type of regulation, fish below a designated length must be released. A minimum length limit (e.g., 457 mm or 18" TL) with a reduced bag limit (e.g., one fish daily) should allow more fish to reach their full growth potential while protecting the resource (Maceina et al. 1998; Slipke et al. 1998). Since largemouth bass recruitment is very low in Lake Whatcom (i.e., no stock-size fish were captured), a minimum length limit should benefit this species as well (Lucas 1986; Willis 1989). However, it should be noted that a minimum length limit might result in little or no change in smallmouth and largemouth bass size structures several years after implementation (Mueller 1999).

A simpler alternative would be to implement catch-and-release fishing on the lake. Under this rule, all smallmouth and largemouth bass captured must be released back into Lake Whatcom alive. Catch-and-release fishing would at least ensure the likelihood of some individuals reaching larger size classes.

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). If the fishing rules are changed to protect Lake Whatcom smallmouth and laremouth bass, clear and concise multilingual posters or signs should be placed at the lake describing the new regulations. Press releases should be sent to local papers, magazines, and sport fishing groups detailing the changes to, and purpose of, the rules. Furthermore, if necessary, increasing the presence of WDFW enforcement personnel at Lake Whatcom should reduce non-compliance.

Eliminate Commercial Crayfish Fishery

Under Washington Administrative Code (WAC) 220-52-060 and the provisions therein, harvest of crayfish for commercial purposes is allowed in selected state waters. Permits are issued only in waters where fishing will not conflict with high-density residential or recreational areas. In 1999, WDFW issued a permit authorizing the commercial harvest of Lake Whatcom crayfish with up to 200 shellfish pots, despite having previously banned such activity in order to protect the lake's native cutthroat trout, a crayfish predator (Turner 1995).

A recent study by Downen (1999) revealed the importance of crayfish in the diet of Lake Whatcom smallmouth bass. Conducted alongside the present study, Downen (1999) found that 54% of the smallmouth bass sampled (n = 51) contained crayfish remains in their stomachs. Biologists have demonstrated stable trophic relationships between smallmouth bass and crayfish in many systems (Bennett et al. 1983; Pflug and Pauley 1984; Probst et al. 1984; Dunsmoor et al. 1991; Ebert and Filipek 1991; Scott and Angermeier 1998). However, continued harvest of Lake Whatcom crayfish for commercial purposes will probably result in substantial declines in biomass, production, and harvest of smallmouth bass and other crayfish predators, such as cutthroat trout (Roell and Orth 1998).

The shorelines of Basins 1 and 2, and to a lesser degree, Basin 3, consist of high-density residential development that precludes the harvest of crayfish for commercial purposes under WAC 220-52-060. Lake Whatcom is also the source of drinking water for 66,000 Whatcom County residents. Shoreline areas not heavily populated or privately owned are used for recreation. For example, Euclid and Bloedel-Donovan Parks, operated by the City of Bellingham, are located in Basin 1. Camp Firwood (including Reveille Island) and Western Washington University's Lakewood Boathouse are located along the western shore of Basin 3, while the North Lake Whatcom Trail, which is maintained by Whatcom County Parks and Recreation, runs along 5 km (3.1 miles) of the eastern shore of the same basin. Furthermore, a large, private campground is located in South Bay. According to WAC 220-52-060, crayfish fishing is not allowed within 400 m (0.25 mile) of the shoreline of developed parks, and no permit will be issued where developed parks encompass more than one-half of the water shoreline.

Lake Whatcom should be placed on the list of waters closed indefinitely to the harvest of crayfish for commercial purposes. The fishery conflicts with recreational fishing opportunities at the lake by impacting vital trophic links between predator (e.g., native cutthroat trout and smallmouth bass) and prey (crayfish) species. Furthermore, the fishery conflicts with the aesthetic qualities of "life on the lake" in high-density residential areas and impacts recreational activities such as swimming, boating, and hiking along the shoreline. Another consideration for eliminating the commercial crayfish fishery is that, given the recent findings of Serdar et al. (1999), the likelihood of harvesting crayfish laden with mercury or other contaminants has greatly increased. For example, the bioaccumulation of contaminants by Lake Whatcom smallmouth bass suggests that the predator is feeding on tainted prey (Serdar et al. 1999). In light of Downen's (1999) study, lentic crayfish are one possible source of this contamination.

Conduct Study of Distribution, Abundance, and Habitat Use by Crayfish

During late summer 1998, crayfish were found to be the primary prey of Lake Whatcom smallmouth bass (Downen 1999). Crayfish are an essential component in the diet of Lake Whatcom cutthroat trout as well (Jim Johnston, WDFW, unpublished data). Despite its importance, little is known about the distribution, abundance, and habitat use of this prey item in Lake Whatcom. A study should be conducted to determine if smallmouth bass, cutthroat trout, and crayfish abundances at Lake Whatcom are related (*sensu* Mather and Stein 1991). For example, underwater survey methods developed by WDFW for stock assessment of marine invertebrates (Goodwin and Pease 1991; Pfister and Bradbury 1996) can be used to determine how crayfish density varies according to smallmouth bass or cutthroat trout abundance, depth, and habitat type. An understanding of how biotic and abiotic factors influence their distribution should lead to better ways of managing predator and preys species alike.

Conduct Comprehensive Creel, Consumption, Fish Tissue, and Diet Studies

The fisheries of Lake Whatcom are well known among Northwest anglers, especially those targeting smallmouth bass (Hawley 1999). In fact, several fishing tournaments are held annually at the lake (Zook 1993; Strahle 1999). Given the recent findings by Serder et al. (1999), a collaborative effort between WDFW, EPA, WDE, and the Washington Department of Health should be made to assess the risk of exposure to humans from consuming contaminated fish. A creel survey would provide information on the type and quantity of fish being caught by anglers, whereas a consumption survey would provide information on the type and quantity of fish being eaten by anglers. Extending the work of Serdar et al. (1999) to include lentic crayfish, cutthroat trout, kokanee, and warmwater species such as largemouth bass and yellow perch, would provide baseline information on other desirable, edible species. Broadening the scope of Downen's (1999) work to include other species (e.g., cutthroat trout, kokanee, and yellow perch) as well as temporal changes would also better our understanding of the pathways in which contaminants are entering the food chain.

Quantify, Analyze, and Monitor Habitat with Geographic Information Systems (GIS)

Large bodies of water, such as Lake Whatcom, often exhibit patches of distinct habitats with different assemblages of fish depending on such factors as life stage, species, and seasonality (Hayes et al. 1996). During late summer 1998, we observed a number of distinct habitat types and associated assemblages of fish species. For example, with few exceptions, brown bullhead and juvenile largemouth bass were captured in Basin 1 only, whereas yellow perch and pumpkinseed were captured in the shallow, vegetated habitats of all three basins. Peamouth were ubiquitous throughout the lake, yet longnose sucker were captured only in the southern half of Basin 3, mostly on the steep, rocky drop-offs of the east shore. Likewise, large numbers of quality-length smallmouth bass were captured along rocky outcroppings and points, while marginal habitats (i.e., barren or sandy) were dominated by sculpin and a paucity of other species.

GIS would be an effective tool for managing and analyzing such data since it can link data by location. Analyses of proximity, quantity (e.g., length or area of disturbed shoreline), spatial autocorrelation, and temporal change can then can allow the resource manager to predict future dynamics in fish populations and assess risks associated with human activity. Effective management of the fish populations in Lake Whatcom would benefit from an inventory and quantification of important habitats as well as disturbances likely to impact these habitats. For example, despite Lake Whatcom's large volume, prime nursery habitat for warmwater species is restricted to a few shallow embayments. The importance of this habitat is apparent, but its extent has not been quantified. Future development (e.g., bulkheading, pile driving, or timber harvests) of spawning, nursery, and foraging habitats throughout the lake could have direct influences on recruitment of both native fishes and introduced warmwater species and subsequent numbers of harvestable fish. However, causal relationships cannot be effectively argued without a means of quantifying habitat and disturbance and determining the extent of their spatial and temporal overlap.

Literature Cited

Anderson, R.O., and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* Murphy, B.R., and D.W. Willis (eds.), Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, MD.

BPWD (Bellingham Public Works Department). 1999. Pure Facts. June 1999 Update of the 1998 Consumer Confidence Report. City of Bellingham, WA, 8 p.

Bennett, G.W. 1962. Management of Artificial Lakes and Ponds. Reinhold Publishing Corporation, New York, NY.

Bennett, D.H., P.M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of the warmwater fishery and the potential for improving warmwater fish habitat in the lower Snake reservoirs. University of Idaho, Department of Fish and Wildlife Resources, Final Report to U.S. Army Corps of Engineers, Contract DACW68-79-C0057.

Bolding, B., S.A. Bonar, M. Divens, D. Fletcher, and E. Anderson. 1997. Stocking walleye to improve growth and reduce abundance of overcrowded panfish in a small impoundment. Washington Department of Fish and Wildlife, Publication # RAD97-05, 27 p.

Carlander, K.D. 1982. Standard intercepts for calculating lengths from scale measurements for some centrarchid and percid fishes. Transactions of the American Fisheries Society 111: 332-336.

Chew, R.L. 1974. Early life history of the Florida largemouth bass. Florida Game and Fresh Water Fish Commission, Fishery Bulletin # 7, 76 p.

Cornelius, R.R., and T.L. Margenau. 1999. Effects of length limits on muskellunge in Bone Lake, Wisconsin. North American Journal of Fisheries Management 19: 300-308.

Divens, M.J., S.A. Bonar, B.D. Bolding, E. Anderson, and P.W. James. 1998. Monitoring warm-water fish populations in north temperate regions: sampling considerations when using proportional stock density. Fisheries Management and Ecology 5: 383-391.

Downen, M.R. 1999. Some evidence for the importance of crayfish in the diet of smallmouth bass of Lake Whatcom, Washington. Washington Department of Fish and Wildlife, Warmwater Enhancement Program, Publication # FPT99-01, 9 p.

Dunsmoor, L.K., D.H. Bennett, and J.A. Chandler. 1991. Prey selectivity and growth of a planktivorous population of smallmouth bass in an Idaho reservoir. Pages 14-23 *in* D.C.Jackson (ed.), The First International Smallmouth Bass Symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Ebert, D.J., and S.P. Filipek. 1991. Evaluation of feeding and habitat competition between native smallmouth bass and rainbow trout in a coolwater stream. Pages 49-54 *in* D.C. Jackson (ed.), The First International Smallmouth Bass Symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Fletcher, D.H. 1982. Lake Whatcom, Whatcom County, Fishery Survey. Pages 180-191 in Warm Water Fishery Investigations in Washington State. Annual Report submitted to the U.S. Fish and Wildlife Service under Federal Aid in Fish Restoration Program, Project # F-71-R.

Fletcher, D.H. 1991. Interspecific impacts of smallmouth bass in the northwestern United States. Pages 104-109 *in* D.C. Jackson (ed.), The First International Smallmouth Bass Symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Fletcher, D., S. Bonar, B. Bolding, A. Bradbury, and S. Zeylmaker. 1993. Analyzing warmwater fish populations in Washington State. Washington Department of Fish and Wildlife, Warmwater Fish Survey Manual, 137 p.

Gabelhouse, D.W., Jr. 1984. A length categorization system to assess fish stocks. North American Journal of Fisheries Management 4: 273-285.

Glass, R.D. 1984. Angler compliance with length limits on largemouth bass in an Oklahoma reservoir. North American Journal of Fisheries Management 4: 457-459.

Goodwin, C.L., and B.C. Pease. 1991. Geoduck, *Panopea abrupta* (Conrad, 1849), size, density, and quality as related to various environmental parameters in Puget Sound, Washington. Journal of Shellfish Research 10: 65-77.

Gustafson, K.A. 1988. Approximating confidence intervals for indices of fish population size structure. North American Journal of Fisheries Management 8: 139-141.

Hawley, K. 1999. Opportunities climb with river opener. Fishing and Hunting News 55 (11): 71.

Hayes, D.B., C.P. Farreri, and W.W. Taylor. 1996. Linking fish habitat to their population dynamics. Canadian Journal of Fisheries and Aquatic Sciences 53: 383-390.

Jearld, A. 1983. Age determination. Pages 301-324 *in* Nielsen, L.A., and D.L. Johnson (eds.), Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Kohler, C.C., and A.M. Kelly. 1991. Assessing predator-prey balance in impoundments. Pages 257-260 *in* Proceedings of the Warmwater Fisheries Symposium I, June 4-8, 1991, Scottsdale, Arizona. USDA Forest Service, General Technical Report RM-207.

Looff, A. 1994. Lake Whatcom kokanee – management history and evaluation of recent population declines. Master's thesis, 127 p. University of Washington, Seattle, WA.

Lucas, B. 1986. Evaluation of the 14-inch minimum size limit on Silver Lake. Washington Department of Game, Fishery Management Report 86-19, 41 p.

Maceina, M.J., P.W. Bettoli, S.D. Finely, and V.J. DiCenzo. 1998. Analyses of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North American Journal of Fisheries Management 18: 66-75.

Masser, M. *Undated*. Recreational fish pond management for Alabama. Auburn University, Alabama Cooperative Extension Service Technical Report, 32 p.

Mather, M.E., and R.A. Stein. 1991. Distribution patterns of smallmouth bass in central Ohio streams: evaluating the role of crayfish. Page 166 *in* D.C. Jackson (ed.), The First International Smallmouth Bass Symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Matthews, R.A., M. Hilles, and G.M. Matthews. 1999. Lake Whatcom Monitoring Project 1997/1998. Western Washington University, Institute for Watershed Studies, Final report prepared for the City of Bellingham Public Works Department.

Mueller, K.W. 1999. 1997 Lake Stevens survey: the warmwater fish community after implementation of a minimum length rule on largemouth and smallmouth bass. Washington Department of Fish and Wildlife, Warmwater Enhancement Program, April 1999 Technical Report, 26 p.

Murphy, B.R., and D.W. Willis. 1991. Application of relative weight (W_r) to western warmwater fisheries. Pages 243-248 *in* Proceedings of the Warmwater Fisheries Symposium I, June 4-8, 1991, Scottsdale, Arizona. USDA Forest Service, General Technical Report RM-207.

ODFW (Oregon Department of Fish and Wildlife). 1997. Fishery biology 104 - Body condition. Oregon Department of Fish and Wildlife, Warmwater Fish News 4(4):3-4.

Olson, M.H., G.G. Mittelbach, and C.W. Osenburg. 1995. Competition between predator and prey: resource-based mechanisms and implications for stage-structured dynamics. Ecology 76: 1758-1771.

Pfister, C.A., and A. Bradbury. 1996. Harvesting red sea urchins: recent effects and future predictions. Ecological Applications 6: 298-310.

Pflug, D.E., and G.B. Pauley. 1984. Biology of smallmouth bass (*Micropterus dolomieui*) in Lake Sammamish, Washington. Northwest Science 58: 118-130.

Pope, K.L., and D.W. Willis. 1996. Seasonal influences on freshwater fisheries sampling data. Reviews in Fisheries Science 4 (1): 57-73.

Probst, W.E., C.F. Rabeni, W.G. Covington, and R.E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society 113: 283-294.

Roell, M.J., and D.J. Orth. 1998. Indirect effects of fishery exploitation and pest control in a riverine food web. North American Journal of Fisheries Management 18: 337-346.

Scott, M.C., and P.L. Angermeier. 1998. Resource use by two black basses in impounded and riverine sections of the New River, Virginia. North American Journal of Fisheries Management 18: 221-235.

Serdar, D., D. Davis, and J. Hirsch. 1999. Lake Whatcom Watershed Cooperative Drinking Water Protection Project–Results of 1998 Water, Sediment, and Fish Tissue Sampling. Washington Department of Ecology, Publication # 99-337, 66 p.

Slipke, J.W., M.J. Maceina, V.H. Travnichek, and K.C. Weathers. 1998. Effects of a 356-mm minimum length limit on the population characteristics and sport fishery of smallmouth bass in the Shoals Reach of the Tennessee River, Alabama. North American Journal of Fisheries Management 18: 76-84.

Strahle, L.K. 1999. Summary of results for bass and walleye fishing contests held in Washington 1997. Washington Department of Fish and Wildlife, Publication # FPA99-02, 14 p.

Swingle, H.S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Auburn University, Alabama Agricultural Experiment Station, Bulletin # 274, 74 p.

Swingle, H.S. 1956. Appraisal of methods of fish population study - part IV: determination of balance in farm fish ponds. Pages 298-322 *in* Transactions of the 21st North American Wildlife Conference, March 5-7, 1956. Wildlife Management Institute, Washington D.C.

Turner, R. 1995. Letter from Washington Department of Fish and Wildlife Director to constituent declining constituent's request to harvest Lake Whatcom crayfish for commercial purposes. Washington Department of Fish and Wildlife, management files, dated April 21, 1995.

Ward, S.M., and R.M. Neumann. 1999. Seasonal variations in concentrations of mercury in axial muscle tissue of largemouth bass. North American Journal of Fisheries Management 19: 89-96.

WDFW (Washington Department of Fish and Wildlife). 1999. Warmwater Game Fish Enhancement Program. Washington Department of Fish and Wildlife, Publication # FM96-04, 2 p.

Willis, D. 1989. Understanding length limit regulations. In-Fisherman 87: 30-41.

Willis, D.W., B.R. Murphy, and C.S. Guy. 1993. Stock density indices: development, use, and limitations. Reviews in Fisheries Science 1(3): 203-222.

Zar, J.H. 1984. Biostatistical Analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, NJ.

Zook, W.J. 1993. 1993 warmwater fishing contests in Washington. Washington Department of Fish and Wildlife, Fisheries Management Division, Summer 1993 Report, 15 p.