1997 Big Lake Survey:
The Warmwater Fish Community Before Treatment with a Selective Herbicide

by

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Introduction and Background

Big Lake is a shallow (mean and maximum depth = 4.3 and 7.0 m, respectively), narrow (width = 0.4 - 0.8 km) body of water located in Skagit County southeast of the City of Mt. Vernon, Washington. The lake is fed by Lake Creek from the south, and six unnamed tributaries which are located along the western shore. Surface water exits Big Lake (surface area ≈ 220 ha) at the northern end, through Nookachamps Creek, eventually discharging into the Skagit River. The watershed supports a variety of cold- and warmwater fish species, including cutthroat trout (*Oncorhynchus clarki*), steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), yellow perch (*Perca flavescens*), pumpkinseed (*Lepomis gibbosus*), and largemouth bass (*Micropterus salmoides*). The aquatic plant community consists of a variety of pondweeds (*Potamogeton* sp.), but mostly invasive Brazilian elodea (*Egeria densa*) and, to a lesser degree, Eurasian watermilfoil (*Myriophyllum spicatum*) [URS *undated*; Washington Department of Ecology (WDE) 1976; RMI 1999; Washington Department of Fish and Wildlife (WDFW), unpublished data; Jim Johnston, WDFW, personal communication; Jenifer Parsons, WDE, personal communication].

Nearshore residential development at Big Lake is extensive. Concern about the invasion of the lake by Brazilian elodea and the spread of Eurasian watermilfoil led residents to form the Big Lake Management District and, with support from Skagit County, sought grants from WDE's Aquatic Weed Program to implement an integrated aquatic vegetation management plan. In 1998, WDE issued a permit and provided funding to Skagit County in order to treat the lake with the herbicide Sonar® (RMI 1999). On July 1, 1998, and every two weeks thereafter for a period of six weeks, a sinking, slow-release pellet form of Sonar® was applied to the aquatic plant beds of Big Lake. The benefits of using the herbicide pellets were two-fold: applicators could target specific areas where noxious weeds had colonized and efficacy of treatment was improved since the pellets remained in direct contact with the targeted plants. By October 1, 1998, most Brazilian elodea was damaged or dying-back throughout Big Lake. Eurasian watermilfoil was similarly affected (RMI 1999).

A healthy aquatic plant community is essential for the well-being of many warmwater fish species, which are more likely to be found in areas with aquatic plants than in areas without them (Killgore et al. 1989). Submersed aquatic vegetation provides important foraging, refuge, and spawning habitat (see review by Willis et al. 1997), improving survival and recruitment to harvestable sizes (Durocher et al. 1984). Changes in the standing crop of aquatic plants can alter fish production (Wiley et al. 1984) as well as the structure of the fish community itself (Bettoli et al. 1993). For these reasons, it is important to gather baseline information and carefully review all proposals to limit or control aquatic vegetation for a given lake, especially when the lake supports a popular fishery.

Big Lake is well known for its recreational opportunities, especially fishing for warmwater species such as largemouth bass (Anonymous 1999). In an effort to assess its warmwater fishery, personnel from WDFW's Warmwater Enhancement Program conducted a fisheries survey at the lake in summer 1997. Since it was gathered before implementation of the integrated aquatic vegetation management plan, the baseline information presented here will be useful when monitoring the long-term effects of the Sonar® treatments at Big Lake.

Materials and Methods

Big Lake was surveyed by a three-person team during July 28 - 31, 1997. Fish were captured using three sampling techniques: electrofishing, gill netting, and fyke netting. The electrofishing unit consisted of a 5.5 m Smith-Root 5.0 GPP 'shock boat' using a DC current of 120 cycles/sec at 3 to 4 amps power. Experimental gill nets (45.7 m long × 2.4 m deep) were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size (13, 19, 25, and 51 mm stretched) monofilament mesh. Fyke nets were constructed of a single 30.4 m-lead and two 15.2 m-wings of 130 mm nylon mesh. The body of the nets contained four 1.2 m aluminum rings each.

Sampling locations were selected by dividing the shoreline into 30 consecutively numbered sections of about 402 m each (determined visually from a map). Using the random numbers table from Zar (1984), 12 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. Fyke nets were set perpendicular to the shoreline with wings extended at 70^o angles from the lead. Sampling occurred during evening hours to maximize the type and number of fish captured. Nighttime electrofishing occurred along 24.2% (~ 2.4 km) of the available shoreline. Gill nets were set overnight at four locations (= 4 'net nights'); however, one gill net was destroyed by a passing motorboat resulting in only 3 'net nights' for this gear type. Fyke nets were set at two locations (= 2 'net nights') around the lake (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.

Water quality data was collected during midday from three locations on July 31, 1997 (Figure 1). Using a Hydrolab® probe and digital recorder, information was gathered on dissolved oxygen, redox, temperature, pH, and specific conductance. Secchi disc readings were recorded in feet and then converted to m (Table 1).

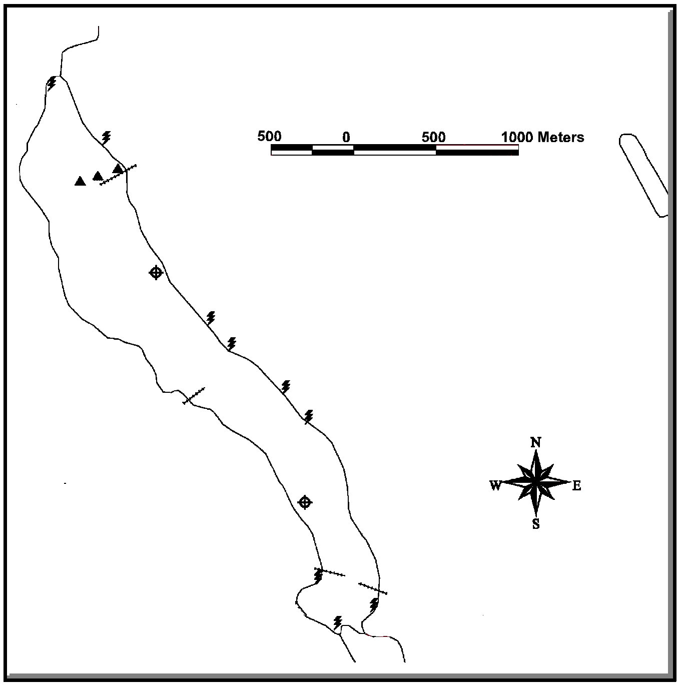

Figure 1. Map of Big Lake (Skagit County) showing sampling locations. Bolts indicate sections of shoreline where electrrofishing occurred. Hatched lines extending into lake indicate placement of gillnets, whereas compass roses indicate placement of fyke nets. Triangles indicate water quality stations.

Table 1. Water quality from three locations (near shore, offshore, and mid-lake) at Big Lake (Skagit County). Samples were collected midday on July 31, 1997.

Location	Secchi (m)	Parameter					
		Depth (m)	DO	Temp (°C)	pH	Conductance	Redox
Near shore	3.5 m	1	8.5	23.8	7.9	83	396
		2	8.7	23.3	7.9	83	395
		3	8.9	22.6	7.9	83	396
		4	5.2	21.1	6.8	83	446
Offshore	3 m	1	8.4	23.4	7.9	83	400
		2	8.7	23.3	7.9	80	400
		3	8.9	22.6	7.9	75	399
		4	5.6	20.8	6.9	83	443
		5	2.9	19.4	6.6	88	456
		6	1.5	18.9	6.5	90	461
Mid-lake	3 m	1	8.4	22.9	7.9	80	411
		2	8.6	22.9	7.9	81	411
		3	8.7	22.3	7.9	80	413
		4	8.1	21.5	7.5	81	430
		5	3.5	19.5	6.7	82	463
		6	1.5	18.4	6.5	85	340

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 2 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$\geq$quality length/number of fish$\geq$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 2). Preferred length (45-55% of world-record length) refers to the minimum size fish anglers would prefer to catch when given a choice. Memorable length (59-64% of world-record length) refers to the minimum size fish most anglers remember catching, whereas trophy length (74-80% of world-record length) refers to the minimum size fish considered worthy of acknowledgment. Like PSD, RSD provides useful information regarding population dynamics, but is more sensitive to changes in year-class strength. RSD was calculated as the number of fish$\geq$specified length/number of fish$\geq$stock length × 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 2. Length categories for warmwater fish species used to calculate stock density indices (PSD and RSD; Gabelhouse 1984) of fish captured at Big Lake (Skagit County) during summer 1997. Measurements are minimum total lengths (mm) for each category (Willis et al. 1993).

Type of fish	Size				
	Stock	Quality	Preferred	Memorable	Trophy
Black crappie	130	200	250	300	380
Brown bullhead	150	230	—	—	—
Largemouth bass	200	300	380	510	630
Pumpkinseed	80	150	200	250	300
Yellow perch	130	200	250	300	380

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

A relative weight (W_r) index was used to evaluate the condition of all species except non-game fish. 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 for the W_s equations of many cold- and warmwater fish species, including the minimum length recommendations for their application, are listed in Anderson and Neumann (1996). With the exception of non-game fish and coho salmon, 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, the fish community of Big Lake during summer 1997 was dominated by largemouth bass and largescale sucker (*Catostomus macrocheilus*). However, in terms of abundance, the lake was clearly dominated by yellow perch (Table 3), which is consistent with survey results from 20 years ago (WDFW, unpublished data). With the exception of largescale sucker, species other than the warmwater variety comprised less than 2% of the biomass captured during summer 1997 and less than 4% by number. Of these, cutthroat trout was dominant.

Table 3. Species composition by weight (kg) and number of fish captured at Big Lake (Skagit County) during a summer 1997 survey of warmwater fish.

Type of fish	Species composition by weight (kg)	by weight (%)	by number (#)	by number (%)	Size range (mm TL)
Black crappie (*Pomoxis nigromaculatus*)	3.99	2.40	97	5.58	72 – 190
Brown bullhead (*Ameiurus nebulosus*)	12.83	7.70	23	1.32	139 – 386
Coho salmon (*Oncorhynchus kisutch*)	0.09	0.05	1	0.06	202
Cutthroat trout (*Oncorhynchus clarki*)	2.09	1.25	9	0.52	225 – 351
Largemouth bass (*Micropterus salmoides*)	58.76	35.27	439	25.24	21 – 488
Largescale sucker (*Catostomus macrocheilus*)	52.30	31.39	53	3.05	176 – 542
Pumpkinseed (*Lepomis gibbosus*)	9.02	5.41	229	13.17	50 – 160
Sculpin (*Cottus* sp.)	0.26	0.15	14	0.81	29 – 155
Yellow perch (*Perca flavescens*)	27.26	16.36	874	50.26	32 – 247
Total	166.60		1,739		

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 total biomass captured was small (Table 3). Moreover, the overall length frequency distribution of fish species may suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes (e.g., Figure 6). 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, the presence of these fish in the system relates directly to fecundity and interspecific and intraspecific competition at lower trophic levels (Olson et al. 1995).

Size Structure

Since selectivity of gear types not only biases species catch based on body form and behavior, but also size classes within species, length frequencies are generally reported by gear type (Willis et al. 1993). However, differences in size selectivity of gear types can sometimes result in offsetting biases (Anderson and Neumann 1996). Therefore, we chose to report the length frequency of each species based on the total catch from combined gear types broken down by the relative contribution each gear type made to each size class. This changed the scale, but not the shape, of the length frequencies by gear type. If concern arises that pooled gear does not represent the least biased assessment of length frequency for a given species, then the shape of the gear type-specific distributions is still represented on the graphs, and these may be interpreted independently.

CPUE

While electrofishing, catch rates were highest for stock-size yellow perch and pumpkinseed, whereas a moderate number of stock-size largemouth bass were captured (Table 4). A similar number of stock-size black crappie (*Pomoxis nigromaculatus*) and yellow perch were captured while gill netting, whereas few fish were captured using fyke nets (Table 4).

Table 4. 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 Big Lake (Skagit County) while electrofishing, gill netting, and fyke netting during summer 1997.

	Gear type					
Type of fish	**Electrofishing (# fish/hour)**	**Shock sites**	**Gill netting (# fish/net night)**	**Net nights**	**Fyke netting (# fish/net night)**	**Net nights**
Black crappie	9.1 ± 5.4	6	16.0 ± 12.2	3	5.0 [a]	2
Brown bullhead	7.7 ± 5.0	6	None captured	3	3.0 ± 2.6	2
Coho salmon	None captured	6	0.3 [a]	3	None captured	2
Cutthroat trout	None captured	6	3.0 ± 2.0	3	None captured	2
Largemouth bass	36.4 ± 5.9	6	1.7 ± 0.4	3	None captured	2
Largescale sucker	5.7 ± 3.3	6	13.0 ± 8.3	3	None captured	2
Pumpkinseed	93.6 ± 36.6	6	0.3 [a]	3	0.5 [a]	2
Sculpin	6.8 ± 2.7	6	None captured	3	None captured	2
Yellow perch	189.5 ± 72.5	6	11.3 ± 8.8	3	1.5 [a]	2

[a] Sample size was insufficient to calculate confidence intervals

Stock Density Indices

Except for largemouth bass and brown bullhead, few quality or preferred size warmwater fish were captured (Table 5). No memorable length fish were captured; yet the electrofishing PSD and RSD-P values for largemouth bass were within the stock density index ranges for a body of water managed for a balance between predator and prey species. For largemouth bass, the generally accepted stock density index ranges for balanced fish populations are PSD values of 40 to 70 and RSD-P values of 10 to 40 (Gabelhouse 1984; Willis et al. 1993). The PSD and RSD-P for fish captured while gill netting and fyke netting 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 5. Traditional stock density indices, including 80% confidence intervals, for cold- and warmwater fishes collected from Big Lake (Skagit County) while electrofishing, gill netting, and fyke netting during summer 1997. 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, and FN = fyke netting.

Type of fish	Gear type	# Stock length fish	PSD	RSD-P	RSD-M	RSD-T
Black crappie	EB	20	0	0	0	0
	GN	48	0	0	0	0
	FN	10	0	0	0	0
Brown bullhnead	EB	16	94 ± 8	88 ± 11	0	0
	GN	0	0	0	0	0
	FN	6	100	67 ± 25	0	0
Cutthroat trout	EB	0	0	0	0	0
	GN	9	11[a]	0	0	0
	FN	0	0	0	0	0
Largemouth bass	EB	81	49 ± 7	17 ± 5	0	0
	GN	5	60 ± 28	20[a]	0	0
	FN	0	0	0	0	0
Pumpkinseed	EB	214	3 ± 2	0	0	0
	GN	1	0	0	0	0
	FN	1	0	0	0	0
Yellow perch	EB	449	1[a]	0	0	0
	GN	34	3[a]	0	0	0
	FN	3	0	0	0	0

[a] Sample size was insufficient to calculate confidence intervals

Black Crappie

Big Lake black crappie ranged from 72 to 190 mm TL (age 1+ to 6+). Few small, young fish were captured, whereas individuals measuring ~ 130 to 150 mm TL (age 3+ to 4+) were dominant (Figure 2). This differs from anecdotal reports that catches of much larger (~ 200 – 350 mm TL) black crappie were common in the 1980's (Curt Kraemer, WDFW, personal communication). A rapid decline in the numbers of fish older than age 4+ or greater than 150 mm TL (Table 6, Figure 2) suggests unusually high natural mortality, excessive angler harvest, or simply that the fish are not reaching their full growth potential. Growth of black crappie in Big Lake was slow when compared to black crappie statewide (Table 6), and their relative weights were consistent with or below the averages for black crappie from up to 25 western Washington warmwater lakes (Figure 3).

Table 6. Age and growth of black crappie (*Pomoxis nigromaculatus*) captured at Big Lake (Skagit County) during summer 1996. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age					
		1	2	3	4	5	6
1996	7	37.7	80.8				
		62.1	93.3				
1995	8	35.4	70.0	107.4			
		61.6	87.5	115.7			
1994	8	35.9	63.6	110.1	135.8		
		62.8	84.3	120.4	140.2		
1993	5	47.4	70.2	100.8	139.4	161.1	
		73.2	91.6	116.2	147.2	164.7	
1992	3	42.4	61.9	94.4	129.0	154.9	170.2
		69.3	85.2	111.6	139.7	160.7	173.1
	Overall mean	42.6	69.3	103.2	134.7	158.0	170.2
	Weighted mean	65.4	88.4	116.8	142.3	163.2	173.1
	State average	46	111.2	156.7	183.4	220	

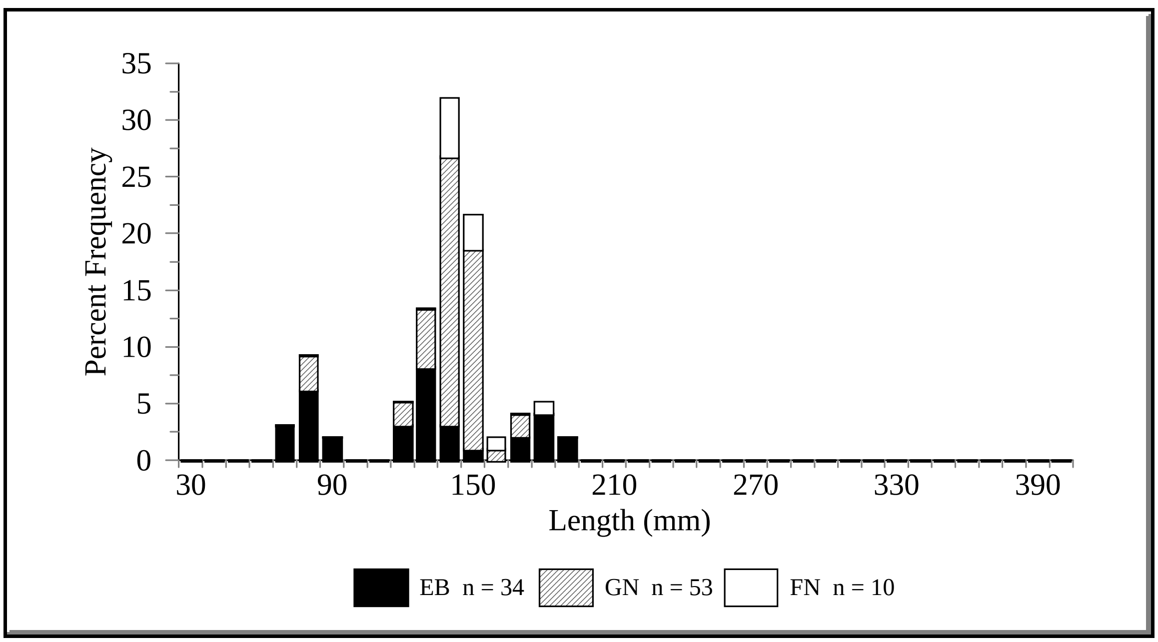

Figure 2. Length frequency histogram of black crappie sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

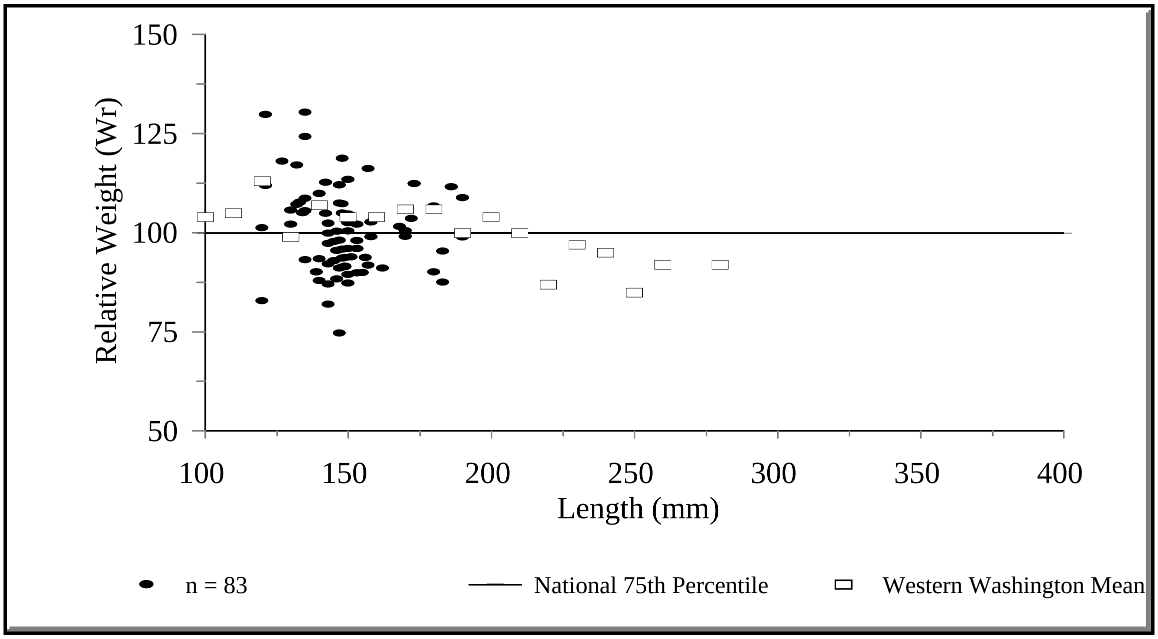

Figure 3. Relationship between total length and relative weight (Wr) of black crappie from Big Lake (Skagit County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Brown Bullhead

Brown bullhead in Big Lake ranged from 139 to 386 mm TL. The dominant size classes were between 330 and 380 mm TL (Figure 4). These fish were not aged. The relative weights were variable, but generally low by national standards (Figure 5).

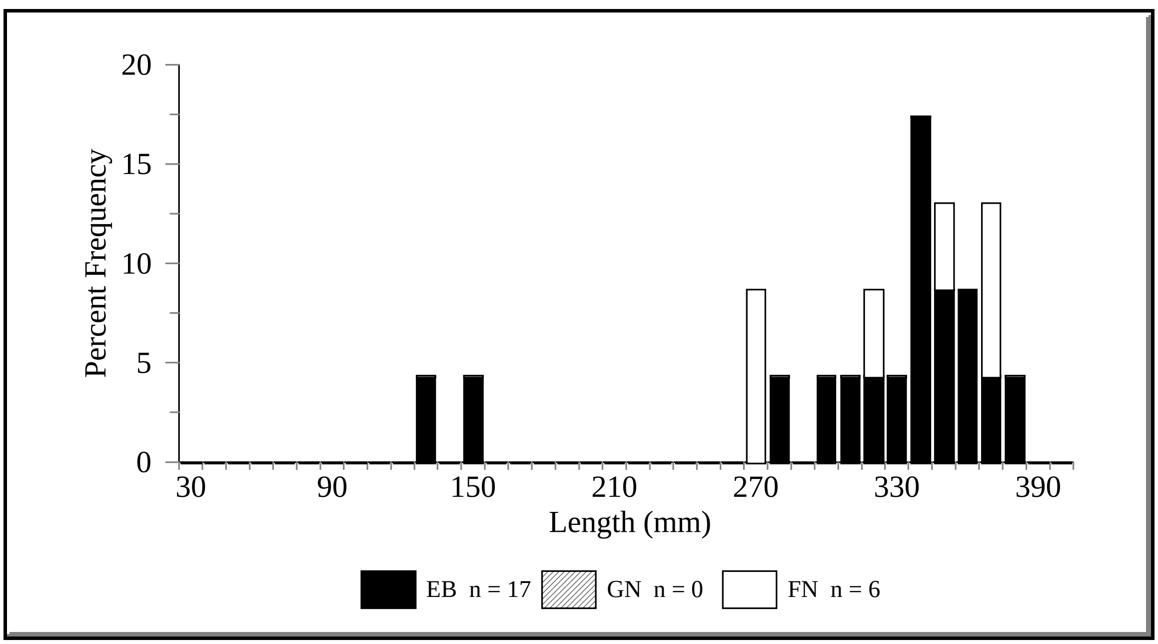

Figure 4. Length frequency histogram of brown bullhead sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

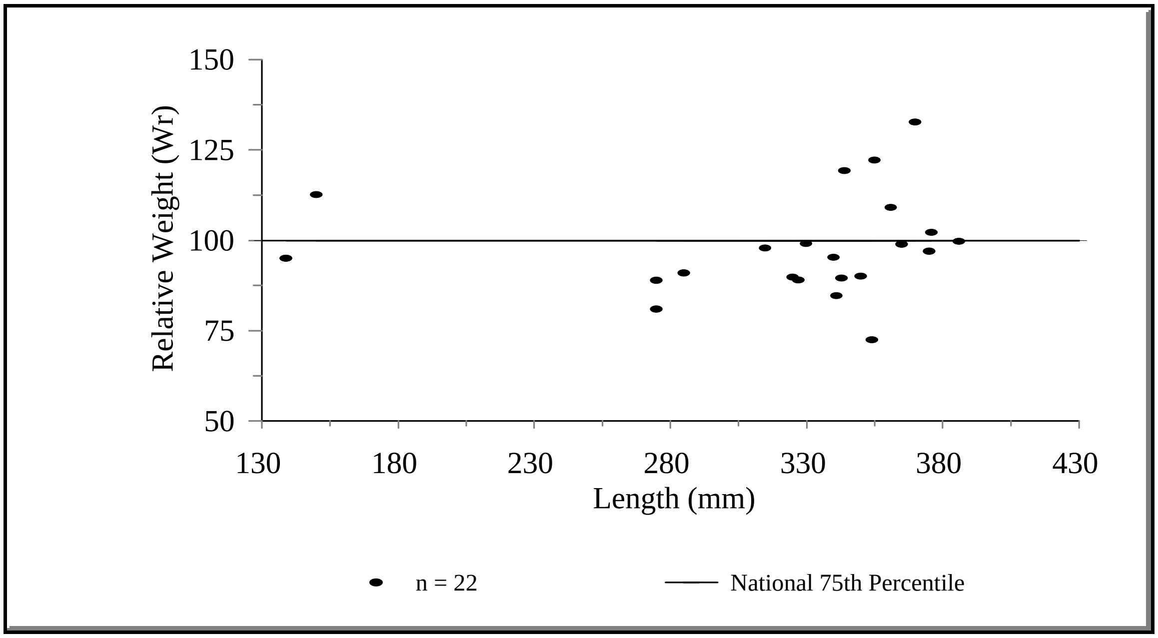

Figure 5. Relationship between total length and relative weight (Wr) of brown bullhead from Big Lake (Skagit County) compared with the national 75th percentile.

Largemouth Bass

Big Lake largemouth bass ranged from 21 to 488 mm TL (age 0+ to 12+). A rapid decline in the numbers of fish older than age 3+ or greater than 160 mm TL (Table 7, Figure 6) suggests unusually high natural mortality, excessive angler harvest, or simply that the fish are not reaching their full growth potential. Yet the size structure of largemouth bass, as indicated by their PSD and RSD-P (Table 5), suggests a balanced condition in the lake (Gabelhouse 1984; Willis et al. 1993). With the exception of their first year, growth of Big Lake largemouth bass was slow when compared to other western Washington fish (Table 7). Relative weights were consistent with, or above, the national standard for the species. However, when compared to largemouth bass from up to 25 western Washington warmwater lakes, the relative weights were similar or below average (Figure 7).

Table 7. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Big Lake (Skagit County) during summer 1996. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age 1	2	3	4	5	6	7	8	9	10	11	12
1996	29	74.4	132.9										
		86.4	137.8										
1995	23	57.9	123.4	159.7									
		71.6	129.8	162.2									
1994	5	60.0	109.4	156.0	186.3								
		74.3	118.9	161.0	188.4								
1993	8	61.9	115.9	166.4	202.9	227.0							
		76.9	126.6	173.0	206.6	228.8							
1992	12	66.5	108.9	152.8	202.9	236.1	265.2						
		81.9	121.3	162.1	208.7	239.6	266.6						
1991	9	61.9	103.1	142.7	183.1	225.7	261.3	285.0					
		77.9	116.3	153.3	191.1	230.9	264.2	286.4					
1990	10	54.7	94.5	128.7	173.0	207.7	245.8	275.5	297.8				
		71.2	108.4	140.4	182.0	214.4	250.1	277.9	298.8				
1989	6	54.5	102.9	156.7	204.6	249.9	289.9	323.7	347.5	368.9			
		71.6	117.6	168.5	214.0	256.9	294.8	326.8	349.4	369.7			
1988	6	55.0	95.5	143.8	187.4	225.4	262.5	301.1	337.7	360.6	377.3		
		72.2	110.7	156.5	197.9	234.0	269.2	305.9	340.6	362.4	378.2		
1987	8	52.8	91.3	130.1	164.6	199.1	226.7	260.8	285.1	318.6	341.4	356.9	
		70.0	106.4	143.1	175.9	208.5	234.6	266.9	289.8	321.6	343.2	357.8	
1986	1	62.6	120.0	161.8	203.6	247.9	287.1	315.8	336.6	401.9	428.0	459.3	475.0
		80.1	135.1	175.2	215.2	257.8	295.3	322.8	342.8	405.4	430.4	460.5	475.5
Overall mean		59.7	108.9	149.9	189.8	227.4	262.6	293.6	320.9	362.5	382.2	408.1	475.0
Weighted mean		75.7	124.2	158.2	195.9	230.0	262.2	290.3	315.8	351.0	363.0	369.2	475.5
Western WA average		60.4	145.5	222.2	261.1	289.3	319	367.8	396	439.9	484.6	471.7	495.6

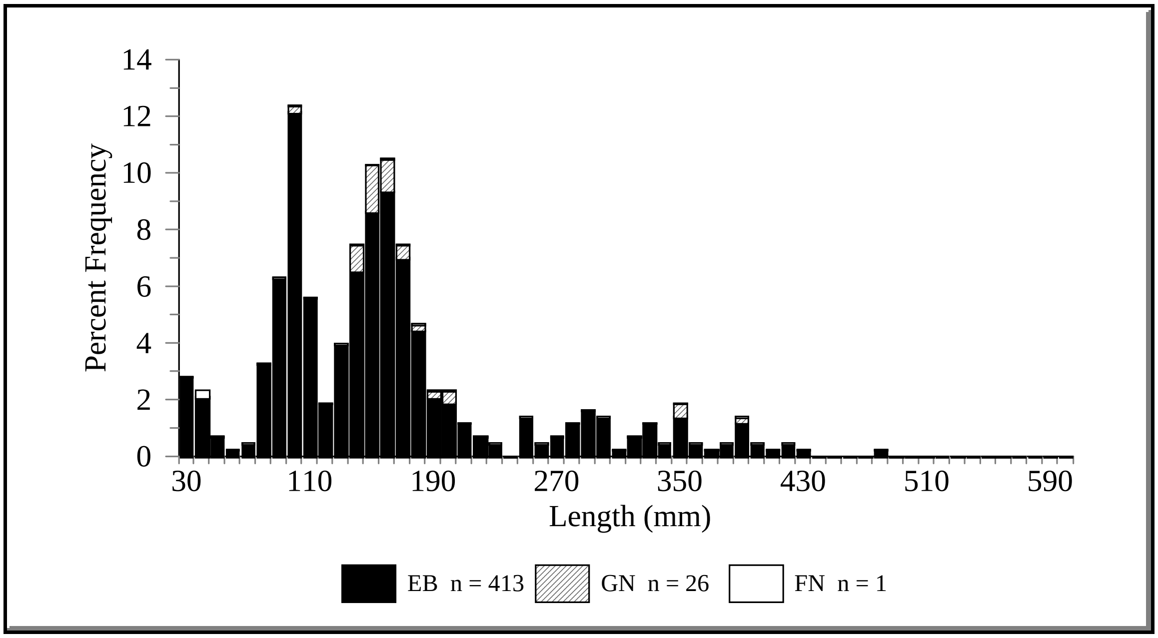

Figure 6. Length frequency histogram of largemouth bass sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

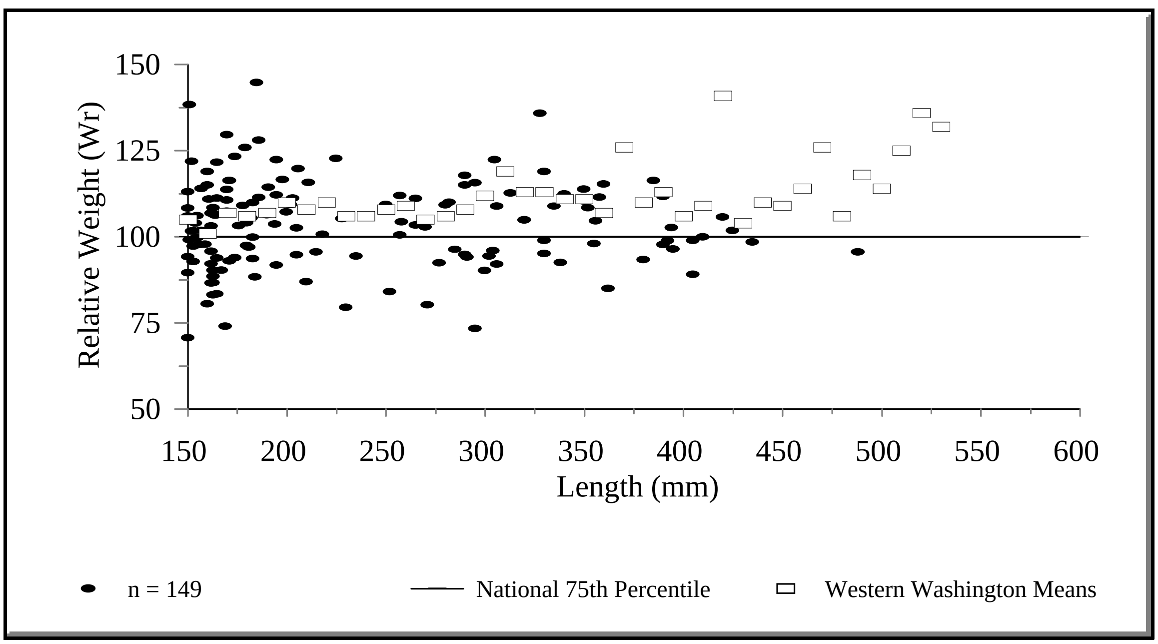

Figure 7. Relationship between total length and relative weight (Wr) of largemouth bass from Big Lake (Skagit County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Pumpkinseed

Pumpkinseed in Big Lake ranged from 50 to 160 mm TL (age 1+ to 6+). Pumpkinseed displayed variable year-class strength; the intermediate age/size classes were dominant (Table 8, Figure 8). Growth of the Big Lake fish was consistent with pumpkinseed statewide (Table 8), and their relative weights were generally well above average (Figure 9).

Table 8. Age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Big Lake (Skagit County) during summer 1996. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age					
		1	2	3	4	5	6
1996	4	62.7	82.0				
		71.4	85.6				
1995	13	49.4	73.0	95.6			
		63.2	81.6	99.1			
1994	14	43.4	70.2	94.2	115.6		
		60.1	81.7	101.0	118.4		
1993	7	36.1	63.6	96.9	123.7	138.9	
		55.0	77.8	105.5	127.8	140.5	
1992	2	38.9	61.3	85.6	105.4	127.2	145.7
		57.6	76.3	96.6	113.1	131.3	146.8
	Overall mean	47.5	70.0	93.1	114.9	133.1	145.7
	Weighted mean	61.6	81.1	100.9	120.8	138.5	146.8
	State average	23.6	72.1	101.6	122.7	139.4	

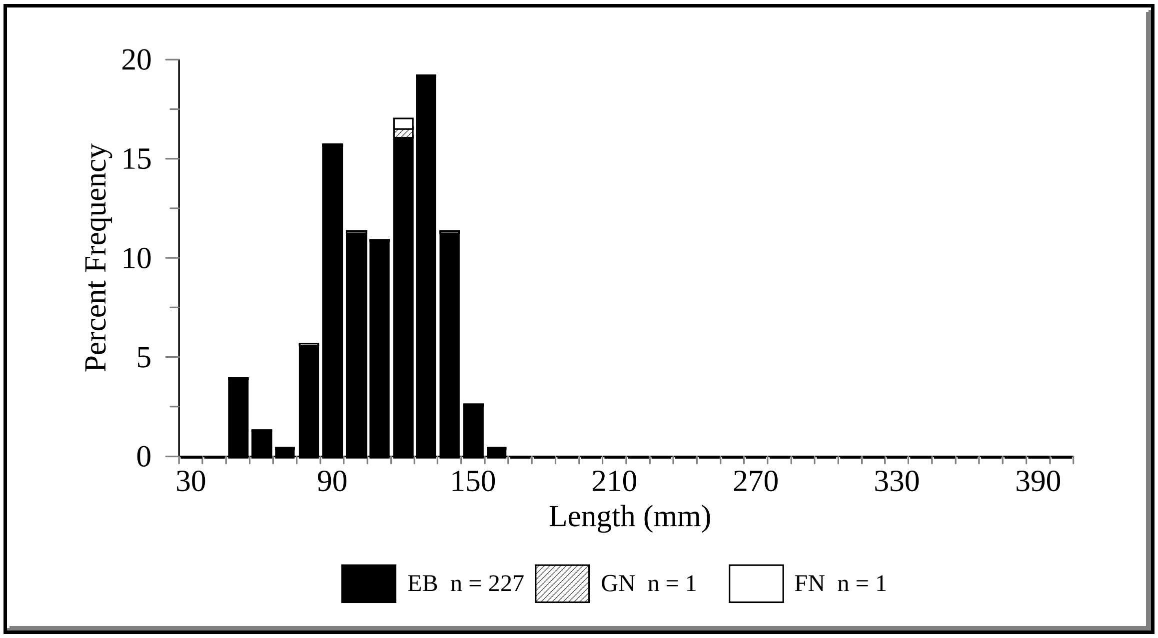

Figure 8. Length frequency histogram of pumpkinseed sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

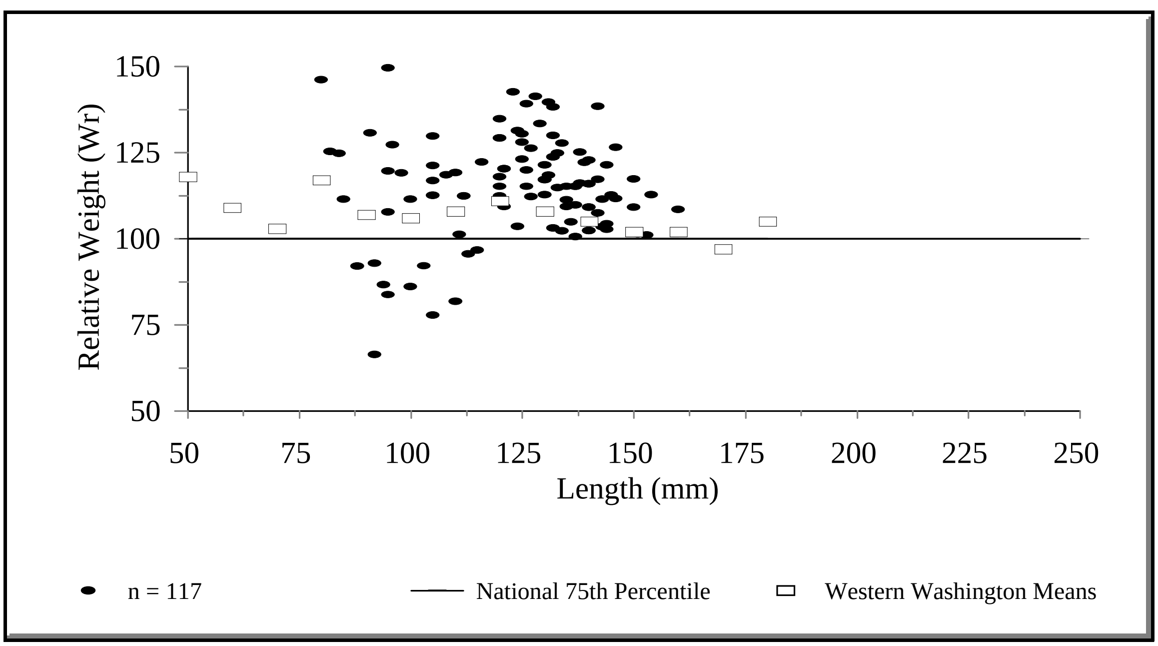

Figure 9. Relationship between total length and relative weight (Wr) of pumpkinseed from Big Lake (Skagit County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Yellow Perch

Yellow perch ranged from 32 to 247 mm TL (age 0+ to 8+). The 1995 and 1996 year-classes were dominant (Table 9), as indicated by the length frequency distribution (Figure 10). After their second year, growth of Big Lake yellow perch slowed down below that of yellow perch statewide (Table 9); however, their relative weights were above average when compared to yellow perch from up to 25 western Washington warmwater lakes (Figure 11).

Table 9. Age and growth of yellow perch (*Perca flavescens*) captured at Big Lake (Skagit County) during summer 1996. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age							
		1	2	3	4	5	6	7	8
1996	16	65.2	97.0						
		80.1	104.5						
1995	14	66.9	105.1	129.3					
		83.5	113.9	133.2					
1994	9	67.4	107.4	139.8	160.4				
		86.0	119.1	146.0	163.1				
1993	7	65.5	100.2	126.8	148.9	169.5			
		84.9	113.9	136.2	154.8	172.0			
1992	3	65.9	91.1	123.3	156.8	181.6	196.9		
		86.5	108.0	135.5	164.3	185.5	198.6		
1991	2	58.7	82.9	127.8	155.4	176.1	192.2	202.5	
		80.6	101.5	140.2	163.9	181.8	195.7	204.6	
1990	1	59.3	86.5	121.0	148.2	192.7	210.0	222.3	232.2
		82.1	106.0	136.3	160.2	199.3	214.5	225.3	234.0
Overall mean		65.8	95.7	128.0	153.9	179.9	199.7	212.4	232.2
Weighted mean		83.6	110.9	137.7	160.6	178.7	200.3	211.5	234.0
State average		59.7	119.9	152.1	192.5	206			

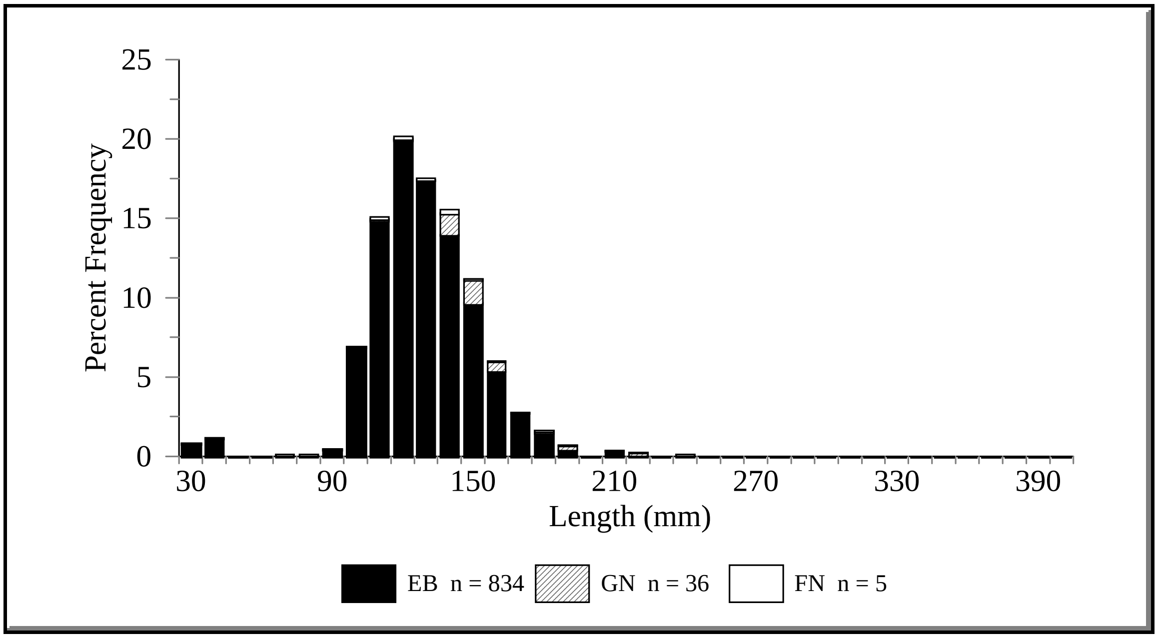

Figure 10. Length frequency histogram of yellow perch sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

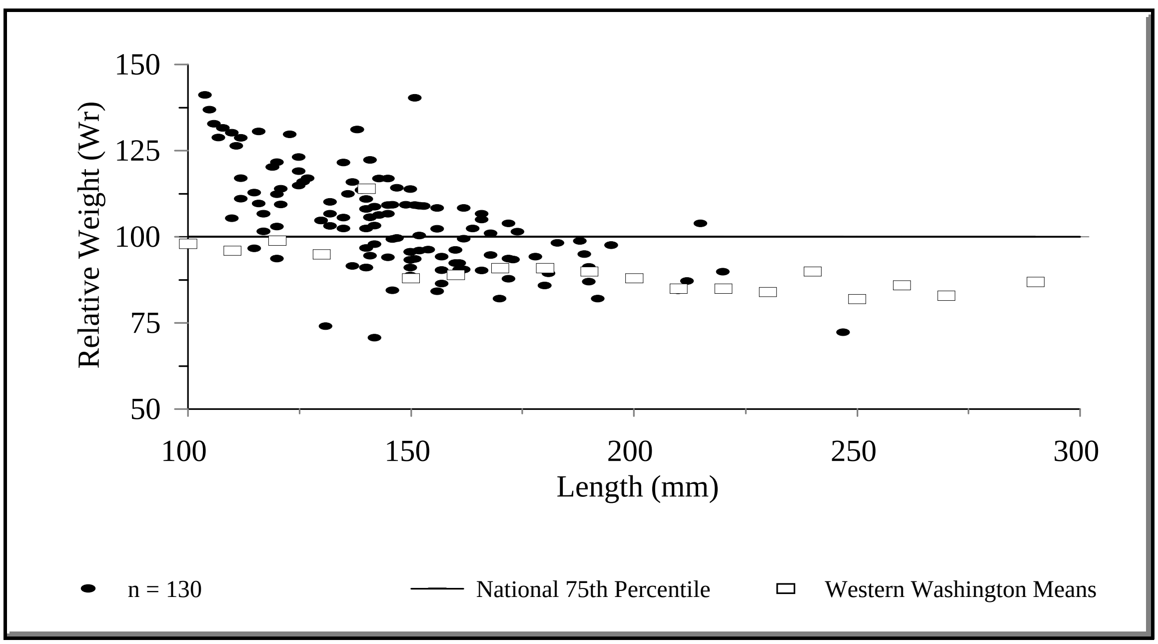

Figure 11. Relationship between total length and relative weight (Wr) of yellow perch from Big Lake (Skagit County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Non-game Fish and Members of the Family Salmonidae

Largescale sucker comprised 31% of the biomass captured at Big Lake, but only 3% by number (Table 3). Several year-classes of largescale sucker were evident from their length frequency distribution (Figure 12); however, these fish were not aged. The smaller fish were captured while electrofishing only, whereas the larger fish were captured while gill netting (Figure 12).

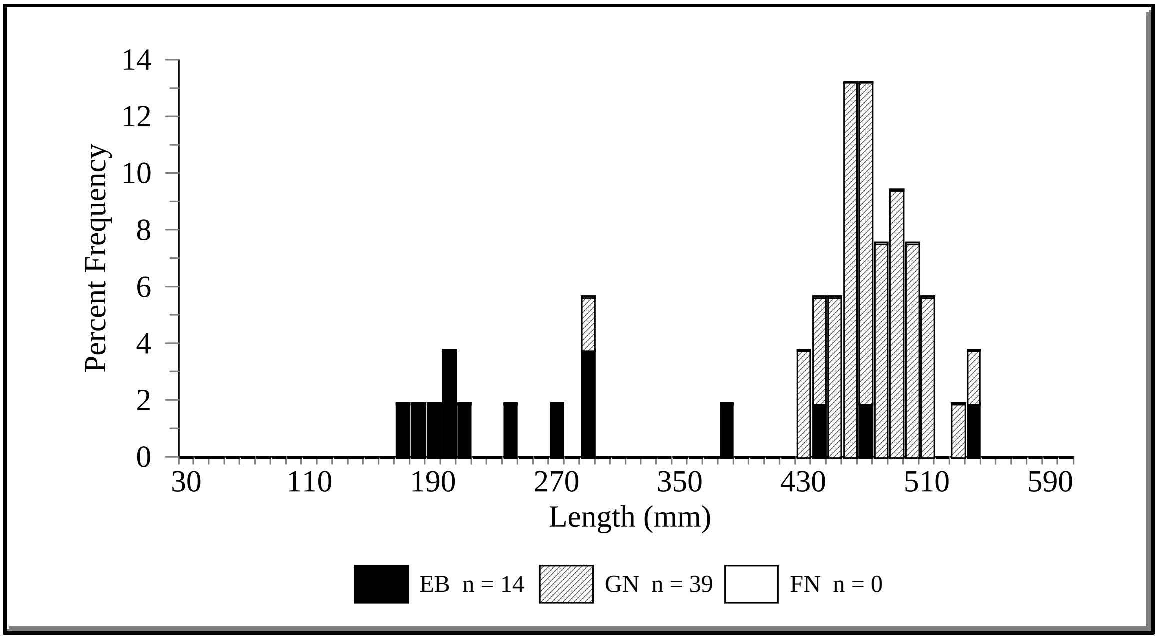

Figure 12. Length frequency histogram of largescale sucker (*Catostomus macrocheilus*) sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

Sculpin ranged from 29 to 155 mm TL (Figure 13) and comprised less than 1% of the biomass and number of fish captured at Big Lake (Table 3). Sculpin were captured while electrofishing only (Figure 13). One coho salmon was captured while gill netting at the north end of the lake. This fish measured 202 mm TL and weighed 88 g. Cutthroat trout ranged from 225 to 351 mm TL and comprised less than 2% of the biomass and number of fish captured (Table 3, Figure 14). The relative weights of cutthroat trout were variable but decreased with size (Figure 15). This differs from a previous survey that showed coho salmon and cutthroat trout were relatively abundant in Big Lake during spring 1978 (WDFW, unpublished data). Seasonal influences and gear-related biases can probably be attributed to the disparate catches of salmonids (Pope and Willis 1996).

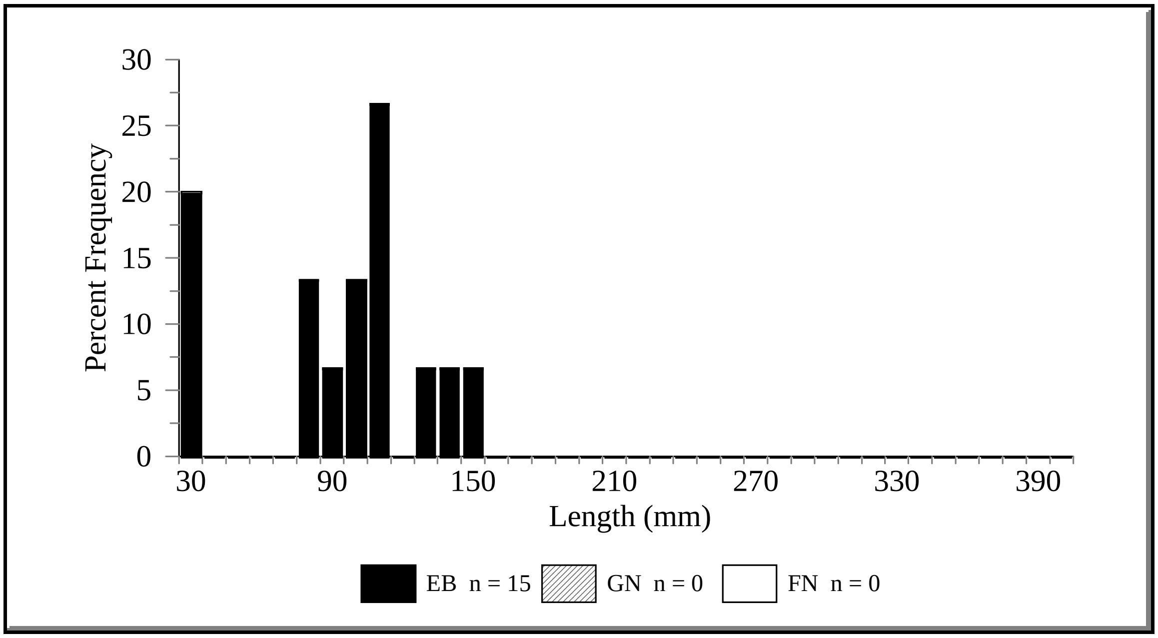

Figure 13. Length frequency histogram of sculpin (*Cottus* sp.) sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

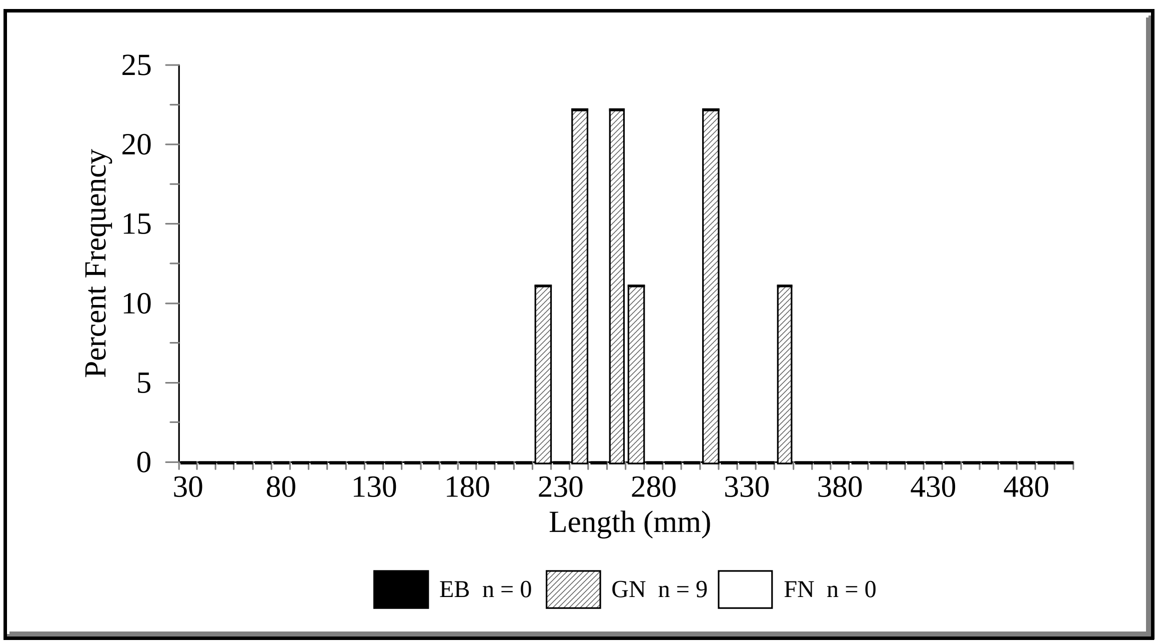

Figure 14. Length frequency histogram of cutthroat trout sampled from Big Lake (Skagit County) in summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

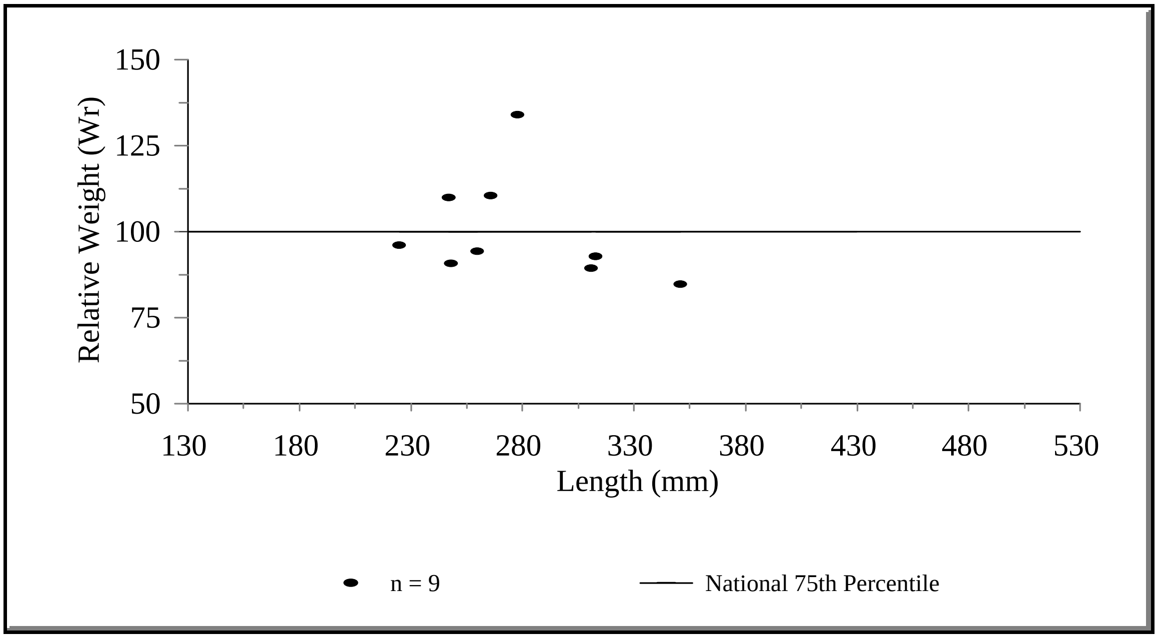

Figure 15. Relationship between total length and relative weight (Wr) of cutthroat trout from Big Lake (Skagit County) compared with the national 75th percentile.

Warmwater Enhancement Options

The clear potential for warmwater species impacting the native anadromous fishes of the Big Lake watershed precludes active management by the WDFW Warmwater Enhancement Program (WDFW 1999), especially given the historical importance of the salmonid fisheries at the lake (WDFW, unpublished data; Jim Johnston, WDFW, personal communication). However, the warmwater fishery at Big Lake is also notable (WDFW 1997; Anonymous 1999) and warrants further discussion.

Extensive aquatic plant cover is one possible cause of the diminished growth observed in the largemouth bass, black crappie, and yellow perch populations of Big Lake during summer 1997. For example, Hoyer and Canfield (1996) showed an inverse relationship between macrophyte abundance and growth of one- and two-year old largemouth bass. As macrophyte density increases, predator foraging efficiency decreases because of increased refuge available to prey. The increased survival of prey leads to greater population density (crowding) and more competition among these fish (Olson et al. 1998 and references therein). Thus, crowding of fish populations can result in slow growth as well (Swingle 1956). This was evident in the fish populations at Big Lake. Their size structures and growth patterns suggest that these fishes were not able to forage effectively, possibly due to overcrowding and competition with the dominant yellow perch, pumpkinseed, and smaller-sized largemouth bass.

Elimination of aquatic vegetation can affect the growth and condition of individuals, as well as the balance of a fish community. A recent study by Olson et al. (1998) showed that growth rates of certain age classes of largemouth bass and bluegill increased substantially by the mechanical removal of aquatic macrophytes from only 20% of the littoral zone. Other studies (Colle and Shireman 1980; Maceina et al. 1991) showed increases in growth and condition of warmwater fish species after removal of aquatic vegetation by grass carp (*Ctenopharyngodon idella*). Conversely, Silver Lake (Cowlitz County, Washington) yellow perch showed little difference in growth and condition before and after the total elimination of submersed aquatic vegetation by grass carp, whereas bluegill (*Lepomis macrochirus*) growth and condition decreased (Mueller 1998). However, removal of too much cover may shift the balance in a lake toward the predators by reducing prey refuge. In the short term, we would expect to see an increase in the numbers of large predators with a subsequent increase in production. In the long term, the result would be an unbalanced fish community with abundant, small predators and few, large prey fish (Swingle 1956; Davies and Rwangano 1991).

Most researchers agree that a low or moderate level of aquatic vegetation is better than none or too much (Savino and Stein 1982; Durocher et al. 1984; Wiley et al. 1984; Killgore et al. 1989; Davies and Rwangano 1991). For example, Wiley et al. (1984) showed a positive correlation between the concentration of aquatic plants and the production of both epiphytic invertebrates and forage fish such as bluegill, whereas largemouth bass production was reduced at both high and low concentrations of aquatic plants. If Sonar® treatments result in negative impacts to the warmwater fishery at Big Lake, because of the reduction or elimination of submersed aquatic vegetation, then remedial action by WDFW may be necessary. Management strategies that might improve the warmwater fishery at Big Lake include, but are not limited to, the following:

Conduct Follow-up Fisheries Survey

If the Sonar® treatments at Big Lake are successful, the subsequent changes in the aquatic plant community will undoubtedly affect the fish community. Whether this impacts the fisheries of Big Lake positively or negatively remains to be seen (see discussion above). Our results provide some baseline information necessary to monitor the long-term effects of the Sonar® treatments at Big Lake. However, without follow-up study, any impacts from applying the herbicide will remain enigmatic.

If Necessary, Change Existing Fishing Rules to Alter Size Structure of Largemouth Bass

Currently, a 305 – 381 mm (12 – 15”) TL slot limit on largemouth bass is in place at Big Lake. Under this rule, only fish less than 305 or greater than 381 mm TL may be kept. Big Lake anglers are allowed to harvest five fish daily, including no more than three over 381 mm (15”) TL. The main objective of a slot limit is to improve the size structure of largemouth bass. The electrofishing PSD and RSD-P values for Big Lake largemouth bass were within the stock density index ranges necessary for a balanced population (Gabelhouse 1984; Willis et al. 1993). Changes in the size structure of largemouth bass, resulting from the reduction or elimination of aquatic vegetation in Big Lake, may require implementing corrective length and bag limits on largemouth bass (sensu Willis 1989) to restore the population to its pre-treatment balance..

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

Mitigate Future Aquatic Vegetation Control Plans

An integrated aquatic plant management plan relies on the cooperative efforts of state, county, and local agencies (i.e., to be fully integrated implies interagency collaboration on such projects). Clear communication lines must be established between interested parties, with ample opportunity for review and comment by all those involved. Integrated aquatic plant management plans must take into consideration their potential impacts to fish and wildlife resources of the affected lakes. The reduction or elimination of aquatic vegetation using Sonar® will undoubtedly affect the fisheries of Big Lake. In the future, potential impacts to the state’s natural resources should be considered alongside the concerns of near-shore residents when developing an aquatic vegetation control plan.

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