

**1997 Horseshoe Lake Survey:
The Warmwater Fish Community Before
Chemical Precipitation of Phosphorus and
Increased Dilution of the Lake**

by

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Abstract

The warmwater fish community of Horseshoe Lake (Cowlitz/Clark County) was studied during late summer 1997 before the application of aluminum sulfate ('alum') and final upgrade to the lake's inlet pump station. In terms of biomass, the lake was dominated by non-game species, primarily largescale sucker and common carp. However, in terms of abundance, the lake was clearly dominated by juvenile largemouth bass. Catch rates for stock-size (varies by species) warmwater fish were below average while electrofishing yet above average when gill netting. Growth of warmwater fish was generally consistent with or below the state average for each species. Relative weight, an index of fish condition, was generally high indicating abundant forage. Traditional stock density indices suggest that Horseshoe Lake is naturally suited for a panfish fishery. Management strategies that might improve the warmwater fishery at Horseshoe Lake include reevaluating the aquatic plant control contingency plan, stocking tiger muskellunge to control forage fish and non-game species, changing fishing rules to increase the size structure of largemouth bass, and continued monitoring of the warmwater fish community. The baseline information presented here will be useful when monitoring the long-term effects of the chemical precipitation of phosphorus and increased dilution of Horseshoe Lake.

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Introduction and Background

Horseshoe Lake (Figure 1) is a narrow, man-made oxbow located along the North Fork Lewis River, just south of the City of Woodland, Washington. The aptly named lake was created in 1940 when the river channel was diverted during construction of U.S. Highway 99, now Interstate 5 (Wolcott 1973). Horseshoe Lake forms a natural boundary between Cowlitz and Clark counties; the county line runs down the middle of the shallow (mean and maximum depth = 3.5 and 7.2 m, respectively), eutrophic lake. It has no natural inlets or outlets. Freshwater has been pumped from the Lewis River into the north arm of Horseshoe Lake since 1957. Water exits the modest-size lake (~ 35 ha or 85 acres) through an outflow structure located at the south end and eventually discharges back into the Lewis River (Figure 1). Substantial water losses occur through evaporation and groundwater exfiltration (Welch et al. 1992).

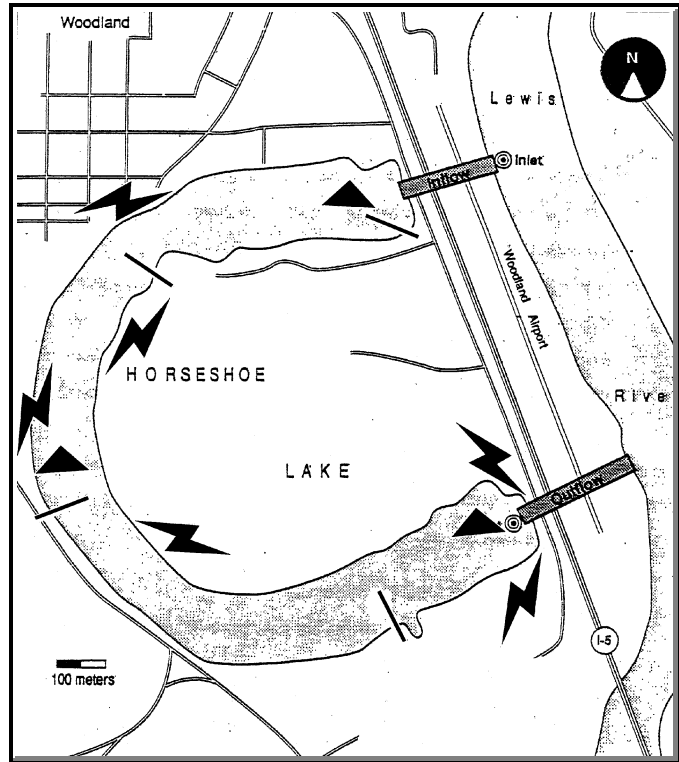


Figure 1. Map of Horseshoe Lake, Cowlitz/Clark County (redrawn from Welch et al. 1992), showing sampling locations. Bolts indicate sections of shoreline where electrofishing occurred. Bars extending into lake indicate placement of gill nets whereas triangles indicate water quality stations.

Surrounding land uses include recreation, private homes, light industry, and agriculture (Welch et al. 1992). The City of Woodland is directly north of the lake, whereas Horseshoe Lake Park runs along the city-side of the north arm. Although the City of Woodland manages the lake and park, the Washington Department of Transportation operates and maintains the pump station used to dilute the lake. Several upland homes occur along the outside bend to the midpoint of the lake. A meat packing plant is situated along the outside shoreline just south of the residential area. The inside point of the lake is natural and wooded. Recreation activities include swimming, small watercraft use, and sport fishing. The Washington Department of Fish and Wildlife (WDFW) releases several thousand hatchery trout into the lake each year.

Since its creation, Horseshoe Lake has been besieged with water quality problems (Welch et al. 1992). The oxbow became stagnant almost immediately after it was isolated from the Lewis River. In 1940, a culvert system was installed between the river and the lake to improve water quality and circulation until the first pump station was constructed in 1957. In 1960, the pump

station was upgraded to achieve an average annual discharge of 2,850 gpm. However, in 1970, the lake was declared polluted and unfit for bathing because of elevated coliform bacteria counts. Subsequently, in 1981, the pump station was upgraded again with flows increased to 3,000 gpm. For the next several years, intense summertime algal blooms were common at the lake.

Concerns from the Woodland community led to the development of a major lake restoration plan (Welch et al. 1992). Although several possible external sources of nutrients occur in the Horseshoe Lake watershed (e.g., two storm drains, an abandoned landfill, a meat packing plant, and two defunct saw mills), internal loading of phosphorus was identified as the culprit fueling the algal growth (Welch et al. 1992). Thus, Welch et al. (1992) recommended chemical precipitation of phosphorus using aluminum sulfate (a.k.a. 'alum') with a buffer of sodium aluminate. Furthermore, Welch et al. (1992) recommended increased dilution of the lake by upgrading the pump station to achieve a discharge of 6,000 gpm.

Several years passed before the recommendations of Welch et al. (1992) were implemented. In spring 1998, Horseshoe Lake received a buffered alum treatment based on a predetermined dosage rate of 70 mg/l, with a mixing ratio of 2.3 parts aluminum sulfate to 1 part sodium aluminate. During March 23 - 25, a private contractor applied 25,863 gallons of liquid aluminum sulfate and 11,193 gallons of liquid sodium aluminate at a cost of approximately \$100,000 (Entranco 1999). In October 1998, the existing 30-hp water pump was replaced with a new 60-hp motor and pump impeller, including an updated electrical control system, that increased the dilution rate by 100%, from 3,000 to 6,000 gpm (Entranco 1999).

Preliminary results indicate that the buffered alum treatment at Horseshoe Lake was successful; however, little information exists concerning the impacts from increased dilution of the lake (Entranco 1999). If the efficacy of the alum treatment continues, the subsequent inactivation of phosphorus will undoubtedly affect the plankton community. Reductions in phosphorus loading can result in pronounced decreases in algal abundance (EPA 1995; KCM 1995; Scheffer 1998; Entranco 1999). Changes at higher trophic levels, from zooplankton to planktivorous fishes, will likely ensue. Whether this impacts the fisheries of Horseshoe Lake remains to be seen. For these reasons, it is important to gather baseline information and carefully review all proposals to limit or control nutrient inputs at a given lake, especially when the lake supports popular fisheries. In an effort to assess its warmwater fish community, WDFW personnel conducted a fisheries survey at Horseshoe Lake during late summer 1997. Since it was gathered before the application of alum and the last upgrade to the pump station, the baseline information presented here will be useful when monitoring the long-term effects of the chemical precipitation of phosphorus and increased dilution of the lake.

Materials and Methods

Horseshoe Lake was surveyed by a three-person team during August 11 - 14, 1997. Fish were captured using two sampling techniques: electrofishing and gill netting. The electrofishing unit consisted of a 5.5 m Smith-Root 5.0 GPP 'shock boat' set to pulsed DC at 120 Hz and 3 to 4 amps power. Experimental gill nets (45.7 m long \times 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 27 consecutively numbered sections of about 183 m each (determined visually from a USGS map in Wolcott 1973). Using the random numbers table from Zar (1984), 10 of these sections were then randomly selected as sampling locations (Figure 1). In order to reduce bias between capture techniques, the sampling time for each gear type was standardized to a ratio of 1:1 (Fletcher et al. 1993). One unit of electrofishing time equal to three 600-second sections was applied for each unit of gill netting, which equaled 24 hours soak time or two 'net nights'. Thus, three sections were electrofished for every two sections gill netted. Sampling occurred during evening hours to maximize the type and number of fish captured. Nighttime electrofishing occurred along six sections or 22.2% (~ 1.1 km) of the available shoreline. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of 18.3 m/minute. Total 'pedal down' time was 3,645 seconds. Gill nets were set overnight at four locations (= 4 net nights). The small-mesh end was attached onshore while the large-mesh end was anchored offshore perpendicular to the shoreline.

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, given the emphasis of this study on warmwater species, age and growth were not assessed for salmonid and non-game fish.

Water quality data was collected during midday from three locations on August 14, 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).

Table 1. Water quality from three locations (north end, mid-lake, and south end) at Horseshoe Lake (Cowlitz/Clark County). Samples were collected midday on August 14, 1997.

Location	Secchi (m)	Parameter					
		Depth (m)	DO	Temp (°C)	pH	Conductance	Redox
North end	1.9	1	9.05	24.35	8.45	50	383
		2	9.40	23.52	8.60	53	383
		3	8.60	22.41	7.82	50	416
		4	7.50	21.86	7.37	55	439
		5	7.50	21.75	7.10	50	448
		6	4.50	21.52	6.76	52	469
Mid-lake	1.5	1	9.25	24.14	9.01	54	366
		2	9.44	23.29	8.94	44	370
		3	8.40	22.90	8.17	51	398
		4	5.75	22.63	7.11	51	448
South end	1.7	1	10.22	25.77	9.31	56	353
		2	10.62	24.95	9.37	51	351
		2.5	10.46	24.95	9.34	56	354

Data Analysis

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

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 $\times 100$. 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 $\times 100$. Young-of-year or small juveniles are often not considered

when analyzing species composition because large fluctuations in their numbers may distort results (Fletcher et al. 1993). For example, the overall length frequency distribution of fish species may suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes. However, many young-of-year and small juveniles would be subject to high mortality during their first winter (Chew 1974), resulting in a different size distribution the following year. Still, the presence of these fish in the system relates directly to fecundity and inter- and intraspecific competition at lower trophic levels (Olson et al. 1995). For these reasons, and since their relative contribution to the total biomass captured was small, we chose to include young-of-year and small juveniles when analyzing species composition data.

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

Catch per unit effort (CPUE) by gear type was determined for all species (number of fish/hour electrofishing and number of fish/net night). Only stock size fish and larger were used to determine CPUE for warmwater species and salmonids, whereas CPUE for 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 $\pm t_{(\alpha, N-1)} \times SE$, where t = Student's t for α confidence level with $N-1$ degrees of freedom (two-tailed) and SE = standard error of the mean. Since it is standardized, CPUE is a useful index for comparing relative abundance of stocks between lakes. The CPUE values from this study were compared to the mean values from up to 12 western Washington warmwater lakes (Table 3) sampled during 1997 and 1998 (Scott Bonar, WDFW, unpublished data).

Table 2. Length categories for cold- and warmwater fish species used to calculate stock density indices (PSD and RSD; Gabelhouse 1984) of fish captured at Horseshoe Lake (Cowlitz/Clark County) during 1996 and 1997. Measurements are minimum total lengths (mm) for each category (Anderson and Neumann 1996).

Type of fish	Size				
	Stock	Quality	Preferred	Memorable	Trophy
Black crappie	130	200	250	300	380
Bluegill	80	150	200	250	300
Brown bullhead ^a	130	200	280	360	430
Brown trout	150	230	300	380	460
Common carp ^a	280	410	530	660	840
Cutthroat trout	200	350	450	600	750
Largemouth bass	200	300	380	510	630
Yellow bullhead ^a	100	180	230	280	360
Yellow perch	130	200	250	300	380

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

Table 3. Mean catch per unit effort (# fish/hour and # fish/net night) for stock-size warmwater fishes sampled from western Washington lakes while electrofishing and gill netting during 1997 and 1998 (Scott Bonar, WDFW, unpublished data). Values in parentheses are number of lakes averaged. BBH = brown bullhead, BC = black crappie, BG = bluegill, LMB = largemouth bass, and YP = yellow perch. EB = electrofishing boat, GN = gill net.

Gear type	BBH	BC	BG	LMB	YP
EB	7.8 (10)	9.6 (4)	169.1 (7)	41.6 (12)	97.5 (8)
GN	14.4 (7)	4.2 (3)	1.6 (4)	1.9 (8)	13.7 (6)

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 \times 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 $\times 100$. For example, RSD P was the percentage of stock length fish that also were longer than preferred length, RSD M, the percentage of stock length fish that also were longer than memorable length, and so on.

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

Table 4. Stock density index ranges for largemouth bass and bluegill under three commonly implemented management strategies (from Willis et al. 1993). PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), and memorable length fish (RSD-M).

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

Table 5. Mean stock density indices for warmwater fishes sampled from western Washington lakes during 1997 and 1998 (Scott Bonar, WDFW, unpublished data). PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T). EB = electrofishing boat, GN = gill net.

Species	Gear type	No. lakes	PSD	RSD-P	RSD-M	RSD-T
Black crappie	EB	3	5	0	0	0
Bluegill	EB	9	16	0	0	0
Brown bullhead	EB	3	11	2	0	0
	GN	5	12	1	0	0
Largemouth bass	EB	12	29	13	0	0
Yellow perch	EB	12	20	2	0	0
	GN	12	53	1	0	0

Age and growth of warmwater fishes in Horseshoe 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 Horseshoe 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). Trends in the dispersion of points on the relative weight graph have been used to infer ecological dynamics of fish populations (Blackwell et al. *in press*). For example, a decrease in relative weight with increasing total length often occurs where competition is high among larger size classes. Conversely, low relative weights in small fish suggest competition and crowding among smaller size classes. Following Murphy and Willis (1991), the index was calculated as $W_r = W/W_s \times 100$, where W is the weight (g) of an individual fish and W_s is the standard weight of a fish of the same total length (mm). W_s is calculated from a standard \log_{10} weight- \log_{10} length relationship defined for the species of interest. The parameters for the W_s equations of many cold- and warmwater fish species, including the minimum length recommendations for their application, are listed in Anderson and Neumann (1996). With the exception of non-game fish, the W_r values from this study were compared to the national standard ($W_r = 100$) and, where available, the mean W_r values from up to 25 western Washington warmwater lakes sampled during 1997 and 1998 (Steve Caromile, WDFW, unpublished data).

Results and Discussion

Species Composition

During late summer 1997, in terms of biomass, our catch was dominated by largescale sucker (*Catostomus macrocheilus*) (26.2%), largemouth bass (*Micropterus salmoides*) (22.2%), cutthroat trout (*Oncorhynchus clarki*) (17.7%), and common carp (*Cyprinus carpio*) (15.0%) (Table 6). However, in terms of abundance, our catch was clearly dominated by largemouth bass (69.9%), and to a lesser degree, bluegill (*Lepomis macrochirus*) (12.3%) and yellow perch (*Perca flavescens*) (7.2%) (Table 6). This was due to the great number of juvenile largemouth bass observed (see Figure 6). Other species, including black crappie (*Pomoxis nigromaculatus*), brown bullhead (*Ameiurus nebulosus*), brown trout (*Salmo trutta*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), sculpin (*Cottus* sp.), and yellow bullhead (*Ameiurus natalis*) comprised less than 6% of the biomass and number of fish captured collectively (Table 6).

Table 6. Species composition by weight (kg) and number of fish captured at Horseshoe Lake (Cowlitz/Clark County) during a late summer 1997 survey of warmwater fish.

Type of fish	Species composition				Size range (mm TL)
	by weight		by number		
	(kg)	(%)	(#)	(%)	
Black crappie (<i>Pomoxis nigromaculatus</i>)	0.170	0.201	1	0.064	215
Bluegill (<i>Lepomis macrochirus</i>)	3.771	4.469	194	12.333	33 – 153
Brown bullhead (<i>Ameiurus nebulosus</i>)	1.847	2.189	18	1.144	153 – 219
Brown trout (<i>Salmo trutta</i>)	1.374	1.629	8	0.509	240 – 258
Common carp (<i>Cyprinus carpio</i>)	12.678	15.027	24	1.526	92 – 630
Cutthroat trout (<i>Oncorhynchus clarki</i>)	14.968	17.742	76	4.832	243 – 300
Largemouth bass (<i>Micropterus salmoides</i>)	18.759	22.234	1,100	69.930	48 – 348
Largescale sucker (<i>Catostomus macrocheilus</i>)	22.110	26.206	19	1.208	443 – 546
Northern pikeminnow (<i>Ptychocheilus oregonensis</i>)	0.191	0.226	1	0.064	276
Peamouth (<i>Mylocheilus caurinus</i>)	0.845	1.002	6	0.381	180 – 267
Sculpin (<i>Cottus</i> sp.)	0.120	0.142	7	0.445	65 – 140
Yellow bullhead (<i>Ameiurus natalis</i>)	0.326	0.386	6	0.381	137 – 211
Yellow perch (<i>Perca flavescens</i>)	7.209	8.545	113	7.184	77 – 246
Total	84.369		1,573		

CPUE

Electrofishing CPUE values (#fish/hour) for warmwater species (Table 7) were below average (Table 3). Conversely, except for brown bullhead, gill netting CPUE values (# fish/net night) for warmwater species (Table 7) were above average (Table 3). Electrofishing catch rates were

highest for stock-size bluegill (100.86), and to a lesser degree, largemouth bass (16.57), sculpin (7.13), and yellow perch (5.35). While gill netting, catch rates were highest for stock-size yellow perch (13.75), and to a lesser degree, bluegill (8.25), largescale sucker (4.75), and brown bullhead (4.25). For species other than the warmwater variety, catch rates were highest for cutthroat trout (19.00 fish/net night), sculpin, and largescale sucker.

Table 7. 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 Horseshoe Lake (Cowlitz/Clark County) while electrofishing and gill netting during late summer 1997.

Type of fish	Gear type			
	Electrofishing (# fish/hour)	Shock sites	Gill netting (# fish/net night)	Net nights
Black crappie	None captured	5	0.25 ^a	4
Bluegill	100.86 ± 40.93	5	8.25 ± 5.62	4
Brown bullhead	1.19 ^a	5	4.25 ± 1.6	4
Brown trout	None captured	5	2.00 ± 1.48	4
Common carp	1.77 ^a	5	0.25 ^a	4
Cutthroat trout	None captured	5	19.00 ± 13.69	4
Largemouth bass	16.57 ^a	5	2.25 ± 1.32	4
Largescale sucker	None captured	5	4.75 ± 3.64	4
Northern pikeminnow	None captured	5	0.25 ^a	4
Peamouth	None captured	5	1.50 ± 0.83	4
Sculpin	7.13 ± 4.45	5	0.25 ^a	4
Yellow bullhead	0.59 ^a	5	None captured	4
Yellow perch	5.35 ± 2.53	5	13.75 ± 6.91	4

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

Stock Density Indices

Few quality-size warmwater fish were captured (Table 8). The PSD values for bluegill, brown bullhead, and largemouth bass (2, 0, and 18, respectively) (Table 8) were low when compared to the averages for these species (16, 11, and 29, respectively) from up to 12 western Washington lakes. However, the gill netting PSD for yellow perch (56) was consistent with the average (53) from 12 western Washington lakes (Table 5). Except for bluegill, largemouth bass, and yellow perch, the PSD values from this study 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 8. Stock density indices for warmwater fishes collected from Horseshoe Lake (Cowlitz/Clark County) while electrofishing and gill netting during late 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 boat and GN = gill netting.

Type of fish	Gear type	# Stock length fish	PSD	RSD-P	RSD-M	RSD-T
Black crappie	EB	0	0	0	0	0
	GN	1	100 ^a	0	0	0
Bluegill	EB	106	2 ± 2	0	0	0
	GN	33	0	0	0	0
Brown bullhead	EB	1	0	0	0	0
	GN	17	0	0	0	0
Brown trout	EB	0	0	0	0	0
	GN	8	100 ^a	0	0	0
Common carp	EB	3	67 ± 35	67 ± 35	0	0
	GN	1	100 ^a	100 ^a	0	0
Cutthroat trout	EB	0	0	0	0	0
	GN	76	0	0	0	0
Largemouth bass	EB	28	18 ± 9	0	0	0
	GN	9	0	0	0	0
Yellow perch	EB	5	60 ± 28	0	0	0
	GN	55	56 ± 9	0	0	0

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

Black Crappie

One quality-size black crappie was captured (Tables 7 and 8). The fish measured 215 mm TL, weighed 170 g, and was aged 1+ (Table 6). Using Lee's modification of the direct proportion method, the fish measured 77.6 mm at first annulus formation. Using the direct proportion method, the fish measured 50.8 mm. This was high when compared to the state average (46.0 mm using the direct proportion method) for the species. Its relative weight was about 110, which was also high when compared to the average for black crappie (~ 100) from up to 25 western Washington warmwater lakes (Steve Caromile, WDFW, unpublished data).

Bluegill

Bluegill ranged from 33 to 153 mm TL (age 0+ to 6+). The 1995 and 1996 year-classes (age 1+ and 2+ fish) were dominant (Table 9), as indicated by the length frequency distribution (Figure 2). The 1993 year-class was not observed. Up to age 2+, growth of Horseshoe Lake bluegill was fairly consistent with bluegill statewide; however, after their second year, growth was below average. With few exceptions, relative weights were high when compared to the national standard and average for bluegill from up to 25 western Washington warmwater lakes (Figure 3).

Table 9. Age and growth of bluegill (*Lepomis macrochirus*) captured at Horseshoe Lake (Cowlitz/Clark County) during late summer 1997. 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	15	49.2					
		58.1					
1995	16	41.0	94.0				
		54.0	98.0				
1994	1	81.0	113.7	123.6			
		89.0	116.8	125.3			
1993	0						
1992	2	40.2	69.0	96.9	117.0	137.8	
		54.7	79.4	103.5	120.9	138.8	
1991	2	55.8	90.5	107.8	122.1	137.2	145.5
		68.4	98.5	113.6	126.0	139.1	146.3
Overall mean		53.4	91.8	109.4	119.5	137.5	145.5
Weighted mean		57.5	97.2	111.9	123.4	138.9	146.3
State average		37.3	96.8	132.1	148.3	169.9	200.9

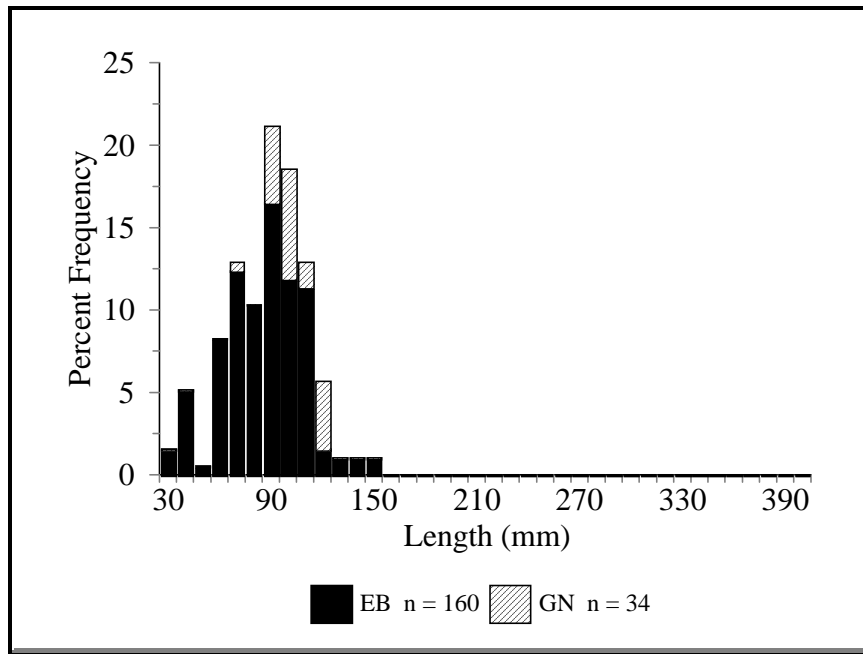


Figure 2. Length frequency histogram of bluegill sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

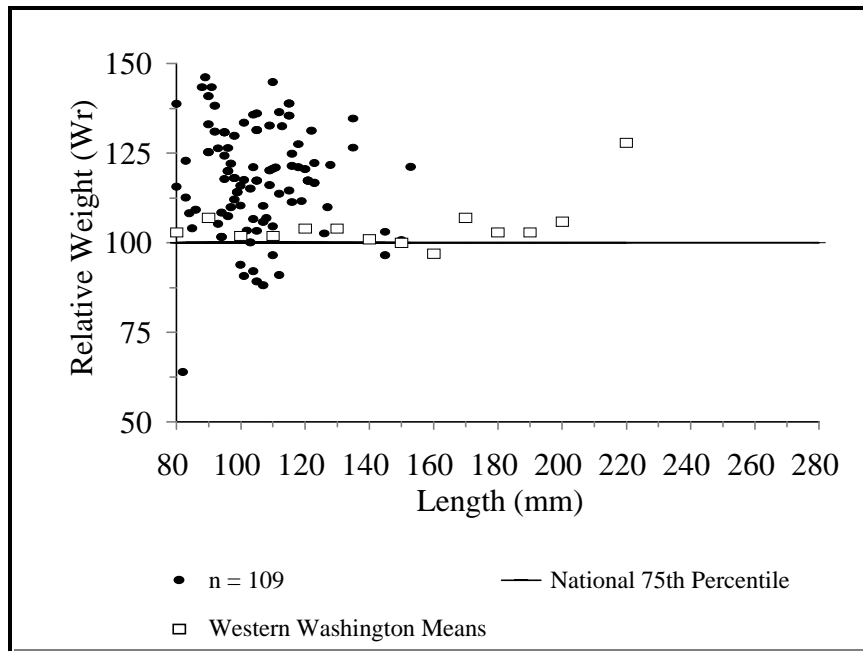


Figure 3. Relationship between total length and relative weight (Wr) of bluegill from Horseshoe Lake (Cowlitz/Clark County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Brown Bullhead

Eighteen brown bullhead were captured that ranged from 153 to 219 mm TL (Table 6). At least two year-classes were evident from the length frequency histogram (Figure 4); however, these fish were not aged. The relative weights were low by national standards (Figure 5).

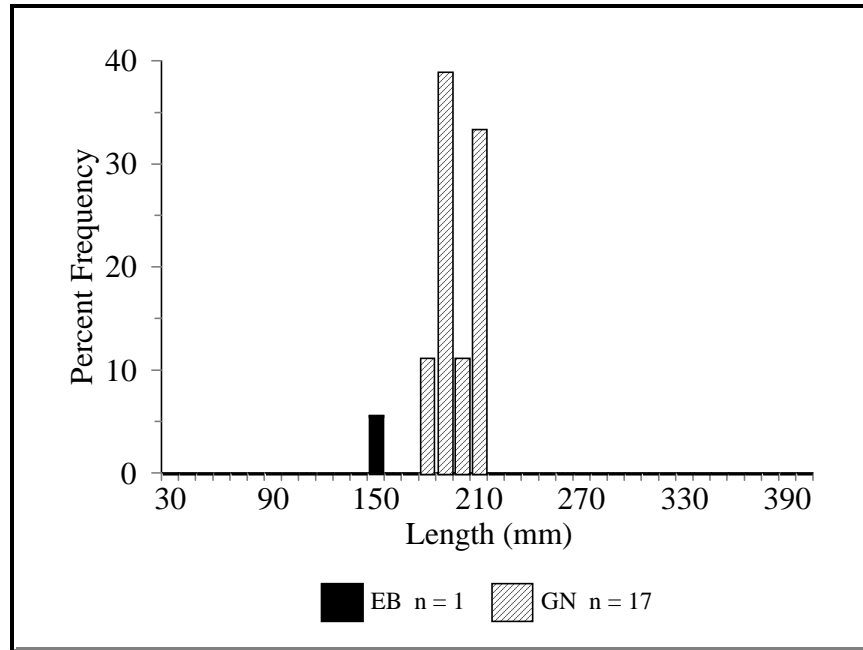


Figure 4. Length frequency histogram of brown bullhead sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

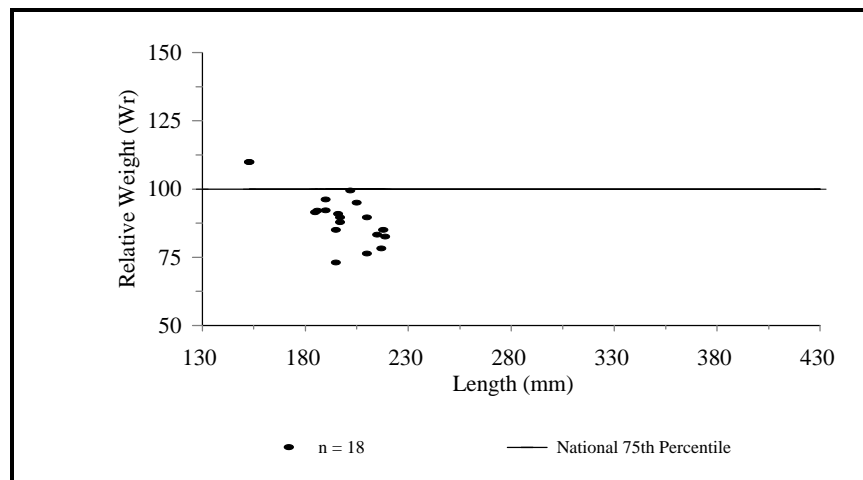


Figure 5. Relationship between total length and relative weight (W_r) of brown bullhead from Horseshoe Lake (Cowlitz/Clark County) compared with the national 75th percentile.

Largemouth Bass

Largemouth bass ranged from 48 to 348 mm TL (age 0+ to 5+) (Table 6). The size structure of largemouth bass, as indicated by their length frequency (Figure 6), PSD and RSD-P values (Table 8), suggests that the lake is naturally suited for a panfish fishery (Table 4) (Gabelhouse 1984; Willis et al. 1993). With exception of the first year, growth of Horseshoe Lake largemouth bass was slow when compared to other western Washington fish (Table 10). However, their relative weights were high when compared to the national standard and averages for largemouth bass from up to 25 western Washington warmwater lakes (Figure 7).

Table 10. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Horseshoe Lake (Cowlitz/Clark County) during late summer 1997. 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
1996	15	73.5				
		81.7				
1995	12	69.1	138.5			
		81.7	143.5			
1994	21	56.0	107.8	175.9		
		70.8	117.9	179.8		
1993	4	83.9	142.8	199.1	241.6	
		98.3	153.2	205.8	245.5	
1992	3	75.0	116.7	220.8	273.1	316.2
		90.5	129.7	227.5	276.7	317.2
Overall mean		71.5	126.4	198.6	257.4	316.2
Weighted mean		79.2	130.0	188.6	258.9	317.2
Western WA average		60.4	145.5	222.2	261.1	289.3

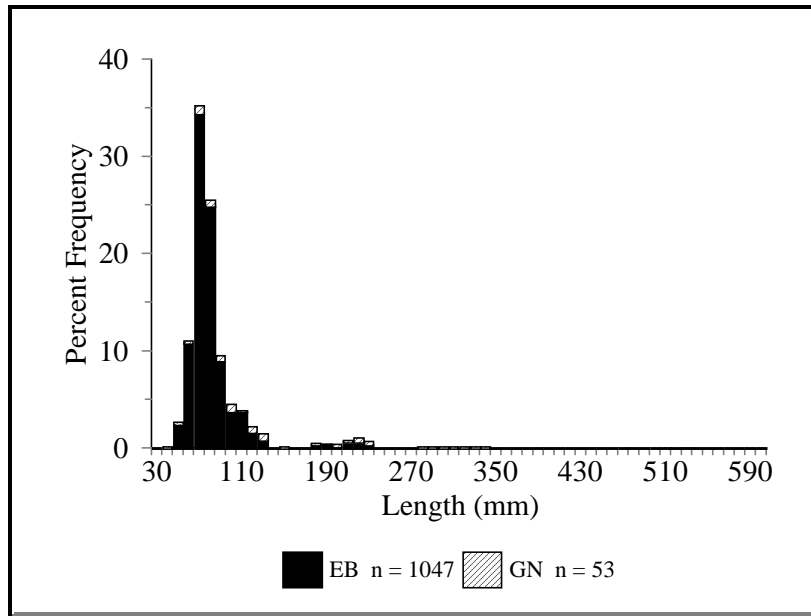


Figure 6. Length frequency histogram of largemouth bass sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

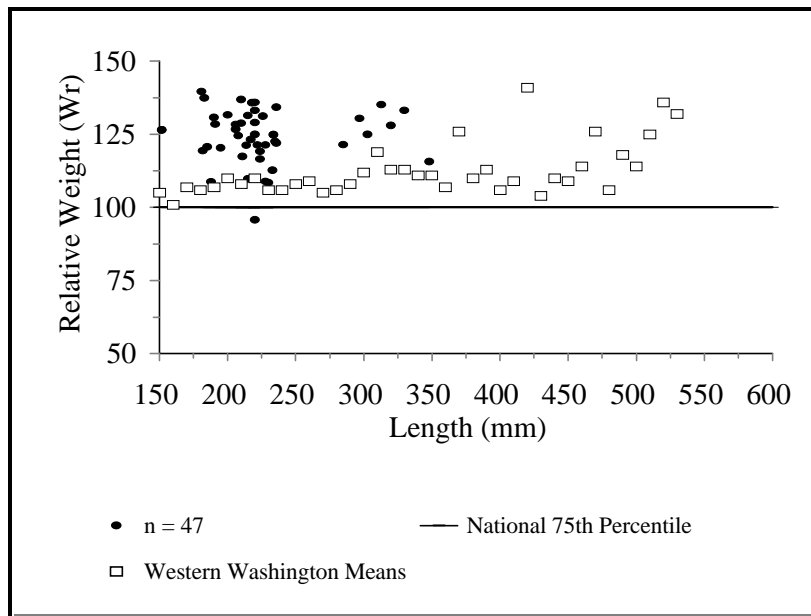


Figure 7. Relationship between total length and relative weight (W_r) of largemouth bass from Horseshoe Lake (Cowlitz/Clark County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Yellow Bullhead

Six yellow bullhead were captured that ranged from 137 to 211 mm TL (Table 6). Like brown bullhead, at least two year-classes were evident from the length frequency histogram (Figure 8); however, these fish were not aged. The relative weights were variable, but mostly low by national standards (Figure 9).

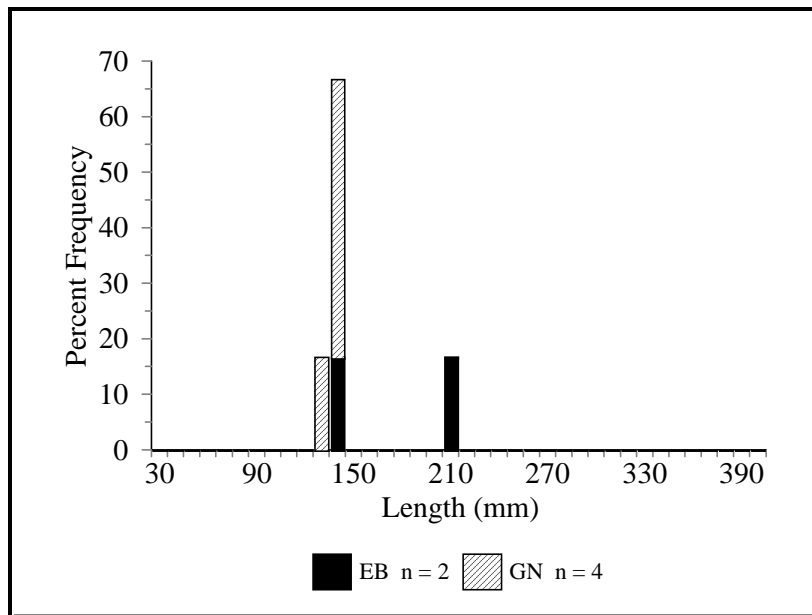


Figure 8. Length frequency histogram of yellow bullhead sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

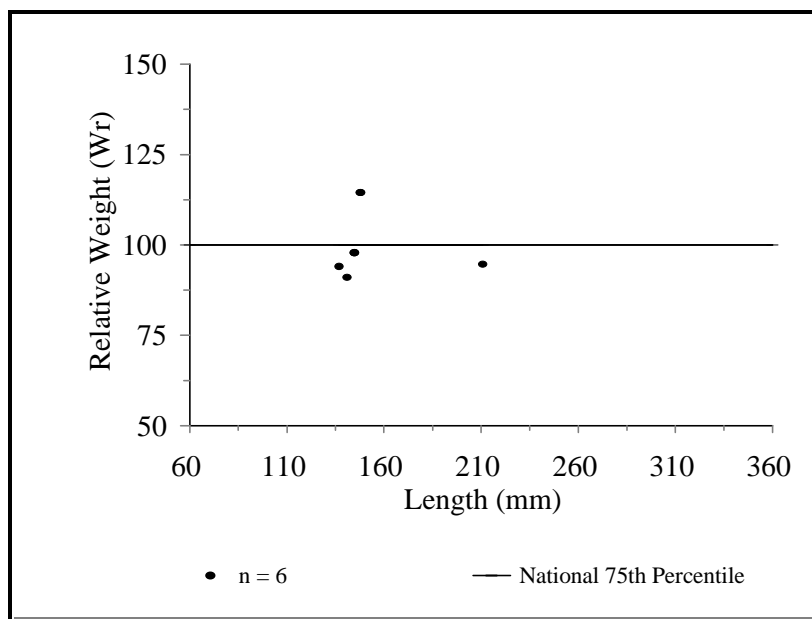


Figure 9. Relationship between total length and relative weight (Wr) of yellow bullhead from Horseshoe Lake (Cowlitz/Clark County) compared with the national 75th percentile.

Yellow Perch

Yellow perch ranged from 77 to 246 mm TL (age 0+ to 5+) (Table 6). The 1994 and 1996 year-classes were dominant, as indicated by the length frequency distribution; however, the 1995 year-class was not observed (Table 11; Figure 10). During their first year, growth of Horseshoe Lake yellow perch was high; however, after age 2+, growth was consistent with yellow perch statewide (Table 11). Relative weights were variable around the national standard for the species, yet high when compared to the averages for yellow perch from up to 25 western Washington warmwater lakes (Figure 11).

Table 11. Age and growth of yellow perch (*Perca flavescens*) captured at Horseshoe Lake (Cowlitz/Clark County) during late summer 1997. 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
1996	24	76.2				
		84.0				
1995	0					
1994	17	74.6	117.1	163.7		
		92.6	128.3	167.4		
1993	11	64.9	112.6	159.8	195.5	
		85.8	126.7	167.4	198.0	
1992	3	66.2	108.0	145.4	177.2	198.9
		86.8	122.6	154.7	181.9	200.5
Overall mean		70.5	112.6	156.3	186.3	198.9
Weighted mean		87.1	127.2	166.2	194.6	200.5
State average		59.7	119.9	152.1	192.5	206

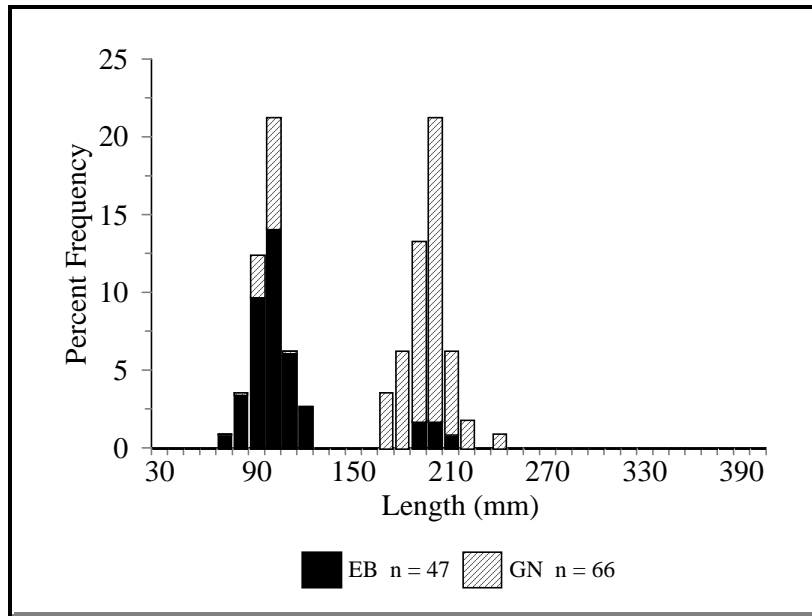


Figure 10. Length frequency histogram of yellow perch sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

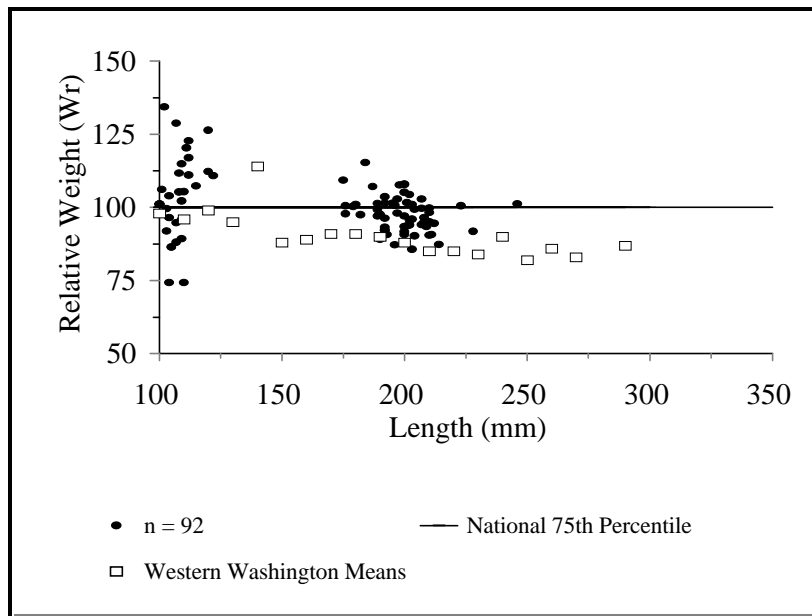


Figure 11. Relationship between total length and relative weight (Wr) of yellow perch from Horseshoe Lake (Cowlitz/Clark County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Non-game Fish and Members of the Family Salmonidae

Common carp ranged from 92 to 630 mm TL and comprised 15.0% of the biomass captured, yet only 1.5% by number (Table 6). Several year-classes were evident from the length frequency distribution (Figure 12). Of the stock-length fish captured, most were of preferred-size (Table 8). Relative weights of common carp were well above the national standard and decreased with size (Figure 13). largescale sucker ranged from 443 to 546 mm TL and comprised 26.2% of the biomass captured, yet only 1.2% by number (Table 6). At least two year-classes of largescale sucker were evident from the length frequency distribution (Figure 14); however, these fish were not aged. Peamouth ranged from 180 to 267 mm TL and comprised no more than 1% of the weight and number of fish captured (Table 6). At least two year-classes were evident from their length frequency distribution (Figure 15). Sculpin comprised less than 0.5% of the biomass and number captured, and ranged from 65 to 140 mm TL (Table 6; Figure 16). One northern pikeminnow was captured that measured 276 mm TL and weighed 191 g.

Brown trout ranged from 240 to 258 mm TL (Figure 17) and comprised 1.6% of the biomass captured and 0.5% by number (Table 6). All of the fish captured were of quality-size (Table 8), and their relative weights were consistent with the national standard for the species (Figure 18). Cutthroat trout ranged from 243 to 300 mm TL (Figure 19) and comprised 17.7% of the biomass captured, yet less than 5% by number. No quality-size cutthroat trout were captured, and their relative weights were below the national standard (Figure 20).

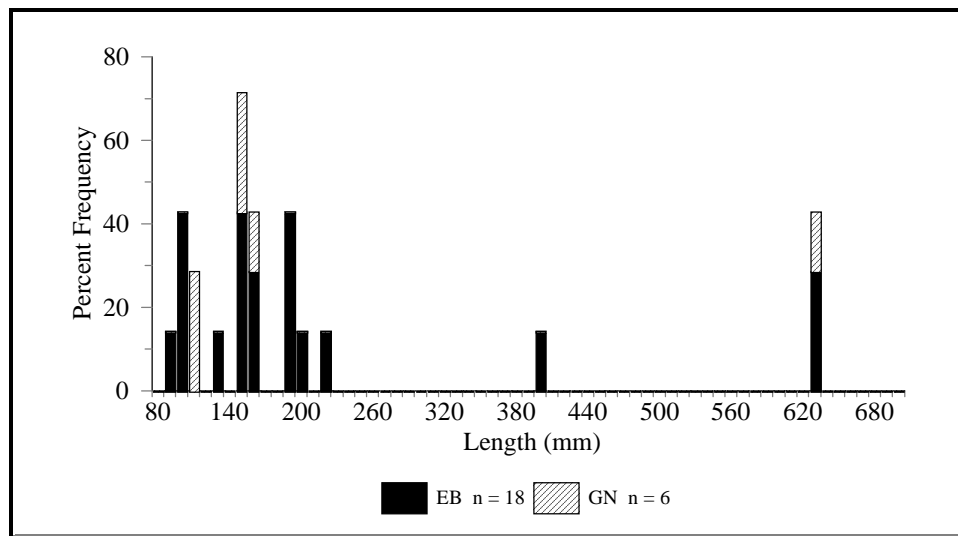


Figure 12. Length frequency histogram of common carp (*Cyprinus carpio*) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

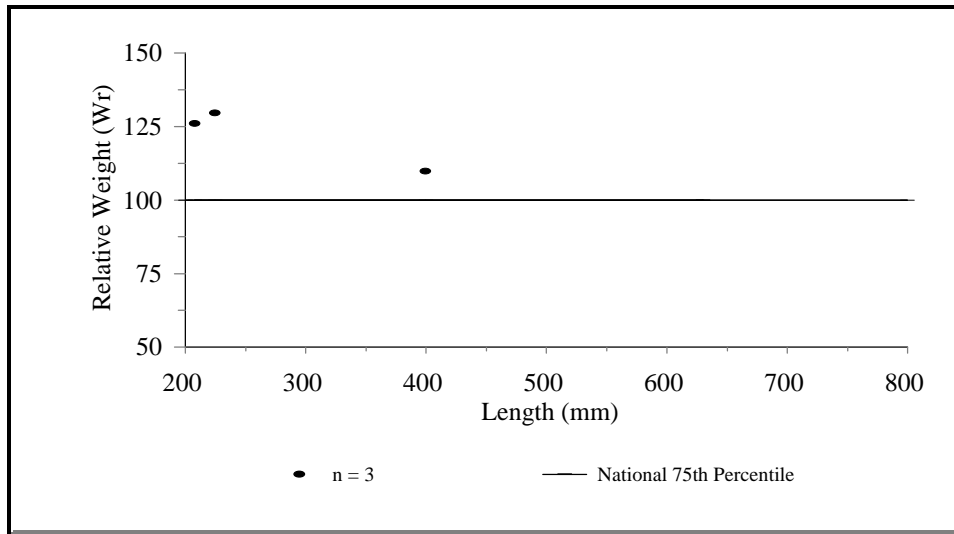


Figure 13. Relationship between total length and relative weight (Wr) of common carp from Horseshoe Lake (Cowlitz/Clark County) compared with the national 75th percentile.

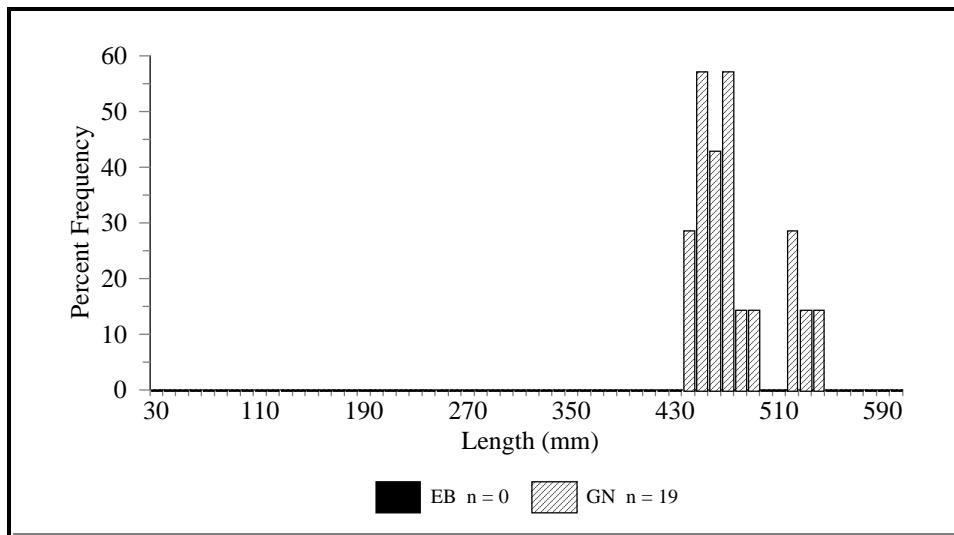


Figure 14. Length frequency histogram of largescale sucker (*Catostomus macrocheilus*) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

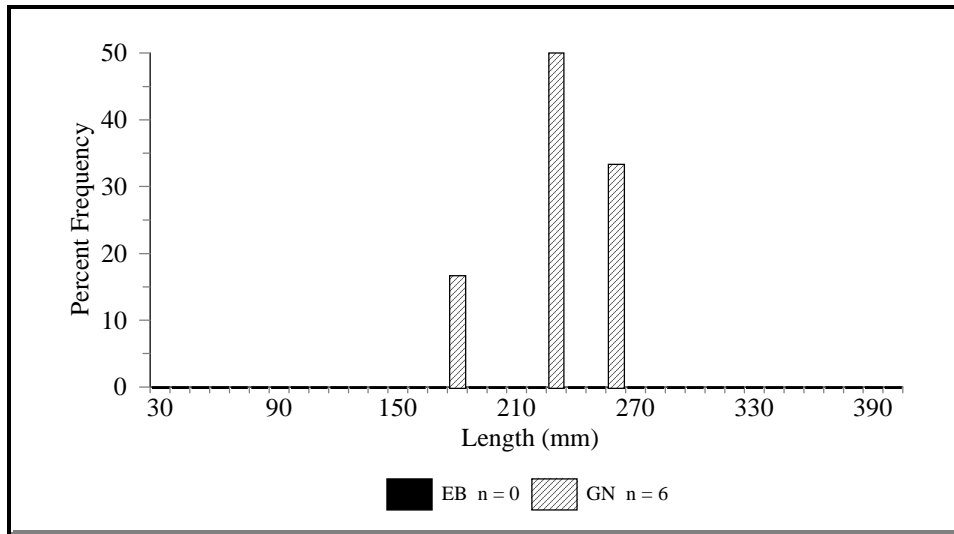


Figure 15. Length frequency histogram of peamouth (*Mylocheilus caurinus*) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

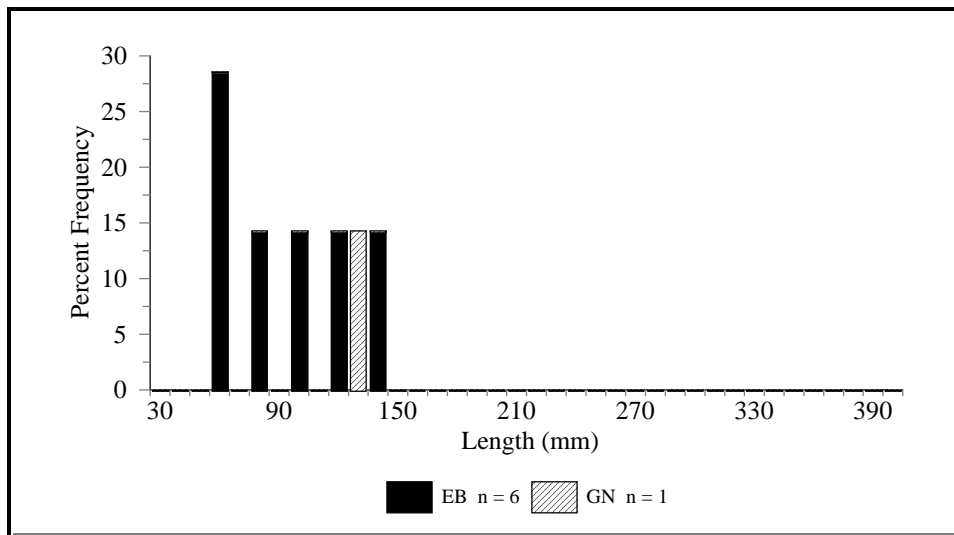


Figure 16. Length frequency histogram of sculpin (*Cottus* sp.) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

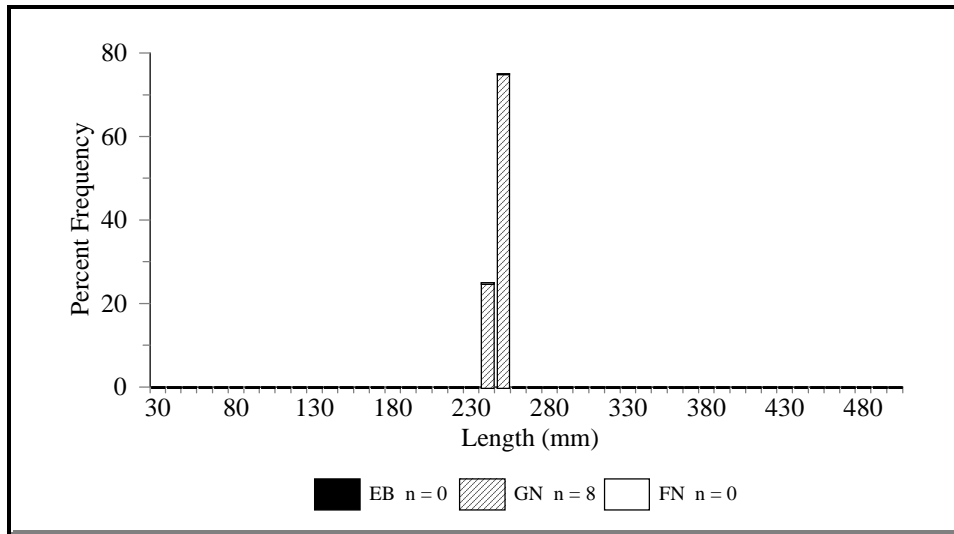


Figure 17. Length frequency histogram of brown trout (*Salmo trutta*) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB=electrofishing and GN=gill netting.

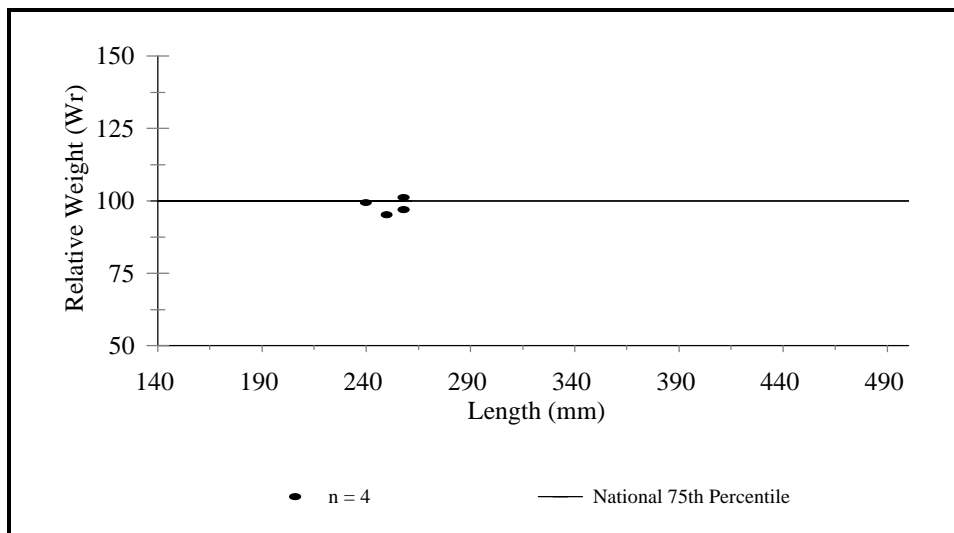


Figure 18. Relationship between total length and relative weight (Wr) of brown trout from Horseshoe Lake (Cowlitz/Clark County) compared with the national 75th percentile.

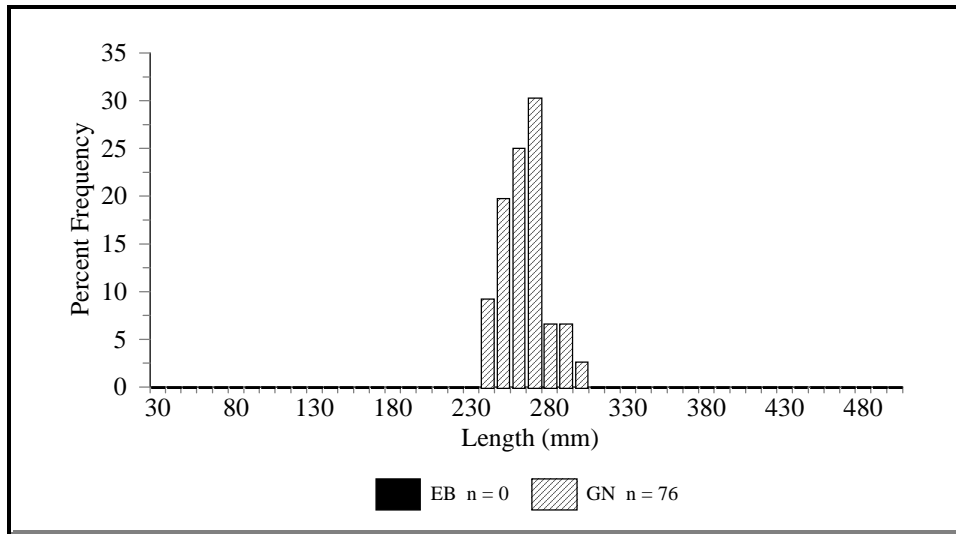


Figure 19. Length frequency histogram of cutthroat trout (*Oncorhynchus clarki*) sampled from Horseshoe Lake (Cowlitz/Clark County) in late summer 1997. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing and GN = gill netting.

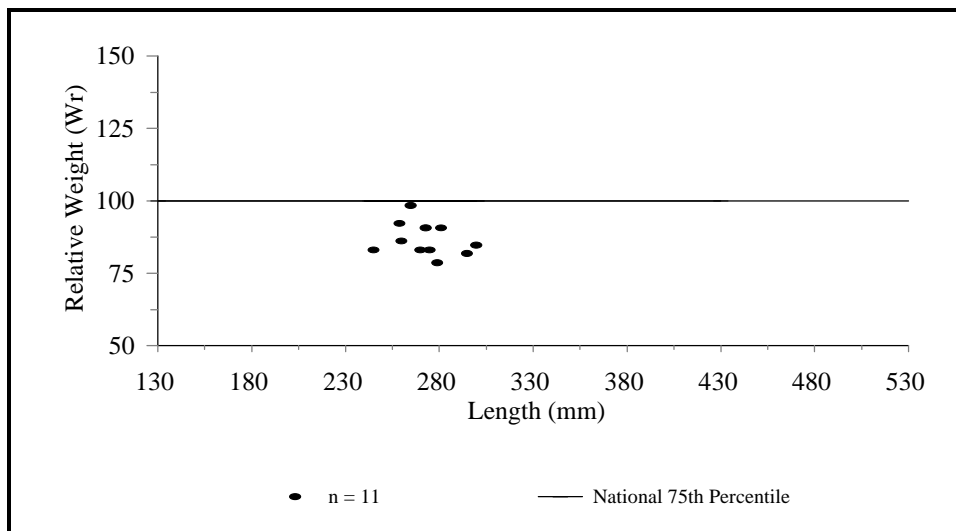


Figure 20. Relationship between total length and relative weight (Wr) of cutthroat trout from Horseshoe Lake (Cowlitz/Clark County) compared with the national 75th percentile.

Warmwater Enhancement Options

Reevaluate Aquatic Plant Control Contingency Plan

In its report to the City of Woodland, Entranco (1999) suggested that increased water clarity as a result of the alum treatment could lead to increased growth of submersed aquatic vegetation. Entranco (1999) recommended implementing a control contingency plan if the coverage of desirable, native aquatic plant species exceeded 25% of the total lake surface area. Currently, submersed aquatic vegetation comprises approximately 7% of Horseshoe Lake's surface area. This figure has changed little over the years (Entranco 1999). Welch et al. (1992) attributed the paucity of aquatic plants at Horseshoe Lake to unsuitable habitat, and suggested that the lake's coarse, relatively compact sediments precluded the successful colonization of aquatic vegetation.

A diverse, thriving 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). Most researchers agree that a low to moderate level of aquatic vegetation is better than too little 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. For these reasons, we recommend increasing the maximum growth area suggested by Entranco (1999) by 5 – 15 % (i.e., no more than 30 - 40% of the total surface area of the lake should be covered with aquatic vegetation before implementing the aquatic plant control contingency plan).

Consider Stocking Tiger Muskellunge to Control Forage Fish and Non-Game Species

During late summer 1997, over 40% of the biomass of our catch was comprised of non-game species (Table 6). Stocking sterile, yearling tiger muskellunge (*Esox masquinongy* × *E. lucius*) should provide some control of undesirable, non-game fish (Wingate 1986; Tipping 1996, 1999) that compete directly or indirectly with sport fish for resources within Horseshoe Lake. Furthermore, increased predation of forage fish and juvenile largemouth bass should allow the remaining fish to realize their full growth potential. This technique has been used with varied degrees of success for years (Bennett 1962; Noble 1981; Newman and Storck 1986; Wahl and Stein 1988; Boxrucker 1992; Bolding et al. 1997). Although tiger muskellunge prefer fusiform, soft-rayed prey, such as catostomids or cyprinids, over deep-bodied, spiny-rayed prey, such as

centrarchids, they generally fare well irrespective of the forage base (Tomcko et al. 1984; Newman and Storck 1986; Wahl and Stein 1988; Kohler and Kelly 1991; Tipping 1996, 1999). Moreover, tiger muskellunge grow rapidly in Washington (Hillson and Tipping 1999). Therefore, in addition to improving balance, stocking tiger muskellunge may also provide a trophy fishing opportunity at Horseshoe Lake (Adair 1986; Storck and Newman 1992; Tipping 1996).

Change Existing Fishing Rules to Alter Size Structure of Largemouth Bass

Currently, Horseshoe Lake anglers are allowed to harvest five largemouth bass daily, including no more than three over 381 mm (15") TL. The PSD and RSD-P values of largemouth bass (Table 8), suggest that the lake is naturally suited for a panfish fishery rather than a big bass fishery or one balanced between predator and prey fish (Table 4) (Gabelhouse 1984; Willis et al. 1993). Changes in the size structure of largemouth bass may require implementing corrective length and bag limits on largemouth bass (*sensu* Willis 1989) to improve this fishery.

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

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

Conduct Follow-up Fisheries Study

Preliminary results indicate that the buffered alum treatment at Horseshoe Lake was successful (Table 12); however, little information exists concerning the impacts from increased dilution of the lake (Entranco 1999). During late summer 1997, the panfish and juvenile largemouth bass of Horseshoe Lake displayed high relative weights, an indication of abundant forage. Not surprisingly, Entranco (1999) reported high densities of phytoplankton and zooplankton, and large numbers of benthic invertebrates during the same period. If the alum treatment remains successful, the subsequent inactivation of phosphorus will undoubtedly affect the plankton

community. Reductions in phosphorus loading can result in pronounced decreases in algal abundance (EPA 1995; KCM 1995; Scheffer 1998; Entranco 1999). Changes at higher trophic levels, from zooplankton to planktivorous fishes, will likely ensue. Whether this impacts the fisheries of Horseshoe Lake remains to be seen. Our results provide some baseline information necessary to monitor the long-term effects of the chemical precipitation of phosphorus and dilution of Horseshoe Lake. However, without follow-up study, any impacts from these restoration efforts will remain enigmatic.

Table 12. Results of buffered alum treatment at Horseshoe Lake, Cowlitz/Clark County (adapted from Entranco 1999). Values are means from samples taken during summer (June to September) 1991, 1997 (pre-treatment), and 1998 (post-treatment).

Environmental Parameter	Pre-treatment Range	Post-treatment	% Improvement	Water Quality Goals ^a
Total phosphorus (µg/l)	23.0 – 29.9	18.3	20 – 39	13.0 – 18.0
Chlorophyll <i>a</i> (µg/l)	14.0 – 15.0	8.5	39 – 43	5.4 – 8.3
Secchi visibility (m)	1.2 – 1.8	2.1	17 – 75	1.8 – 2.4

^a Water quality goals set by Welch et al. (1992).

Literature Cited

- Adair, B.C. 1986. Tiger muskellunge as a trophy species in Iowa lakes. Page 343 *in* Hall, G.E. (ed.), *Managing Muskies*. American Fisheries Society, Special Publication 15, Bethesda, MD.
- 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.
- Bennett, G.W. 1962. *Management of Artificial Lakes and Ponds*. Reinhold Publishing Corporation, New York, NY.
- Bettoli, P.W., M.J. Maccina, R.L. Noble, and R.K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. *North American Journal of Fisheries Management* 13: 110-124.
- Blackwell, B.G., M.L. Brown, and D.W. Willis. *In press*. Relative weight (W_r) status and current use in fisheries assessment and management. South Dakota Agricultural Experiment Station, Journal Series # 3056, 00 p.
- 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, Research Report No. RAD97-05, 27 p.
- Boxrucker, J. 1992. Results of concomitant predator and prey stockings as a management strategy in combatting stunting in an Oklahoma crappie population. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 46: 327-336.
- 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 No. 7, 76 p.
- Davies, W.D., and F. Rwangano. 1991. Farm pond fish populations in the Willamette Valley, Oregon: assessment and management implications. Pages 143-148 *in* *Proceedings of the Warmwater Fisheries Symposium I*, June 4-8, 1991, Scottsdale, Arizona. USDA Forest Service, General Technical Report RM-207.

- 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.
- Durocher, P.P., W.C. Provine, and J.E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. *North American Journal of Fisheries Management* 4: 84-88.
- Entranco. 1999. Final Report Horseshoe Lake Restoration Project, Phase II Implementation. Entranco, Inc., Bellevue, in association with Gibbs and Olson, Inc., Longview, WA.
- EPA (Environmental Protection Agency). 1995. Phosphorus inactivation and wetland manipulation improve Kezar Lake, NH. Watershed protection: clean lakes case study. U.S. Environmental Protection Agency, Report # EPA841-F-95-002, 7 p.
- 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.
- Hillson, T.D., and J.M. Tipping. 1999. Lewis River Hatchery complex fish biologist annual report for 1998. Washington Department of Fish and Wildlife, Technical Report No. 99-7, 30 p.
- Jearld, A. 1983. Age determination. Pages 301-324 *in* Nielsen, L.A., and D.L. Johnson (eds.), *Fisheries Techniques*. American Fisheries Society, Bethesda, MD.
- KCM. 1995. Green Lake Phase IIC Restoration Project, Volume 1-Project Completion Report. KCM, Inc., Seattle, WA.
- Killgore, K.J., R.P. Morgan II, and N.B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9: 101-111.
- 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.

- Masser, M. *Undated*. Recreational fish pond management for Alabama. Auburn University, Alabama Cooperative Extension Service Technical Report, 32 p.
- McHugh, J.J. 1990. Response of bluegills and crappies to reduced abundance of largemouth bass in two Alabama impoundments. *North American Journal of Fisheries Management* 10: 344-351.
- 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.
- Newman, D.L., and T.W. Storck. 1986. Angler catch, growth, and hooking mortality of tiger muskellunge in small centrarchid-dominated impoundments. Pages 346-351 *in* Hall, G.E. (ed.), *Managing Muskies*. American Fisheries Society, Special Publication 15, Bethesda, MD.
- Noble, R.I. 1981. Management of forage fishes in impoundments of the southern United States. *Transactions of the American Fisheries Society* 110: 738-750.
- 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.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Board of Canada* No. 191, 382 pp.
- Scheffer, M. 1998. *Ecology of Shallow Lakes*. Chapman and Hall, New York, NY.
- Storck, T.W., and D.L. Newman. 1992. Contribution of tiger muskellunge to the sport fishery of a small, centrarchid-dominated impoundment. *North American Journal of Fisheries Management* 12: 213-221.
- Savino, J.F., and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. *Transactions of the American Fisheries Society* 111: 255-266.
- Swingle, H.S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Auburn University, Alabama Agricultural Experiment Station Bulletin No. 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.
- Tipping, J.M. 1996. Mayfield Lake tiger muskie progress report for 1995. Washington Department of Fish and Wildlife, Technical Report No. H96-01, 21 p.
- Tipping, J.M. 1999. Mayfield Lake tiger muskie progress report for 1998. Washington Department of Fish and Wildlife, Technical Report No. IN99-01, 20 p.
- Tomcko, C.M., R.A. Stein, and R.F. Carline. 1984. Predation by tiger muskellunge on bluegill: effects of predator experience, vegetation, and prey density. Transactions of the American Fisheries Society 113: 588-594.
- Wahl, D.H., and R.A. Stein. 1988. Selective predation by three esocids: the role of prey behavior and morphology. Transactions of the American Fisheries Society 117: 142-151.
- Welch, E.B., A.J. Whiley, and D.E. Spyridakis. 1992. Horsehoe Lake quality, nutrient loading and management. University of Washington, Department of Civil Engineering, Environmental Engineering and Science, Water Resources Series Technical Report No. 136.
- Wiley, M.J., R.W. Gordon, S.W. Waite, and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4: 111-119.
- 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.
- Willis, D.W., D.O. Lucchesi, and B.G. Blackwell. 1997. Influence of Aquatic Vegetation on Natural Recruitment of Some Centrarchid, Esocid, and Percid Fishes: A Literature Review. South Dakota Department of Game, Fish and Parks, Special Report No. 97-4, 26 p.
- Wingate, P.J. 1986. Philosophy of muskellunge management. Pages 199-202 *in* Hall, G.E. (ed.), Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, MD.
- Wolcott, E.E. 1973. Lakes of Washington, Volume 1: Western Washington, 3rd edition. Washington Department of Ecology, State Water Program, Water Supply Bulletin No. 14, 619 p.
- Zar, J.H. 1984. Biostatistical Analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, NJ.



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