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The Warmwater Fish Community of Duck Lake, Grays Harbor County 1999-2004

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Abstract

Duck Lake was surveyed in spring 1999, fall 2002, and spring 2004 by three-person teams using multiple gear types (electrofishing, gill netting, and fyke netting.) Twelve species were represented: largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavens*), black crappie (*Pomoxis nigromaculatus*), rainbow trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), grass carp (*Ctenopharyngodon idella*), peamouth chub (*Mylocheilus caurinus*), threespine stickleback (*Gasterosteus aculeatus*), sculpin (Cottidae), brown bullhead (*Ameiurus nebulosus*) and northern pikeminnow (*Ptychocheilus oregonensis*). Comparing the results of the three surveys reveals a warmwater population undergoing change. Yellow perch were introduced to Duck Lake sometime between 1999 and 2002, and by 2004 had become the most abundant species in our sample. During the same period largemouth bass have been dominated by a series of consecutive large year classes, 1994-1997, that were 7-10 years of age as of the 2004 survey. Coincidental with these two change, bluegill abundance declined 97.8% from 1999 to 2004.

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Introduction and Background

Duck Lake is shallow, eutrophic lake located on the Point Brown peninsula, Ocean Shores, Washington. The main body of the lake is approximately 252 surface acres, with a maximum depth of 9 m (Scherer, et al 1994). There are also approximately 200 acres of dredged canals and associated wetlands, bringing the total area of Duck Lake to approximately 450 acres. In the 1960's, the original lake was significantly altered by dredging and filling, resulting in the series of lakes and canals that is known as Duck Lake today. There is a total of six main sections that together comprise the lake. They are: North Duck Lake, Duck Lake, Bass Canal, the Grand Canal, the Bell Canals, and Lake Minard.

Duck Lake is fed mainly by shallow groundwater, but it also serves as the main stormwater retention basin for the peninsula. As such, it has experienced water quality problems associated with high nutrient loads from runoff and through poorly designed septic systems in the area. The poor water quality, dense algal blooms, and thick aquatic vegetation spurred the local government, the City of Ocean Shores, to contract KCM, Inc. to develop a lake restoration plan (Scherer, et al 1994). In April 1995, the city planted 2,400 grass carp (*Ctenopharyngodon idella*), averaging 11 inches long, into Duck Lake for vegetation control. This fish plant was followed by a multi-year aquatic plant and waterfowl evaluation by Envirovision Corporation (2000), which found little to no overall change in macrophyte density within the lake from 1996-1999, although some species of macrophytes preferred by grass carp were replaced by less preferred species. In April, 2002 an additional 5,000 grass carp were planted in Duck Lake.

Three surveys of the warmwater fish community were conducted in Duck Lake between the spring of 1999 and the spring of 2004 using the “Standard Fish Sampling Guidelines for Washington State Ponds and Lakes” (Bonar et al. 2000), described in part below. The 1999 and 2004 surveys were conducted in the spring, while the 2002 survey occurred in the fall. Comparisons between spring and fall survey data are discouraged (Pope and Willis, 1996; Bonar et al. 2000), and are included hereafter only sparingly and with associated qualifying language.

Methods and Materials

Data Collection

Duck Lake was surveyed three times from 1999 to 2004. Each survey was conducted by a three-person team over several days: May 4-5 and 10-11, 1999, September 30 - October 3, 2002, and May 3-5, 2004. Fish were captured using 3 sampling techniques: electrofishing, gill netting, and fyke netting. (Gill nets were not used during the 1999 survey.) The electrofishing unit consisted of a Smith-Root SR-16s electrofishing boat, with a 5.0GPP pulsator unit. Peak efficiency of the electrofishing unit is defined as producing a ¼ sine wave. The boat was fished using a pulsed DC current of 60 Hz at 2-4 amps power, as close to peak efficiency as possible. Experimental gill nets, 45.7 meters (m) long x 2.4 m deep, were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size (1.3, 1.9, 2.5, and 5.1 cm stretch) monofilament mesh. Fyke (modified hoop) nets were constructed of five 1.2 m diameter hoops with two funnels, and a 2.4 m cod end (6 mm nylon delta mesh). Attached to the mouth of the net were two 7.6 m wings, and a 30.5 m lead.

In order to reduce the gear induced bias in the data, the sampling time for each gear was standardized so that the ratio of electrofishing to gill netting to fyke netting was 3:2:2. The standardized sample is 1800 sec of electrofishing (3 sections), 2 gill net nights, and 2 fyke net nights. (This standardization occurred in 2000 (Bonar, at al 2000); the 1999 survey had a ratio of 3.75 electrofished sections per fyke net, with no gill nets set.) Sampling occurred during the evening hours to maximize the type and number of fish captured. Sampling locations were selected from a map by dividing the entire shoreline into 400 m sections, numbering them consecutively and randomly choosing them without replication. While electrofishing, the boat was maneuvered slowly through the shallows for a total of 600 seconds of "pedal-down" time. Gill nets were fished perpendicular to the shoreline; the small-mesh end was tied off to shore, and the large- mesh end was anchored off shore. Fyke nets were fished perpendicular to the shoreline as well. The lead was tied on shore, and the cod-end was anchored off shore, with the wings anchored at approximately a 45° angle from the net lead. Fyke nets are fished with the hoops 0.3 - 0.5 m below the water surface, this sometimes requires shortening the lead. Twelve 400' sections were electrofished; gill nets and fyke nets were each set overnight at eight locations around the lake. (The 1999 survey consisted of 15 electrofished sections and 4 fyke net sets.)

With the exception of sculpin (family Cottidae), all fish captured were identified to the species level. Most fish were measured to the nearest millimeter (mm) and weighed to the nearest gram (g). Fish less than 70 mm were not weighed due to inadequate scale precision. In order to reduce handling stress, where large numbers (>200) of obviously similar-sized fish were collected simultaneously, a subsample was measured to the nearest millimeter and weighed to the nearest gram. The remaining fish were counted and the subsampled data expanded. Weights were then assigned using a length-weight regression formula.

For aging purposes, scales were taken from five individuals of each warmwater game species per centimeter size class (70 mm minimum). All fish providing scales were measured to the nearest millimeter and weighed to the nearest gram individually.

Water quality data was collected during midday from the deepest section of the lake Using a Hydrolab® probe and digital recorder, dissolved oxygen (mg/l), temperature (C°), pH, turbidity (NTU), and conductivity (μsiemens/cm) data were gathered in the deepest section of the lake at 1 m intervals through the water column. Secchi disk readings, used to measure transparency, were taken by the methods outlined by Wetzel (1983).

Data Analysis

Species Composition

The species composition by number of fish captured was determined using procedures outlined by Fletcher et al.(1993). Species composition by weight (kg) of fish captured, was determined using procedures adapted from Swingle (1950). All fish, including young of the year, are used to determine biomass and species composition. Due to obvious differences in young of the year presence from spring to fall, species composition data is not be compared across seasons.

Catch Per of Unit Effort

The catch per unit of effort (CPUE) of electrofishing for each species was determined by dividing the total number in all size classes equal or greater than stock size (defined in Appendix A), by the total electrofishing time (sec). The CPUE for gill nets and fyke nets was determined similarly, except the number equal or greater than stock size was divided by the number of net-nights for each net (usually one). An average CPUE (across sample sections) with 80% confidence interval was calculated for each species and gear type. Differences in mean electrofishing CPUE between 1999 and 2004 were tested with the Mann-Whitney rank-sum test. This test was selected due to the possibility that CPUE data is not normally distributed.

For fishes in which there is no published stock size (i.e., sculpins, suckers, etc.), CPUE is calculated using all individuals captured. Furthermore, since it is standardized, the CPUE is useful for comparing stocks between lakes.

Length-Frequency

A length-frequency histogram was calculated for warmwater gamefish species by calculating the number of individuals of a species in a given size class divided by the total individuals of that species sampled, creating a percentage graph. Typically these graphs are constructed for each gear type and are limited to age-1 fish and above, as determined by the aging process. For this survey all gear types are combined on a single graph and all fish collected were included. Plotting the histogram by percentages tends to flatten out large peaks created by an abundant size class, and makes the graph easier to read. These length-frequency histograms are helpful when trying to evaluate the size and age structure of the fish community, and their relative abundance in the lake.

Stock-Density Indices

To assess the size structure of fish populations, stock density indices were calculated as described by Gablehouse (1984). Proportional stock density (PSD and relative stock density RSD) are calculated as proportions of various size-classes of fish in a sample.. The size classes are referred to as minimum stock (S), quality (Q), preferred (P), memorable (M), and trophy (T). Lengths have been published to represent these size classes for each species, and were developed to represent a percentage of world-record lengths as listed by the International Game Fish Association (Gablehouse 1984). These lengths are presented in Appendix A. Comparisons of PSDs from one survey to another were done using the z-test for proportions

The indices are accompanied by a 80% confidence interval (Gustafson 1988) to provide an estimate of statistical precision.

Relative Weight

A relative weight index (W_r) was used to evaluate the relative condition of fish in the lake. A W_r value of 100 generally indicates a fish in good condition when compared to the national average for that species and size. Furthermore, relative weights are useful for comparing the condition of different size groups within a single population to determine if all sizes are finding adequate forage or food. Relative weights were calculated following Murphy and Willis (1991). The parameters for the standard weight (W_s) equations of many fish species, including the minimum length recommendations for their application, are listed in Anderson and Neumann (1996). Comparisons of mean relative weights from one survey to another were conducted using the Student's *t*-test, one-tailed.

Age and Growth

Age determination and annuli measurements from scales or other structures were determined by the Department of Fish and Wildlife Aging Unit. Total length at annulus formation was back-calculated using the Fraser-Lee method with *y*-axis intercepts specified by Carlander (1982). Mean back-calculated lengths at each age for each species were presented in tabular form for easy comparison between year classes. Results for each survey were compared to one another and to regional averages using the Student's *t*-test, one-tailed. Regional averages were developed from age data collected on other western Washington lakes in this same manner then calculated as a mean of means.

Age frequency graphs were constructed by determining the ages of fish within each centimeter class and adding all the fish of the same age together. This was done by first determining the age per centimeter class *for the fish that were aged*, then applying the appropriate ages to the entire sample of fish, both aged and non-aged, within each centimeter class. Where multiple ages occurred in a single centimeter class, the ratio of the ages from the aged fish were multiplied by the number of fish in a centimeter class for the entire (aged and non-aged) sample.

Results

Water Quality and Habitat

Table 1 shows water quality parameters that were collected in the deepest section of Duck Lake during each survey. Temperature and dissolved oxygen stratification were more apparent in spring than fall, with 2004 being more stratified than the other two surveys. Conductivity and pH readings changed from 1999 to 2002, then remained consistent from 2002-2004. The increase in conductivity after 1999 is particularly intriguing.

Extensive habitat evaluations were conducted by KCM Inc. (Scherer, et al 1994) and Envirovision Corporation (2000). The Washington Department of Ecology (DOE) has also conducted aquatic plant surveys; that data can be found on their website at http://www.ecy.wa.gov/programs/eap/lakes/aquaticplants/index.html.

Table 1. Water quality measurements from Duck Lake, Grays Harbor County, 1999-2004

	Depth (m)	Temp C	pH	DO mg/l	Conductance
1999					
05/03/99	1	15.30	8.25	8.03	76.5
05/03/99	2	14.90	8.27	8.13	76.4
05/03/99	3	14.50	8.27	8.17	76.3
05/03/99	4	15.25	8.71	8.92	77.0
05/03/99	5	14.86	8.64	8.27	76.9
05/03/99	6	14.51	8.60	8.03	76.8
05/03/99	7	13.71	8.46	7.20	77.1
2002					
10/03/02	1	16.05	6.41	9.27	177.4
10/03/02	2	16.08	7.01	9.18	177.8
10/03/02	3	16.09	7.32	9.21	178.4
10/03/02	4	16.09	7.43	9.07	178.4
2004					
05/05/04	0	17.17	7.62	10.8	177
05/05/04	1	17.52	7.74	10.76	177
05/05/04	2	16.80	7.76	10.65	176
05/05/04	3	14.72	7.54	9.50	175
05/05/04	4	13.74	7.39	8.70	176
05/05/04	5	13.41	7.23	7.41	180
05/05/04	6	12.52	7.12	6.01	176
05/05/04	7	11.22	7.02	2.69	176
05/05/04	8	10.55	6.89	1.29	173

Species Composition and Relative Abundance

A total of twelve different species of fish were collected in Duck Lake over the course of these three surveys; seven in 1999, and 10 in both 2002 and 2004 (Table 2). Six species were common to all three surveys: largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), sculpin (Cottidae), rainbow trout (*Oncorhynchus mykiss*), and grass carp (*Ctenopharyngodon idella*). Hatchery planted coho salmon fry (*O. kisutch*) were present in 1999 and 2002, but absent from the 2004 survey. Two species, yellow perch (*Perca flavens*) and peamouth chub (*Mylocheilus caurinus*), showed up in 2002 and persisted in the 2004 survey. In the fall 2002 survey a fairly large number of threespine stickleback (*Gasterosteus aculeatus*) were collected, but none were found in either spring survey; this may be indicative of seasonal differences in habitat use. The 2004 survey included two new species: brown bullhead (*Ameiurus nebulosus*) and northern pikeminnow (*Ptychocheilus oregonensis*).

Table 2. Species Composition by weight and number for fish sampled from Duck Lake, Grays Harbor County, 1999-2004

	Species Composition					
	by Weight		by Number		Size Range (mm TL)	
Type of Fish	(kg)	(%w)	(#)	(%n)	Min	Max
1999						
Largemouth Bass	93.0	72.1	653	47.7	52	477
Bluegill	18.2	14.1	634	46.3	53	203
Black Crappie	5.2	4.0	63	4.6	118	253
Sculpin	0.3	0.2	15	1.1	75	163
Coho	1.0	0.7	2	0.1	175	456
Grass Carp	11.2	8.7	2	0.1	695	726
Rainbow Trout	0.1	0.1	1	0.1	245	245
2002						
Black Crappie	8.3	6.2	903	43.5	44	270
Largemouth Bass	83.8	62.3	553	26.6	32	477
Sculpin	4.0	3.0	400	19.3	22	225
Threespine Stickleback	0.1	0.1	93	4.5	40	60
Coho	9.1	6.7	73	3.5	137	279
Rainbow Trout	19.0	14.1	30	1.4	267	461
Bluegill	0.8	0.6	16	0.8	72	210
Peamouth Chub	0.8	0.6	4	0.2	252	285
Yellow Perch	0.2	0.1	3	0.1	140	177
Grass Carp	8.5	6.3	1	0.0	870	870
2004						
Yellow Perch	11.2	5.4	584	41.8	78	232
Black Crappie	10.9	5.3	401	28.7	60	315
Largemouth Bass	139.3	67.1	190	13.6	50	505
Sculpin	0.9	0.4	96	6.9	52	175
Rainbow Trout	19.9	9.6	87	6.2	222	430
Bluegill	0.7	0.3	18	1.3	70	191
Grass Carp	21.3	10.3	17	1.2	404	466
Northern Pikeminnow	2.3	1.1	2	0.1	465	497
Peamouth Chub	0.6	0.3	2	0.1	270	307
Brown Bullhead	0.6	0.3	1	0.1	320	320

Table 3 shows the stock density indices of fish caught in the three surveys, separated by gear type and length category. The electrofishing PSD for largemouth bass has increased with each survey, and as of 2004 is at 90, indicating an imbalance in the predator/prey ratio. Largemouth bass PSDs below 60 are considered more balanced with available prey (Novinger and Legler 1978). The reason for the increase in Duck Lake PSD becomes clear with the largemouth bass length-frequency distribution graph (Figure 4), and the age-frequency graph (Figure 5) which both show a cluster of year classes dominating both spring surveys (1994-1997). Black crappie PSD declined from a high of 32 in 1999 to single digits the last two surveys. Bluegill had insufficient sample size in the latter two surveys to make any meaningful comparisons.

Table 3. Stock density indices, by gear type and survey, for fish sampled from Duck Lake, Grays Harbor County, 1999-2004

Species	# Stock Length	PSD	Quality 80% CI	Preferred RSD-P	Preferred 80% CI	Memorable RSD-M	Memorable 80% CI	Trophy RSD-T	Trophy 80% CI
1999									
Electrofishing									
Black Crappie	37	32	10	3	3	–	–	–	–
Bluegill	500	12	2	–	–	–	–	–	–
Largemouth Bass	197	35	4	13	3	–	–	–	–
Fyke Net									
Black Crappie	21	38	14	–	–	–	–	–	–
Bluegill	10	30	19	–	–	–	–	–	–
2002									
Electrofishing									
Largemouth Bass	78	60	7	29	7	–	–	–	–
Black Crappie	16	6	8	–	–	–	–	–	–
Rainbow Trout	15	–	–	–	–	–	–	–	–
Bluegill	6	–	–	–	–	–	–	–	–
Yellow Perch	2	–	–	–	–	–	–	–	–
Gill net									
Largemouth Bass	47	66	9	13	6	–	–	–	–
Black Crappie	37	30	10	5	5	–	–	–	–
Rainbow Trout	15	27	15	–	–	–	–	–	–
Bluegill	8	13	15	13	15	–	–	–	–
Fyke net									
Black Crappie	2	–	–	–	–	–	–	–	–
2004									
Electrofishing									
Black Crappie	23	4	5	–	–	–	–	–	–
Bluegill	11	27	17	–	–	–	–	–	–
Largemouth Bass	101	90	4	74	6	–	–	–	–
Rainbow Trout	11	9	11	–	–	–	–	–	–
Yellow Perch	52	12	6	–	–	–	–	–	–
Gill net									
Black Crappie	107	4	2	4	2	2	2	–	–
Bluegill	6	–	–	–	–	–	–	–	–
Largemouth Bass	28	89	7	75	10	–	–	–	–
Rainbow Trout	67	1	2	–	–	–	–	–	–
Yellow Perch	29	21	10	–	–	–	–	–	–
Fvke net									
none									

Catch rate data can be found in Table 4. Comparisons of CPUE data between years is limited to electrofishing CPUE, and only the two fall surveys (1999 and 2004) are compared due to seasonal variations in catch rates (Pope and Willis 1996). From 1999 to 2004 largemouth bass mean CPUE declined 48.4% (P= .0035), and bluegill mean CPUE declined 97.8% (P= .0001).

Change in the black crappie mean CPUE (a decline of 37.4%) was found to be statistically insignificant (P= .2709).

Table 4. Mean Catch Per Unit Effort (CPUE). By gear type and survey, for fish sampled from Duck Lake, Grays Harbor County, 1999-2004

	Electrofishing			**Gill Netting**			**Fyke Netting**		
Species	**(# / hour)**	**80% CI**	**Sample Sites**	**#/net night**	**80% CI**	**# net nights**	**#/net night**	**80% CI**	**# net nights**
1999									
Black Crappie	14.74	7.57	15	-	-	0	5.25	1.69	4
Bluegill	199.33	37.16	15	-	-	0	2.50	2.79	4
Coho	0.40	0.51	15	-	-	0	0.25	0.32	4
Grass Carp	0.80	1.03	15	-	-	0	0.00	-	4
Largemouth Bass	78.42	10.59	15	-	-	0	0.00	-	4
Sculpin, Unknown	5.97	2.60	15	-	-	0	0.00	-	4
2002									
Black Crappie	7.99	3.46	12	4.63	1.55	8	0.25	0.21	8
Bluegill	2.99	1.48	12	1.00	0.54	8	0.13	0.16	8
Coho	23.45	6.90	12	3.25	1.82	8	0.00	-	8
Grass Carp	0.50	0.64	12	0.00	-	8	0.00	-	8
Largemouth Bass	38.97	10.09	12	5.88	2.09	8	0.00	-	8
Peamouth Chub	0.00	-	12	0.50	0.34	8	0.00	-	8
Rainbow Trout	7.46	3.77	12	1.88	2.05	8	0.00	-	8
Sculpin, Unknown	195.27	67.15	12	0.38	0.34	8	0.75	0.47	8
Three-Spine Stickleback	6.49	3.47	12	0.13	0.16	8	9.88	3.88	8
Yellow Perch	1.00	0.86	12	0.13	0.16	8	0.00	-	8
2004									
Black Crappie	9.23	3.51	15	13.38	3.99	8	0.13	0.16	8
Bluegill	4.41	1.91	15	0.75	0.53	8	0.00	-	8
Brown Bullhead Catfish	0.00	-	15	0.13	0.16	8	0.00	-	8
Grass Carp	0.00	-	15	2.13	0.74	8	0.00	-	8
Largemouth Bass	40.48	11.81	15	3.50	1.51	8	0.00	-	8
Northern Pike-Minnow	0.00	-	15	0.25	0.21	8	0.00	-	8
Peamouth Chub	0.00	-	15	0.25	0.21	8	0.00	-	8
Rainbow Trout	4.39	1.39	15	8.38	1.86	8	0.00	-	8
Sculpin, Unknown	38.92	15.24	15	0.00	-	8	0.00	-	8
Yellow Perch	20.76	9.84	15	3.63	1.68	8	0.00	-	8

Largemouth Bass *(Micropterus salmoides)*

From 1999 to 2004 the largemouth bass population of Duck Lake has undergone a distinct transformation in its size and age structure. This transformation has been driven by a large cohort of 1994-1997 brood year fish that has dominated the population for several years.

Table 5. Mean Length-at-age for largemouth bass sampled from Duck Lake, Grays Harbor County, 1999-2004

1999 Survey		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Year Class	**# Fish**												
1998	0												
1997	47	91	152										
1996	28	72	159	215									
1995	35	75	137	222	267								
1994	25	84	151	215	284	318							
1993	14	82	175	260	316	349	374						
1992	17	89	189	276	334	365	395	411					
1991	6	81	178	294	358	393	408	424	435				
1990	5	76	191	283	347	393	417	431	443	454			
Fraser -Lee	**177**	**82**	**157**	**236**	**298**	**349**	**392**	**417**	**438**	**454**			
2002 Survey													
2001	52	69											
2000	27	72	136										
1999	10	68	143	206									
1998	11	85	129	186	249								
1997	13	102	173	233	295	331							
1996	6	68	136	199	253	313	348						
1995	11	69	129	223	275	315	351	374					
1994	10	79	148	226	289	326	356	384	404				
1993	2	87	169	244	308	358	385	402	419	435			
Fraser -Lee	**142**	**75**	**142**	**215**	**276**	**324**	**354**	**381**	**407**	**435**			
2004 Survey													
2003	17	99											
2002	34	72	176										
2001	3	82	144	252									
2000	5	68	129	189	284								
1999	1	71	125	174	242	314							
1998	7	72	121	179	248	306	356						
1997	15	84	148	205	267	316	360	388					
1996	8	78	159	221	272	316	354	383	399				
1995	22	75	140	224	272	306	352	377	399	414			
1994	18	72	148	212	289	331	361	387	406	421	432		
1993	6	75	164	240	298	348	375	394	354	426	439	447	
1992	1	72	151	227	270	318	361	377	401	411	420	426	432
Fraser -Lee	**137**	**78**	**153**	**214**	**275**	**318**	**358**	**384**	**397**	**418**	**433**	**444**	**432**
W WA Ave		**80**	**176**	**265**	**335**	**376**	**417**	**451**	**471**	**493**	**502**	**507**	**503**

Length at age data for largemouth bass are in Table 5. Unlike other types of data (catch rate, relative weight, PSD, etc.), the methods used for computing growth rates are free of seasonal influences, allowing for comparisons of inter-seasonal data. From spring 1999 to fall 2002, the mean length at age for largemouth bass age-1 to age-8 in Duck Lake declined at every age class (*P*= .0001 - .0087), and showed no significant change from 2002 to 2004 for age-1 and age-3 to age-8 (*P*= .0735 - .4528). Age-2 bass mean length at age increased from 2002 to 2004 (*P*=.0077).

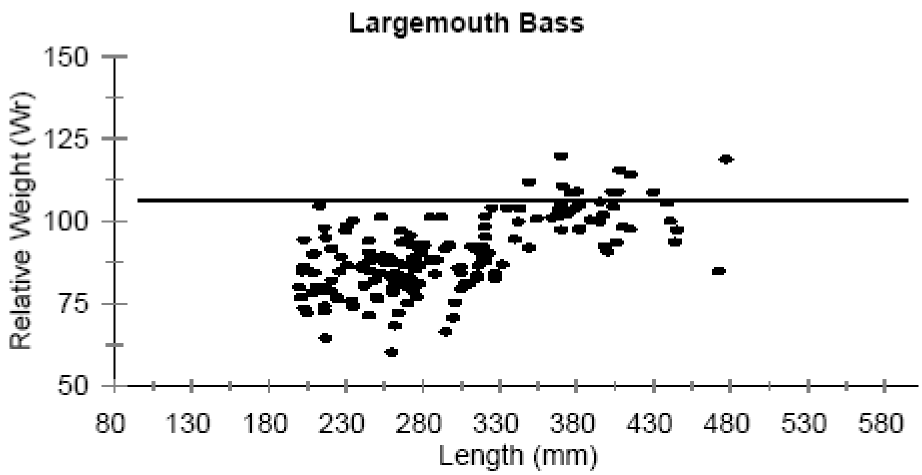

Figure 1. Relative weights of stock-size largemouth bass from the spring 1999 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents the national 75th percentile.

Conversely, the relative weights of the largemouth bass population appear to have increased from 1999 to 2004 (Figures 1-3). The mean relative weights for 1999, 2002, and 2004 are 88, 111, and 108, respectively. A comparison of the two spring surveys shows validates this increase as significant (P<.0001).

The LFD comparison graph (Figure 4) and the age-frequency distribution graph (Figure 5) clearly show the strong 1994-1997 year classes, particularly in the two spring surveys. (The fall 2002 data is included for information purposes but should not be used for comparison.) The increasing PSDs (Table 3) from 1999 to 2004 is further indication of a population dominated by a single year class.

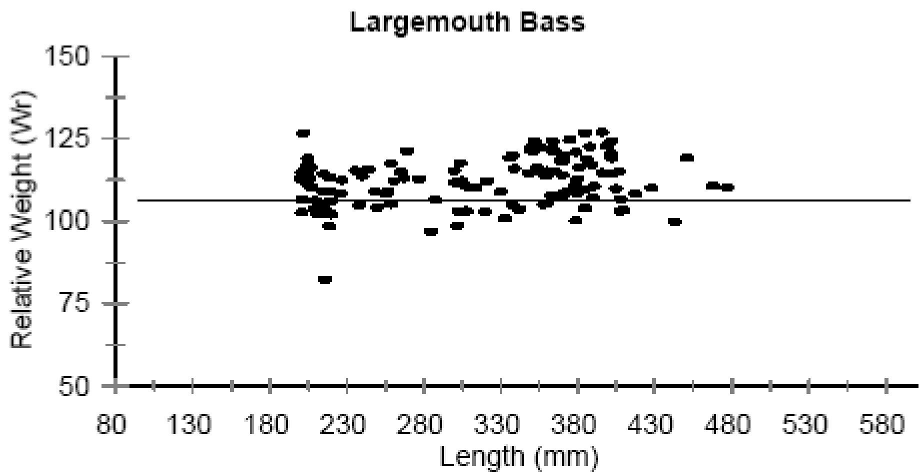

Figure 2. Relative weights of stock-size largemouth bass from the fall, 2002 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents the national 75th percentile.

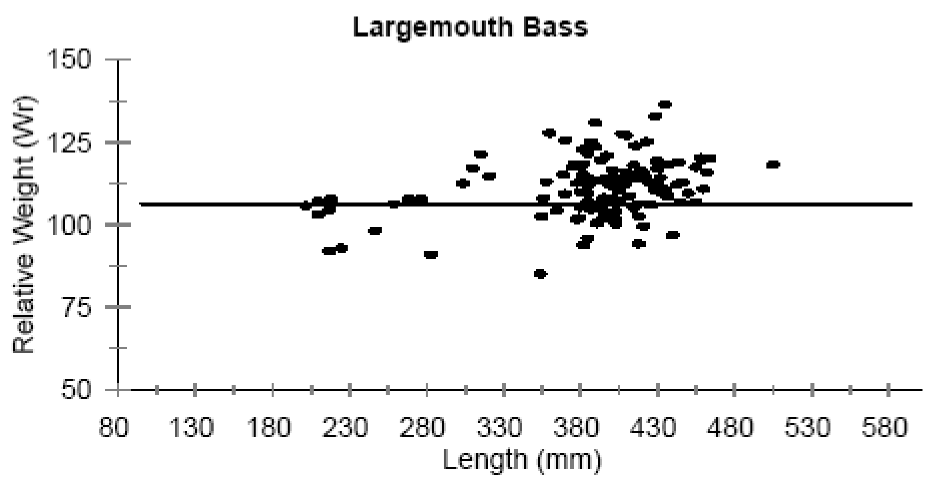

Figure 3. Relative weights of stock-size largemouth bass from the spring, 2004 survey of Duck Lake, Grays harbor County. Horizontal line at 100 represents the national 75th percentile.

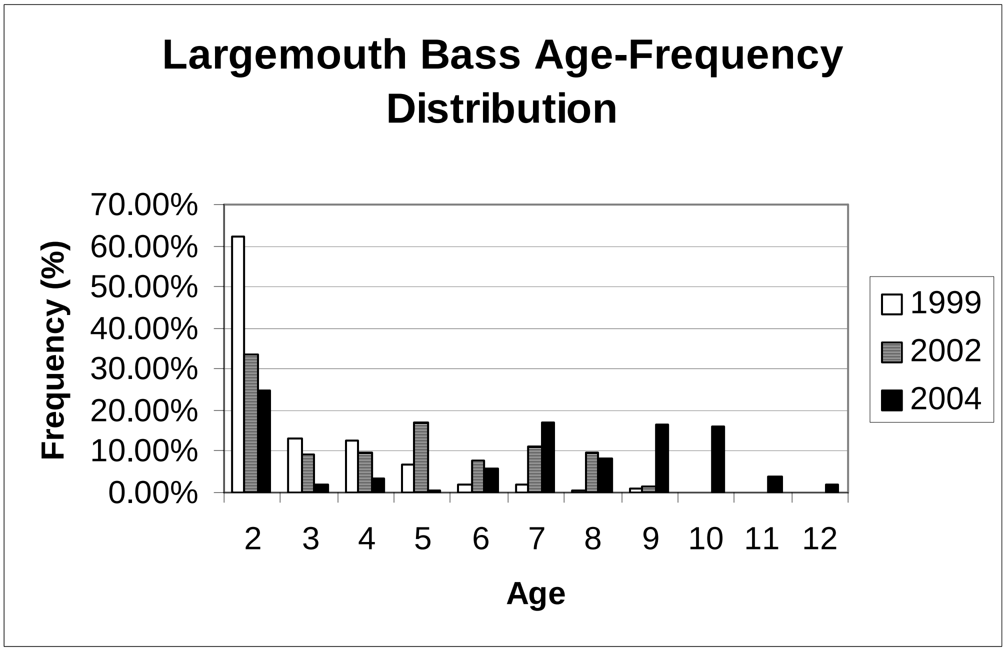

Figure 4. Age-frequency distribution for largemouth bass collected from Duck Lake, Grays Harbor County, 1999-2004.

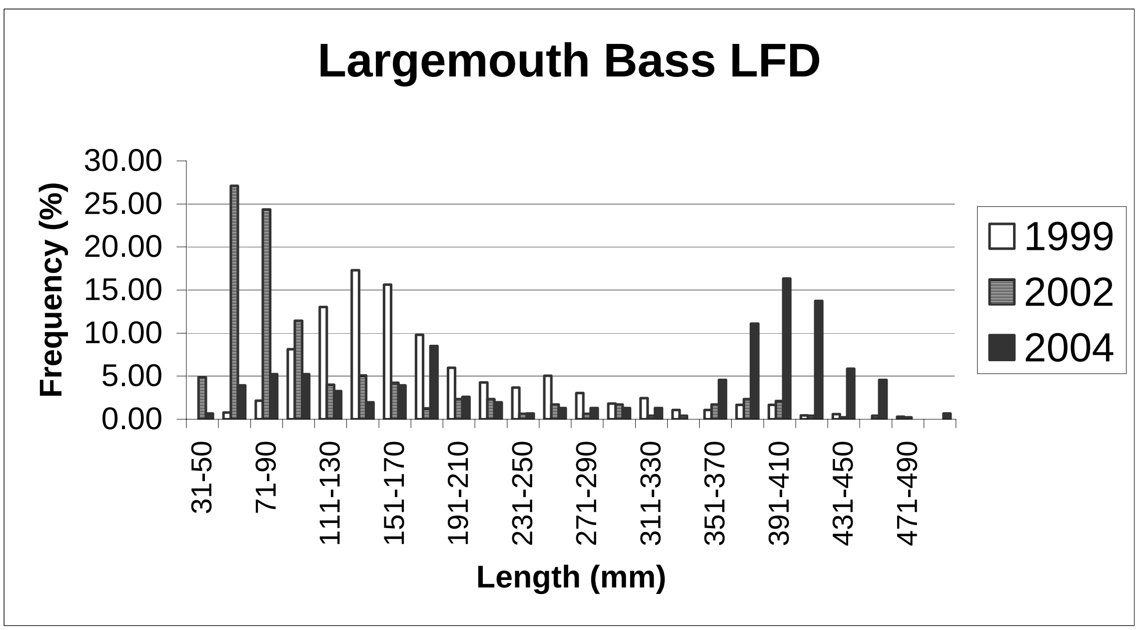

Figure 5. Length-frequency distribution for largemouth bass collected from Duck Lake, Grays Harbor County, 1999-2004.

Bluegill *(Lepomis macrochirus)*

In 1999, the bluegill population of Duck Lake was robust, with a high abundance (electrofishing CPUE of 199.3), solid growth rates (Table 6), and a respectable (if not ideal) PSD of 12. (Bluegill PSDs between 20 - 40 are considered optimal - Novinger and Legler 1978.) By 2004, Duck Lake bluegill appear to be suffering from high mortality, with abundance declining 97.8% (electrofishing CPUE of 4.41). Growth rates were lower in 2004 for age-1 fish (P = .0035), but statistically unchanged for age-2 thru age-4 (P = .0712 - .1295). The mean relative weight did show a significant increase, from 96 in 1999 to 105 in 2004 (P = .0003). The length-frequency distribution is increasingly dominated by fish less than 130 mm (Figure 7).

Table 6. Mean length-at-age for bluegill sampled from Duck Lake, Grays Harbor County, 1999-2004.

Year Class	# Fish	1	2	3	4	5	6	7
1999 Survey								
1998	0	-						
1997	27	45	103					
1996	20	32	87	148				
1995	8	34	76	126	167			
1994	9	34	74	132	163	182		
1993	5	34	80	124	157	176	191	
1992	1	37	85	132	148	160	169	180
Fraser -Lee	**70**	**38**	**90**	**137**	**162**	**178**	**187**	**180**
2002 Survey								
2001	0							
2000	11	31	63					
1999	0							
1998	0							
1997	0							
1996	1	34	75	116	137	171	191	
Fraser -Lee	**12**	**32**	**64**	**116**	**137**	**171**	**191**	
2004 Survey								
2003	0	-						
2002	14	33	88					
2001	1	30	73	151				
2000	1	35	57	137	181			
1999	1	49	89	153	171	191		
Fraser -Lee	**17**	**34**	**86**	**147**	**176**	**191**		
W WA Ave		**37**	**88**	**118**	**161**	**176**	**199**	**201**

The lack of age-0 and age-1 bluegills on the age frequency graph (Figure 6) may be a function of our sampling techniques. Scales are not collected on fish less than 70 mm, and bluegills of that size are well above the average length-at-age for age-1 bluegills (Table 6). Of the 99 bluegills aged from Duck Lake from 1999 thru 2004, none were found to be below age-2. The inability of our sampling techniques to collect and analyze age-0 and age-1 bluegill data creates a knowledge gap regarding bluegill recruitment.

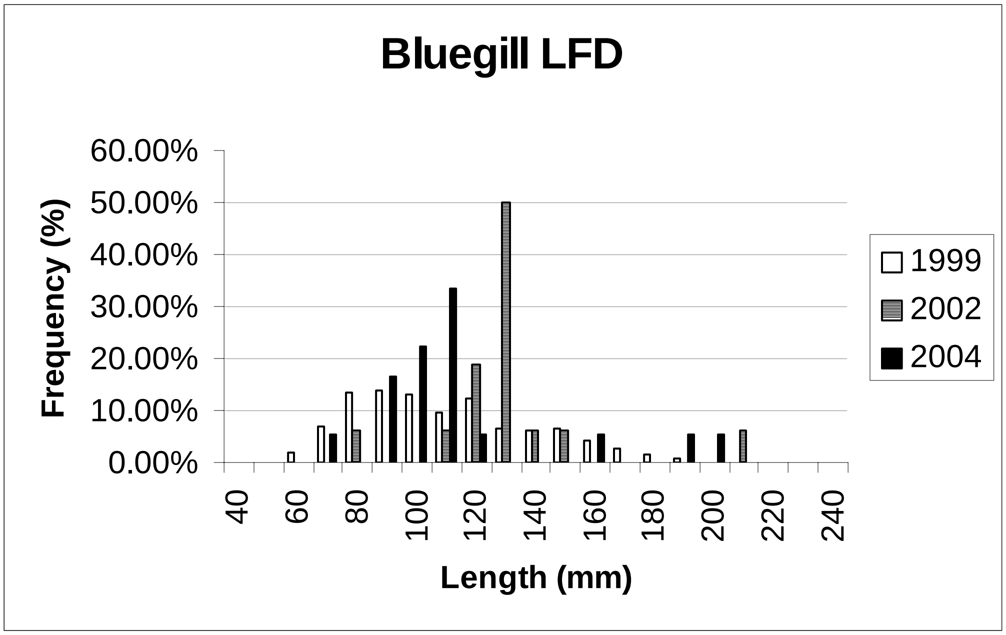

Figure 6. Length-frequency distribution for bluegills collected from Duck Lake, Grays Harbor County, 1999-2004.

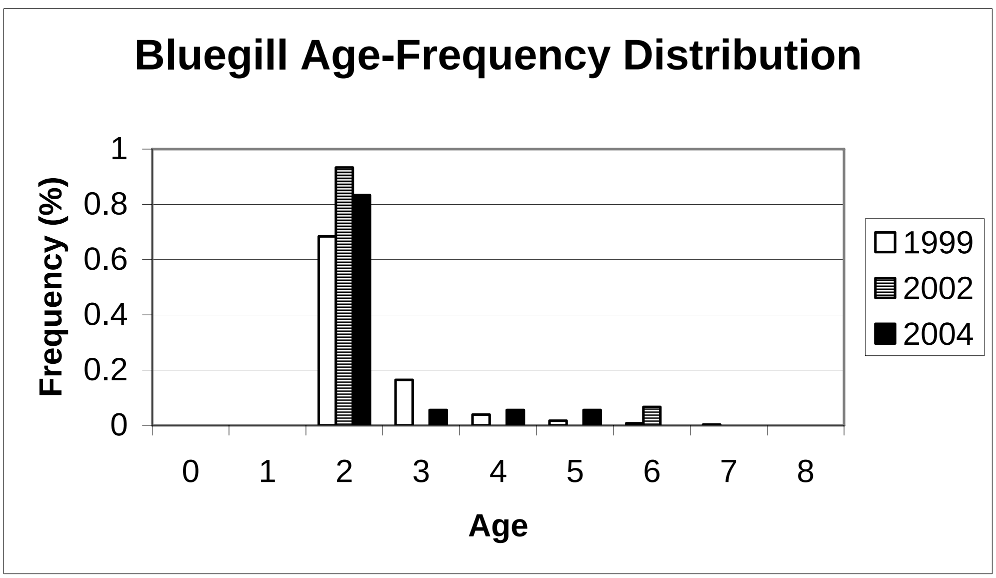

Figure 7. Age-frequency distribution for bluegills collected from Duck Lake, Grays Harbor County, 1999-2004.

Black Crappie *(Pomoxis nigromaculatus)*

The black crappie population of Duck Lake appears to be relatively stable. Length-at-age data for each survey are in Table 7. Differences between surveys are statistically insignificant for most age classes (α = 5%). Differences in spring catch rates (Table 4) and mean relative weights (*P*=.2279) are also statistically insignificant. Mean relative weights are 96 for 1999, 100 for 2002, and 98 for 2004. Relative weights showed a negative trend in relation to length in 1999 and 2002 (Figures 8 and 9), but no trend was clear in 2004 (Figure 10).

Spring PSD declined from 1999 to 2004 (*P*=.0051). The length frequency distribution and age frequency graph (Figures 11 and 12) show a bimodal distribution in the 1999 data due to a strong 1994 year class, and in the 2001 data from a strong 1997 year class. The next big year class appears to be 2002.

Table 7. Mean length-at age for black crappie sampled from Duck Lake, Grays Harbor County, 1999-2004.

Year Class	# Fish	1	2	3	4	5	6	7
1999 Survey								
1998	0	0						
1997	25	81	152					
1996	5	76	142	199				
1995	5	79	130	177	214			
1994	10	76	121	149	186	215		
1993	2	82	133	161	189	212	238	
1992	1	75	110	169	224	241	266	286
Fraser-Lee	**48**	**79**	**140**	**168**	**196**	**217**	**247**	**286**
2002 Survey								
2001	16	66						
2000	18	69	123					
1999	9	59	125	158				
1998	2	54	101	146	173			
1997	5	76	128	159	186	213		
Fraser-Lee	**50**	**66**	**123**	**157**	**182**	**213**		
2004 Survey								
2003	9	88						
2002	33	71	136					
2001	8	66	131	179				
2000	1	72	120	152	195			
1999	0	0	0	0	0	0		
1998	0	0	0	0	0	0	0	
1997	4	80	136	169	196	228	265	295
Fraser-Lee	**55**	**73**	**135**	**174**	**196**	**228**	**265**	**295**
W WA Ave		**70**	**153**	**221**	**259**	**277**	**293**	

The low number of fish caught in 1999 compared to 2002 and 2004 (Table 2) can be accounted for by seasonal variation and gear differences. The 2002 black crappie sample was dominated by age-0 fish (Figure 12) that inflated catch rates, as expected for a fall survey, and 63% of the spring 2004 sample were collected with gill nets that were not used in 1999.

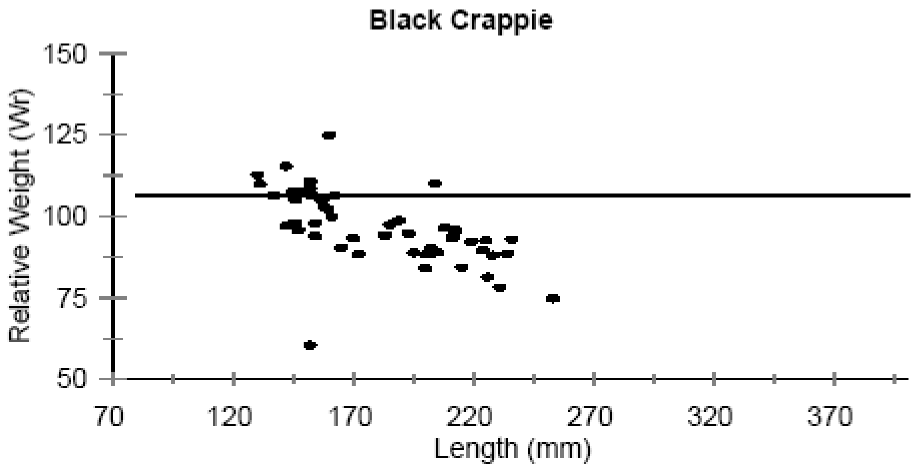

Figure 8. Relative weights of stock-size black crappie from the spring, 1999 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents the national 75th percentile.

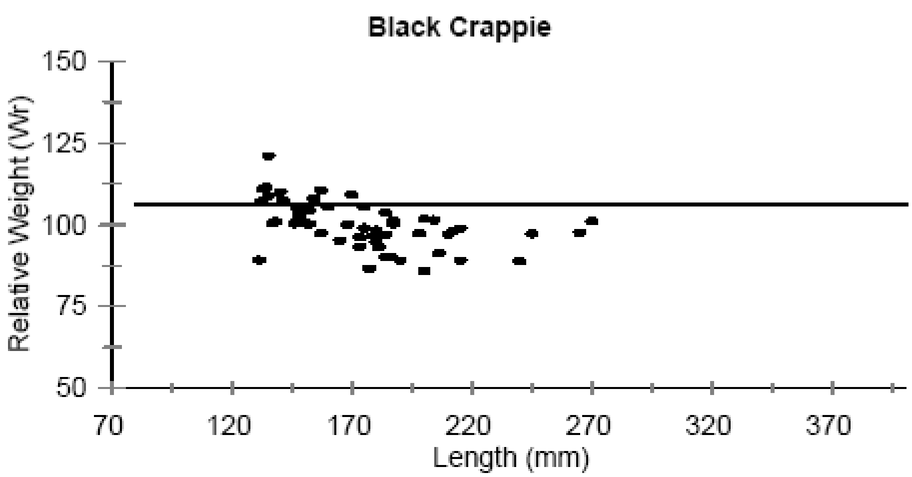

Figure 9. Relative weights of stock-size black crappie from the full, 2002 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents national 75th percentile.

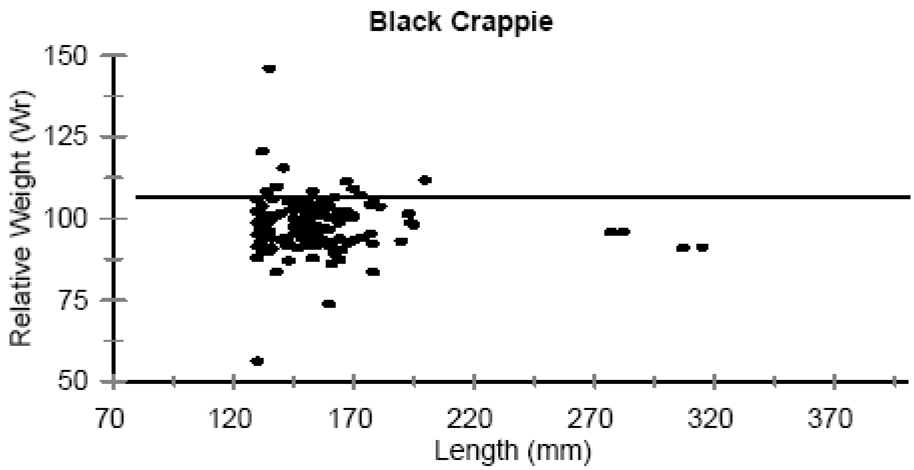

Figure 10. Relative weights of stock-size black crappie from the fall, 2002 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents national 75th percentile.

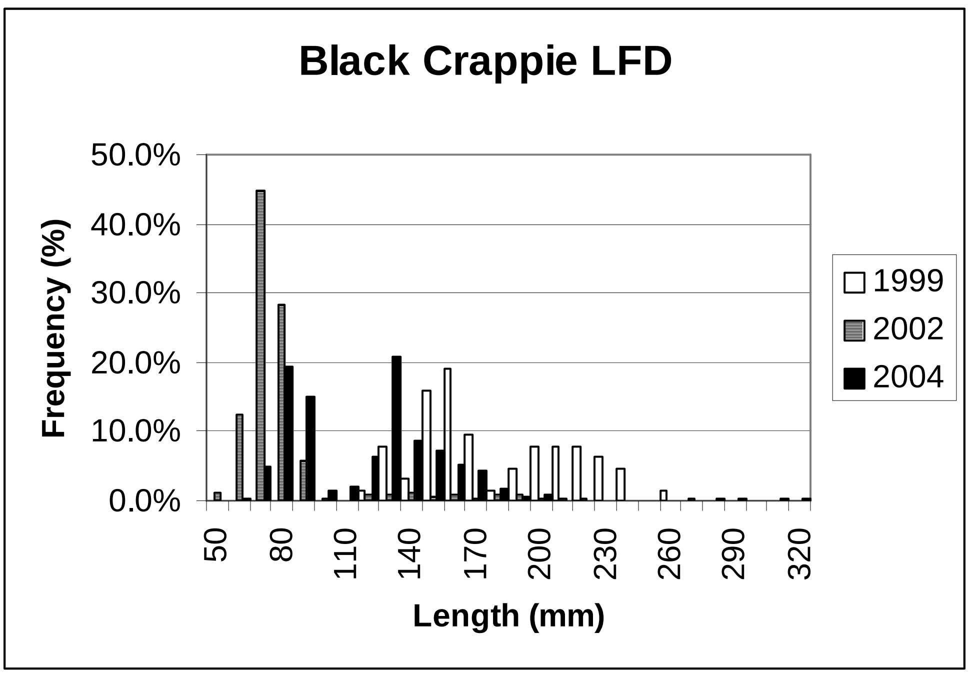

Figure 11. Length-frequency distribution for black crappie collected from Duck Lake, Grays Harbor County, 1999-2004.

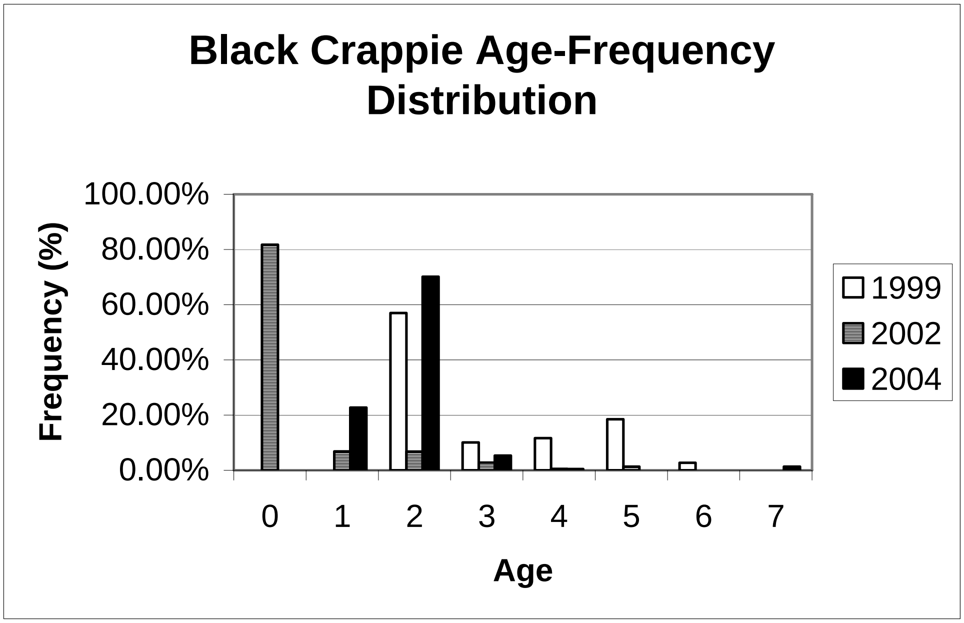

Figure 12. Age-frequency distribution for black crappie collected from Duck Lake, Grays Harbor County, 1999-2004.

Yellow Perch *(Perca flavascens)*

Yellow perch were not sampled in Duck Lake in 1999. In 2002, three yellow perch were collected, all age-1, with an average length-at-age of 84.2 mm. (The western Washington average is 89 mm at age 1.) The sizes ranged from 140 to 177 mm total length (Table 2).

A total of 584 yellow perch were collected in the fall of 2004, representing three age classes (Table 8) and ranging in size from 78 to 232 mm (Table 2). These data point rather convincingly toward an introduction of yellow perch (unauthorized by WDFW) sometime in 2000 or 2001.

Table 8. Mean length-at-age for yellow perch sampled from Duck Lake, Grays Harbor County, 1999-2004.

Year Class	# Fish	1	2	3
2004 Survey				
2003	31	106		
2002	33	92	175	
2001	7	77	160	216
Fraser -Lee 71		**96**	**173**	**216**
W WA Ave		**89**	**159**	**205**

Relative weight data for spring 2004 can be seen in Figure 13. The mean relative weight is 89. Figure 14 shows the length-frequency distribution for the spring 2004 survey.

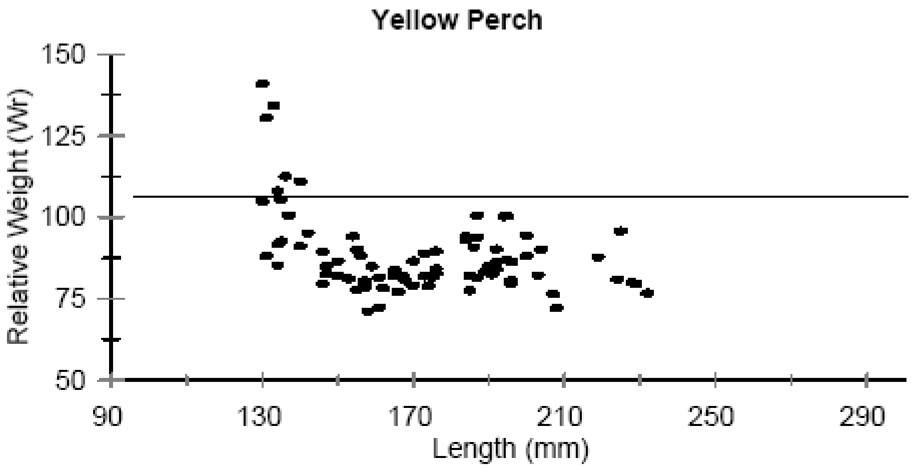

Figure 13. Relative weights of stock-size yellow perch from the spring, 2004 survey of Duck Lake, Grays Harbor County. Horizontal line at 100 represents the national 75th percentile.

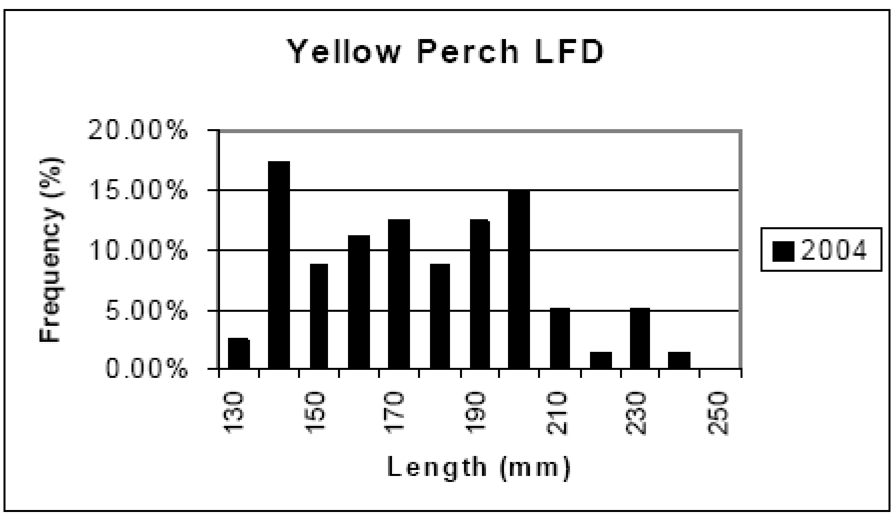

Figure 14. Length-frequency distribution for yellow perch collected from Duck Lake, Grays Harbor County, spring 2004.

Rainbow Trout *(Oncorhynchus mykiss)*

Duck Lake stocking data from 1995 through 2004 show that rainbow, steelhead, and cutthrout trout were all planted into the lake at various times (Appendix B, Duck Lake Stocking Data). Rainbow and steelhead are virtually indistinguishable at the sizes encountered and are considered a single species, *Oncorhynchus mykiss*, (Wydoski and Whitney 2003; Behnke 1992).

Table 9 shows the combined rainbow / steelhead planting data for 1995-2004, with a downward trend in the number of fish planted at all sizes. Our catch data trends in the opposite direction, from 1 fish in 1999, to 30 in 2002, and 87 in 2004. Sizes ranged from 222 to 461 mm (8.7" to 18"), consistent with hatchery planted fish. No age or growth analysis was conducted on these fish.

Table 9. Annual hatchery plants of rainbow trout in Duck Lake, Grays Harbor County, 1995-2004.

	Rainbow trout planted per year									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
fry / fingerlings	121,588	60,560	190,530	43,500	0	62,100	0	0	0	0
catchables	7,220	9,100	7,000	6,340	3,000	3,000	9,000	3,000	3,000	2,000

Grass Carp *(Ctenopharyngodon idella)*

Grass carp were sampled in all three surveys: two in 1999 (695 and 726 mm), one in 2002 (870 mm), and 17 in 2004 (404 - 466 mm). No age or growth analysis was conduced. As mentioned in the Introduction, 2,400 triploid grass carp were planted in Duck Lake in April 1995, and another 5,000 were planted in April, 2002.

Coho *(Oncorhynchus kistuch)*

Excess hatchery coho were planted as fry into Duck Lake in 1998, 1999, and 2000 (279,000 in 1998, 714,100 in 1999, and 100,000 in 2000). Two were sampled in 1999 (175 and 456 mm), and 73 were collected in 2002, ranging from 137 to 279 mm total length. None were sampled in 2004. No age or growth analysis was conducted on these fish. Future plantings of coho are unlikely due to changes in the management of hatchery salmon.

Sculpin (Cottidae)

Scuplins were sampled in all three surveys, and were collected at a much higher rate in the fall survey (Table 2). Sculpins were only identified to the family level, Cottidae. These native fish are not an important game fish and a limited forage fish, so no age or growth analysis was performed on them. The size range was 22 to 225 mm.

Peamouth Chub *(Mylocheilus caurinus*)

No peamouth were sampled from Duck Lake in 1999; four were sampled in 2002, ranging from 252 to 285 mm, and two were collected in 2004, 270 and 307 mm. This native minnow species is not an important game fish, so no age or growth analysis was performed on them.

Threespine Stickleback *(Gasterosteus aculeatus)*

Ninety three of these small, native fish were collected from Duck Lake in 2002, ranging from 40-60 mm. None were collected in either spring survey. In Washington, threespine sticklebacks rarely live beyond one year or grow larger than 75 mm in total length (Wydoski and Whitney 2003). As they are not an important game fish, no age or growth analysis was performed.

Brown Bullhead *(Ameiurus nebulosus)*

A single brown bullhead, 320 mm long, was collected from Duck Lake in 2004. None were sampled in either of the two previous surveys. Wydoski and Whitney (2003) indicate the Washington range of brown bullheads as being entirely east of Grays Harbor county, while in fact they were found in Loomis Lake, Pacific County during a 1997 survey (Mueller 1998).

Northern Pikeminnow *(Ptychocheilus oregonensis)*

Two northern pike minnows were sampled in 2004 (465 and 497 mm); none were collected in either previous survey. These are a native fish and their presence in Duck Lake is not unexpected. No age or growth analysis was conducted on these fish.

Discussion

Changes in the warmwater fish community over the past several years include an increasingly unbalanced population of large, aging largemouth bass, the apparent introduction and proliferation of yellow perch, and a decline in the abundance and growth rates of bluegills. It is reasonable to suggest that these changes are at least partially related to one another.

Several authors have documented the relationship between largemouth bass and bluegill (Anderson 1978; Novinger and Legler 1978; Mittelbach 1981; Guy and Willis 1990; Willis and Paukert 2000). Their collective findings can be summed up as follows: more bass equals smaller bass. More bass also equals fewer bluegill due to increased predation pressure. Fewer bluegill means larger bluegill as stunting pressures are alleviated. The converse is also true: larger bass equals fewer bass equals more and smaller bluegill, as predation pressure decreases and bluegill stunting becomes worse. The explanation for these relationships is that both largemouth bass and bluegill are at a maximum biomass capacity for their environment, and any adjustment in the size-structure or abundance causes a reciprocal adjustment in the other.

The assumptions that largemouth bass and bluegill are at maximum biomass capacity do not appear valid for Duck Lake. From 1999-2004, Duck Lake largemouth bass experienced an increase in size-structure (Table 3), with an expected decrease in abundance (Table 4) (Novinger and Legler 1978; Guy and Willis 1990.) Theoretically this should have resulted in reduced predation pressure on bluegills and increased bluegill abundance. Our data indicates that the opposite happened - bluegill numbers dropped significantly. The best explanation is that largemouth bass abundance did not decline proportionally with the increased size-structure, and predation pressure actually increased. This is possible if the 1999 largemouth bass population was not at maximum biomass capacity, allowing for an increase in largemouth bass biomass as the strong 1994-1997 year classes aged.

The bluegill population also responded differently from literature-cited expectations. Despite the 98% decline in abundance, bluegill showed no statistically significant increases in growth rates for most age classes, with a significant *decline* in age-1 bluegill length-at-age. In another example, the 1999 Duck Lake survey data shows a bluegill population with the highest recorded catch rate of any spring-season lake survey in western Washington (Table 10), but with average or above average lengths-at-age (Table 6). If the population were overcrowded and stunted, one would expect below average growth. It is possible that the 1999 bluegill population was not at maximum biomass capacity despite the high abundance, so the decrease in abundance subsequent to 1999 did not relieve any overcrowding pressure - there wasn't any overcrowding to relieve.

Table 10. Bluegill electrofishing catch rates, PSD, and number of stock fish collected in western Washington spring surveys, 1999-2004.

Lake	Season	Year	CPUE - EB	PSD - EB	# stock
Duck Lake	**spring**	**1999**	**193.70**	**12**	**485**
Swofford Pond	spring	2004	55.86	52	64
Silver Lake	spring	2000	45.31	24	441
Silver Lake	spring	2001	38.46	36	77
Lake Terrell	spring	1999	29.75	7	30
Lake St. Clair	spring	2000	27.00	25	69
Horseshoe Lake	spring	2001	20.40	21	34
Tanwax Lake	spring	2000	5.35	27	11
Duck Lake	**spring**	**2004**	**4.41**	**27**	**11**
Long Lake	spring	2000	3.20	50	8
Big Chambers Lake	spring	1999	3.00	0	5
Ohop Lake	spring	2000	1.33	50	2
Loomis Lake	spring	2001	0.50	0	4
Harts Lake	spring	1999	0.00	0	0
Lake Desire	spring	1999	0.00	0	0
Lawrence Lake	spring	2003	0.00	0	0
Spanaway	spring	2000	0.00	0	0

Adding to this scenario is the introduction of a competitor, yellow perch. Schneider (1997) documented a decline in yellow perch biomass, abundance, and size of large fish, despite constant recruitment, after the introduction of bluegill into the walleye - yellow perch dominated community of a Michigan lake. Aday et al. (2003) compared bluegill populations in 10 Illinois lakes with sympatric populations of gizzard shad, another competitive zooplantivore, against bluegill populations in 10 lakes without gizzard shad. They found that competition with gizzard shad reduced the adult size structure and increased density of bluegills. Although yellow perch and bluegills are known to co-exist in a state of equilibrium (Willis and Paukert 2000), it is also apparent from Schneider (1997) and Aday et al. (2003) that the effects of competition likely limit the growth potential (some combination of abundance and size-structure) of one or both species. Although direct competition pressures in Duck Lake are probably modified by the low bluegill abundance and a yellow perch population that has not yet achieved its maximum potential, the presence of yellow perch in Duck Lake has the ability to affect the population structure of bluegill in the future.

Bluegill numbers in Duck Lake may rebound as aging takes its toll on the 1994-1997 year classes of largemouth bass. However, they may never achieve pre-1999 abundance levels due to competition with yellow perch. It is hoped that once predation pressures normalize, bluegill and yellow perch will establish an equilibrium.

There are a number of factors that may have contributed to the abundance and size-structure of the largemouth bass and bluegill populations of Duck Lake that were not taken into account in this survey. The decline in bluegill abundance could be the result of such things as disease, loss of habitat, recruitment failure, increased harvest mortality, or a decline in food resources. Although not directly measured, inferences can be made about these possibilities. For example, none of the bluegills sampled showed any overt signs of disease. Habitat alterations have occurred, but not anywhere near the rate of bluegill decline. Recruitment failure seems unlikely since all year classes seem equally affected. Increased harvest mortality or a decline in food resources should have affected more than just bluegill. Future fish surveys of type described in this paper will yield more information on the largemouth bass - bluegill relationship in western Washington. Should bluegill numbers fail to respond as expected to changes in the largemouth bass population, other causes of the bluegill decline may have to be explored.

In September, 2004, approximately 5600 age-0 black crappie fry were planted in Duck Lake. Although these fish were not marked or tagged in any way, their inclusion in the fishery and impact on the black crappie population of the lake will be measured in future surveys. The stability of the black crappie population prior to planting and the availability of data from three surveys in the past five years will provide an excellent backdrop against which to evaluate the effects of this planting.

Management Considerations

Duck Lake is managed as a mixed-species fishery, with annual trout plantings and a reputation as a destination largemouth bass lake. The numerous water bodies and canals provide for a wide range of fishing opportunities and experiences. Two public boat launches, owned by the city of Ocean Shores, provide ample access.

At the request of lake residents and the City of Ocean Shores, heavy aquatic plant growth, particularly Brazilian Elodea, is currently being managed with triploid grass carp. Habitat surveys conducted by the Washington Department of Ecology and private consultants from 2000-2003 indicate that the initial grass carp introduction did not produce the desired results, as Brazilian Elodea is actually spreading (Kathy Hamel, DOE, pers. comm.) Effects of the second grass carp planting have yet to be measured. Using grass carp to micro-manage the level of vegetation desired by residents without reducing it below the needs of the fish community is difficult at best. (Crowder and Cooper 1984; Olson et al. 1998; Pothoven et al. 1999).

Bluegill recovery could be hastened with temporary sport regulation changes decreasing bluegill harvest and/or increasing harvest on large largemouth bass, either of which should reduce bluegill mortality. Data on bluegill recruitment could be collected, but would require different sampling techniques than are currently included in our standardized sampling protocols. The unfortunate introduction of yellow perch creates a potential hindrance to bluegill growth and survival that can only be corrected through a complete lake rehabilitation, an unlikely option given the size of Duck Lake and the current management environment.

The information generated by conducting three surveys in Duck Lake over the course of five years increased significantly with each subsequent survey. Some species were found in much higher numbers (sculpin), or exclusively (threespine stickleback), in the fall survey. Some fish were not encountered until the third survey (brown bullhead, northern pikeminnow). Trend data could not be compared until two surveys were conducted in the same season (in different years). The short time-frame between surveys limits the introduction date of yellow perch to within a year or two, providing an opportunity to study the early development of a yellow perch population and its impacts on the rest of the warmwater fish community. These benefits highlight the advantages of conducting several surveys on the same lake over the course of a shorter time frame (2-4 years).

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Appendix A

Table 11 Length Categories that have been proposed for various fish species. Measurements are for total lengths (updated from Neumann and Anderson 1996).

	Category									
	Stock		Quality		Preferred		Memorable		Trophy	
Species	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)
Black bullhead	6	15	9	23	12	30	15	38	18	46
Black crappie	5	13	8	20	10	25	12	30	15	38
Bluegill	3	8	6	15	8	20	10	25	12	30
Brook trout	5	13	8	20						
Brown bullhead	5	13	8	20	11	28	14	36	17	43
Brown trout	6	15	9	23	12	30	15	38	18	46
Burbot	8	20	15	38	21	53	26	67	32	82
Channel catfish	11	28	16	41	24	61	28	71	36	91
Common carp	11	28	16	41	21	53	26	66	33	84
Cutthroat trout	8	20	14	35	18	45	24	60	30	75
Flathead catfish	11	28	16	41	24	61	28	71	36	91
Green sunfish	3	8	6	15	8	20	10	25	12	30
Largemouth bass	8	20	12	30	15	38	20	51	25	63
Pumpkinseed	3	8	6	15	8	20	10	25	12	30
Rainbow trout	10	25	16	40	20	50	26	65	31	80
Rock bass	4	10	7	18	9	23	11	28	13	33
Smallmouth bass	7	18	11	28	14	35	17	43	20	51
Walleye	10	25	15	38	20	51	25	63	30	76
Warmouth	3	8	6	15	8	20	10	25	12	30
White catfish	8	20	13	33	17	43	21	53	26	66
White crappie	5	13	8	20	10	25	12	30	15	38
Yellow bullhead	4	10	7	18	9	23	11	28	14	36
Yellow perch	5	13	8	20	10	25	12	30	15	38

Appendix B

Table 12. Fish plant data for Duck Lake, Grays Harbor County, 1995-2004.

Date of Release	Species	Brood Year	Size	Number
March-95	rainbow	1993	Legals	600
May-95	rainbow	1993	Legals	500
May-95	rainbow	1994	Fry	14,994
May-95	rainbow	1994	Fry	14,994
May-95	rainbow	1994	Fry	12,600
April-95	rainbow	1993	Legals	6,120
July-95	steelhead	1995	Fry	79,000
April-96	rainbow	1994	Legals	9,100
June-96	rainbow	1995	Fry	60,560
March-97	rainbow	1996	Legals	7,000
April-97	rainbow	1996	Fry	36,800
May-97	rainbow	1996	Fry	16,080
June-97	steelhead	1997	Fry	9,700
July-97	steelhead	1997	Fry	51,250
July-97	steelhead	1997	Fingerling	26,000
September-97	steelhead	1997	Fingerling	32,100
September-97	steelhead	1997	Fingerling	3,600
October-97	cutthroat	1997	Fry	15,000
April-98	rainbow	1997	Legals	5,840
April-98	steelhead	1996	Smolt	500
June-98	coho	1997	Fingerling	279,000
August-98	steelhead	1998	Fingerling	31,500
September-98	steelhead	1998	Yearlings	12,000
April-99	rainbow	1997	Legals	3,000
September-99	coho	1998	Fingerling	100,000
July-99	coho	1998	Fingerling	149,100
July-99	coho	1998	Fingerling	28,900
July-99	coho	1998	Fingerling	117,600
July-99	coho	1998	Fingerling	96,000
July-99	coho	1998	Fingerling	39,000
July-99	coho	1998	Fingerling	183,500
April-00	rainbow	1998	Legals	3,000
May-00	coho	1999	Fingerling	100,000
September-00	steelhead	2000	Fingerling	62,100
April-01	rainbow	1999	Legals	2,400
April-01	rainbow	1999	Legals	6,600
April-02	rainbow	2000	Legals	3,000
April-03	rainbow	2001	Legals	3,000
April-04	rainbow	2002	Legals	2,000
September-04	black crappie	2004	Fry	5,628