1998 Sunset Pond Survey: The Warmwater Fish Community In a Disturbed, Urban System and Salmonid Migration Route

by

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Introduction and Background

Sunset Pond is a small, constructed body of water located in Whatcom County within the city limits of Bellingham, Washington. Sunset Pond, occurring on river km 4 of Squalicum Creek, and Bug Lake, occurring on river km 3.5, were carved directly into the watercourse during the construction of Interstate-5 in the 1960's, and now function as part of a flood control system for the city of Bellingham. Sunset Pond is eleven m deep and five ha in surface area (Table 1). Bug Lake is six m deep and 2.5 ha, but much of the lake is only one to two m deep resulting in a lower volume than Sunset Pond. Both of these riverine ponds are productive, highly stratified throughout most of the year, and fished year round for introduced largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ameiurus nebulosus*), yellow bullhead (*Ameiurus natalus*), native steelhead trout (*Oncorhynchus mykiss)*, and native cutthroat trout (*Oncorhynchus clarki*). These water bodies represent potential rearing habitat and refugia from summer low flows and winter high flows for juvenile salmonids (R.W. Beck and Associates 1994). However, illegally introduced species of the families Centrarchidae, Ictaluridae, and Percidae are well suited to conditions in these ponds, and may compete with and prey upon salmonids.

Table 1. Morphometry of Sunset Pond and Bug Lake as determined from 1:24,000 USGS hydrology and digitized field survey data by geographic information system analysis.

Morphometric Measurement	Sunset Pond	Bug Lake
Surface Area (m^2)	49,865	24,895
Volume (m^3)	149,512	33,904
Perimeter (m)	1,526	928
Maximum Depth Z_{max} (m)	11	8
Mean Depth Z_{mean} (m)	3	1.4
Shoreline Development	1.9	1.6

The Squalicum Creek system historically supported populations of anadromous fish and formed a migration route for chum salmon (*Oncorhynchus keta*), coho salmon (*Oncorhynchus kisutch*), steelhead trout, and sea-run cutthroat trout. Squalicum Creek is one of the largest independent drainages in Whatcom County. Originating in the hills west of the Nooksack Basin it flows westward, draining 6,750 hectares of early successional forested, agricultural, residential, and urban areas around and within the city of Bellingham into Bellingham Bay. The watershed is independent of the Cascade foothills and is not influenced by mountain snowmelt. A third order stream, Squalicum Creek and its adjoining tributaries consist of 84 km of stream habitat. However, culverts bar salmonid migration from as much as 12 km of stream reaches that include adequate salmonid spawning and rearing habitat in the upper watershed (WDFW Spawner Escapement Survey Report 1998, Downen 1999). Native lotic fish species include coho salmon, steelhead trout, cutthroat trout, three-spine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper)*, western brook lamprey (*Lamptera richardsoni*), and Pacific lamprey *(Lampetra tridentata*).

Squalicum Creek and Sunset Pond lie in a watershed dominated by human activity and associated disturbance regimes. Historically, Squalicum Creek flowed through lowland forests of western red cedar, Douglas fir, big leaf maple, alder, and willow (R.W. Beck and Associates 1994). Today, upper portions of the watershed, above river km 6 on Squalicum Creek, are agricultural, residential, or forested with second growth vegetation. These land uses impose disturbance regimes characterized by vegetation removal, elevated water temperatures, summer low flow, lowered dissolved oxygen, encroachment of invasive grasses, sedimentation, and streambed disturbance (Brown and Krygier 1970; Lenth 1995). Impervious surfaces have expanded steadily in the lower portion of the watershed below river km 6 of Squalicum Creek, that channel storm water runoff, tainted with fertilizers, trace heavy metals, hydrocarbons, and organic wastes (Herrera Environmental Consultants Inc. 1991). Land uses throughout the lower watershed are primarily urban, residential, and industrial, and these impose disturbance regimes characterized by heavy storm water runoff, extreme discharge peaks, sedimentation, scouring, and non-point source pollution (Casper 1994; R.W. Beck and Associates 1994).

The relevance of these conditions to salmonid restoration and persistence in lowland stream systems resulted in an examination of outmigration timing, species composition, environmental conditions, growth, mortality and life histories of salmonids inhabiting the watershed. Downen (1999) monitored the outmigration of salmonids with a complete smolt trap between 21 March and 21 June 1998. Although fish appeared in the trap in small numbers, beginning in March when the full-spanning smolt trap was installed, 83% of the run occurred between 25 May and 1 June during a single discharge event, coincident with a new moon (Figure 1). Positive correlations for all species were significant with respect to timing. The outmigration consisted of 7,168 coho salmon, 1,270 cutthroat trout, 180 steelhead trout, 6 fall-run chinook salmon, and 423 marked Skookum hatchery stock coho salmon with estimated instantaneous growth rates of 3.7, 3.8, 4.2, 11.1 and 4.9, respectively. In view of conformity with assumptions and using Peterson mark and recapture data collected from two release groups, exploitation and initial population estimates were calculated for the coho salmon parr population as 0.57 and 12,575, and 0.42 and 17,066, respectively. Estimated instantaneous mortality for marked coho salmon released in Sunset Pond, marked coho salmon released in Bug Lake, and system-reared coho salmon were 2.2, 3.5, and 2.3, respectively. Ninety-six percent of coho salmon, 41% of steelhead trout, and 14% of cutthroat trout migrated at age 1 (Table 2). The balance of these populations migrated at age 2 with the exception of 4% of cutthroat trout and 1% of steelhead trout migrating at age 3. All fall-run chinook were age-0 fingerlings. Seventy-nine adult cutthroat trout and four steelhead trout were also retained in the trap between 21 March and 21 June. Life history patterns for adult fish were characterized by short freshwater residence times and rapid growth prior to their first seaward migration.

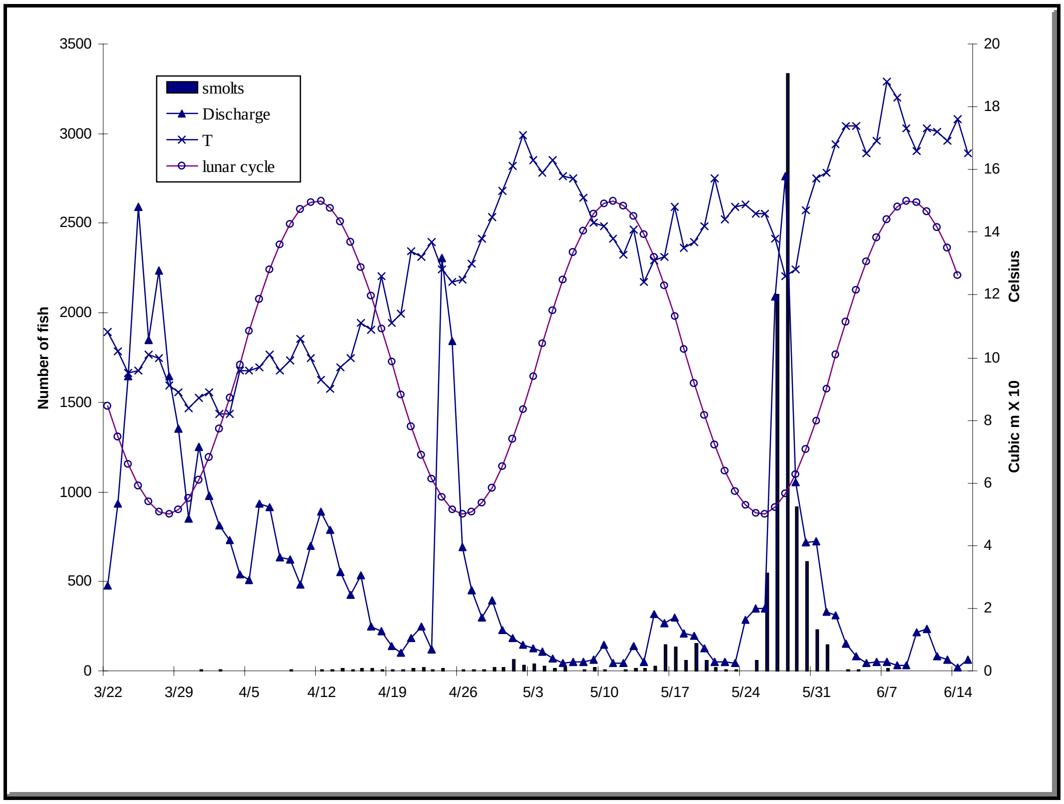

Figure 1. Temporal distribution of coho, cutthroat and steelhead smolt outmigration with respect to temperature, discharge, and lunar cycle from Squalicum Creek between 22 March and 15 June 1998. Maxima of lunar cycle series correspond to full moons and minima correspond to new moons.

Table 2. Number, proportion of migration by species and mean fork Length by age of coho salmon, cutthroat trout, and steelhead trout outmigrating from Squalicum Creek, Washington between 21 March and 21 June, 1998.

Species	**Age**		
	1	**2**	**3**
Coho salmon			
Number	1752	68	
Proportion	0.96	0.04	
Mean FL±SD	140 ± 19.1	178 ± 19.6	
Cutthroat trout			
Number	70	393	22
Proportion	0.14	0.81	0.05
Mean FL±SD	129 ± 17.9	203 ± 26.3	242 ± 34.5
Steelhead trout			
Number	59	83	2
Proportion	0.52	0.47	0.01
Mean FL±SD	183 ± 14.4	200 ± 20.4	250 ± 14.1

Downnen collected extensive data on salmonid populations and some limited data from introduced fish populations the previous spring. Rapid growth, high mortality, and decreased freshwater residence time for salmonids appeared correlated with environmental conditions in this disturbed system. The presence of some of the previously mentioned introduced species was confirmed, and downstream dispersal of age-1 largemouth bass feeding on coho salmon fry was observed. However, the relative abundance, growth, and condition of introduced species were unknown in Sunset Pond, their principal habitat in the Squalicum Creek system, Assessing the potential for ecological interactions between salmonids and introduced fish species required an assessment of introduced populations as well. To this end the Warmwater Enhancement Program of the Washington Department of Fish and Wildlife (WDFW) conducted a warmwater stock assessment of Sunset Pond during fall of 1998.

Materials and Methods

Two WDFW biologists and one scientific technician surveyed Sunset Pond during September29 through October 3, 1998. Fish were captured using three sampling techniques: electrofishing, gill netting, and fyke netting. The electrofishing unit consisted of a 4.9 m Smith-Root 5.0 GPP electrofishing boat set to a DC current of 120 cycles/sec at 3 to 4 amps power. Experimental gill nets (45.7 m long × 2.4 m deep) were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size (13, 19, 25, and 51 mm stretched) monofilament mesh. Fyke nets were constructed of a single 30.4 m-lead and two 15.2 m-wings of 130 mm nylon mesh. They body of the nets contained four 1.2 m aluminum rings each.

Sampling locations were selected by dividing the shoreline into 3 consecutively numbered sections of about 400 m each as determined from a 1:24,000 USGS map (Figure 2). Essentially the entire shoreline was sampled by electrofishing the three sections. However, the vicinities of two beaver lodges were avoided to prevent injury to their occupants. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of approximately 18.3 m/minute. Two gill nets were set perpendicular to the shoreline. The small-mesh end was attached onshore while the large-mesh end was anchored offshore.

Two fyke nets were set in water less than 3 m in depth, perpendicular to the shoreline with wings extended at 70° angles from the lead. Sampling occurred during evening hours to maximize the

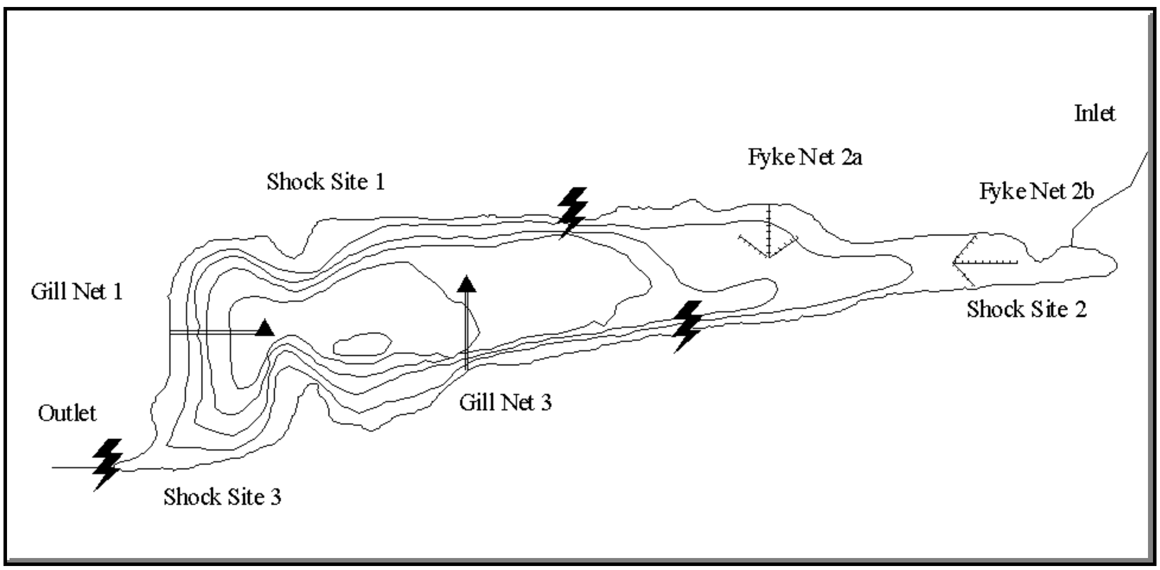

Figure 2. Hydrography and bathymetry of Sunset Pond (Whatcom County) and sampling locations of the 1998 stock assessment.

type and number of fish captured. In order to reduce bias between techniques and standardize effort, the sampling time for each gear type was standardized to a ratio of 1:1:1 (Fletcher et al. 1993) as follows: total electrofishing time was one unit of 1,800 sec (actual pedal-down time), or roughly three sections of 600 sec each; total gill netting and fyke netting time was one unit of 24 h (= 2 net nights) for each net type.

All fish captured were identified to species. Each fish was measured to the nearest 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. Fish were weighed to the nearest 0.5 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 5 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). Scales were also measured for standard back-calculation of growth. However, a lack of technical resources precluded aging members of the family Ictaluridae (catfish). Furthermore, given the emphasis of this study on warmwater species, growth was not assessed for salmonid and non-game fish and only small samples of these fish were aged from scales.

Water quality data was collected during midday from two basins on September 10, 1997. 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 m (Table 3).

Table 3. Water quality from two basins (west and east end) on Sunset Pond (Whatcom County). Samples were collected midday on October 2, 1998.

		Parameter					
Location	**Secchi (m)**	**Depth (m)**	**DO (mg/L)**	**Temp (°C)**	**pH**	**Conductance (uS/cm)**	**TDS (g/L)**
East end	1.4 m	1	7.69	16.51	8.23	164.1	0.1049
		2	7.30	16.44	8.00	163.8	0.1048
		3	7.10	16.41	7.93	163.7	0.1047
		4	6.78	16.03	7.87	165.7	0.1055
West end	1.7 m	1	7.76	16.52	8.16	162.7	0.1044
		2	7.41	16.51	8.07	162.9	0.1044
		3	7.53	16.48	8.04	163.2	0.1045
		4	7.07	16.44	7.96	162.5	0.1039
		5	1.34	12.88	7.68	147.9	0.0956
		6	0.33	9.51	7.25	187.2	0.1191
		7	0.25	8.55	7.22	227.0	0.1442
		8	0.16	8.31	7.07	515.7	0.3196

Data Analysis

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

We determined species composition by weight (kg) of fish captured using procedures adapted from Swingle (1950). The species composition by number of fish captured was determined using procedures outlined in Fletcher et al. (1993). While young-of-year or small juveniles are often not considered because large fluctuations in their numbers may distort results (Fletcher et al. 1993), we chose to include them since their relative contribution to total species biomass was small. Moreover, the overall length frequency distribution of fish species may suggest successful spawning and initial survival during a given year, as indicated by a preponderance of fish in the smallest size classes. Although many of these fish would be subject to natural attrition during their first winter (Chew 1974), resulting in a different size distribution by the following year, the presence of these fish in the system relates directly to fecundity and interspecific and intraspecific competition at lower trophic levels (Olson 1997).

Catch per unit effort (CPUE) by gear type was determined for each warmwater fish species (number of fish/hour electrofishing and number of fish/net night). Only stock size fish and larger were used to determine CPUE. 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 ± $t_{(\alpha, N\text{-}1)} \times SE$, where t = Student's t for α confidence level with N-1 degrees of freedom (two-tailed) and SE = standard error of the mean. Since it is standardized, CPUE is a useful index for comparing relative abundance of stocks between lakes and the confidence intervals express the relative uniformity of species distributions throughout the lakes.

The size structure of each species captured was evaluated by constructing a stacked length frequency histogram (percent frequency of fish in a given size class captured by each gear type). Although length frequencies are generally reported by gear type, we report the length frequency of our catch with combined gear types which is then broken down by the relative contribution each gear type makes to each size class. Selectivity of gear types not only biases species catch based on body form, and behavior, but also based on size classes within species (Willis et al. 1993). Therefore, an unbiased assessment of length frequency is unlikely under any circumstance. Our standardized 1:1:1 gear type ratio adjusts for differences in sampling effort between sampling times and locations. Furthermore, differences in size selectivity of gear types may in some circumstances, result in offsetting biases (Anderson and Neumann 1996). Length frequency proportions for each gear type are divided by the total numbers of fish caught by all gear types for each size class. This changes the scale but not the shape of the length frequency percentages 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. Salmonid size structures were evaluated with stacked length frequency histograms as well.

The proportional stock density (PSD) of each warmwater fish species was determined following procedures outlined in Anderson and Neumann (1996). PSD, which was calculated as the number of fish≥quality length/number of fish≥stock length×100, is a numerical descriptor of length frequency data that provides useful information about size class structure. 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 4). 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 size class structure, but is more sensitive to changes in year-class strength. RSD was calculated as the number of fish≥specified length/number of fish≥stock length×100. For example, RSD P was the percentage of stock length fish that also were longer than preferred length, RSD M, the percentage of stock length fish that also were longer than memorable length, and so on. Eighty-percent confidence intervals for PSD and RSD were selected from tables in Gustafson (1988).

Table 4. Length categories for warmwater fish species by Gabelhouse (1984) used to calculate stock density indices (PSD,RSD) for fish captured at Sunset Pond (Whatcom County) during early fall 1998. Measurements are minimum total lengths (mm) for each category (Willis et al. 1993; Bister et al. unpublished data).

Species	Size				
	Stock	Quality	Preferred	Memorable	Trophy
Yellow perch	130	200	250	300	380
Yellow Bullhead	100	180	230	280	360
Brown bullhead	130	200	280	360	430
Largemouth bass	200	300	380	510	630
Bluegill	80	150	200	250	300

Bister et al. Dept. of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, South Dakota 57007.

Age and growth of warmwater fishes in Sunset Pond 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 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 Sunset Pond fish and the state average (listed in Fletcher et al. 1993) for the same species.

A relative weight (W_r) index was used to evaluate the condition of fish in the lake. A W_r value of 100 generally indicates that a fish is in good condition when compared to the national standard (75th percentile) for that species. Furthermore, W_r is useful for comparing the condition of different size groups within a single population to determine if all sizes are finding adequate forage or food (ODFW 1997). Following Murphy et al.(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 coho salmon, the W_r values from this study were compared to the national standard ($W_r = 100$) and were available, with 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 early fall 1998, our sample from the fish community of Sunset Pond was dominated by warmwater species, primarily age-1 largemouth bass and older yellow perch. Together, largemouth bass and yellow perch accounted for about two-thirds of the biomass and number captured, 48% and 20% by weight, respectively. Bluegill accounted for only 16% of the species composition by biomass but 25% by number. Members of the family Ictaluridae made up 4% of the biomass and number while salmonids accounted for 10% of the biomass and number of fish captured (Table 5).

Table 5. Species composition by weight (kg) and number of fish captured at Sunset Pond (Whatcom County) during an early fall 1997 survey of warmwater fish.

Species	Species Composition by weight (kg)	by weight (%w)	by number (#)	by number (%n)	Size Range (mm TL)
Largemouth bass (*Micropterus salmoides*)	16.047	48.448	280	53.232	50-445
Yellow perch (*Perca flavescens*)	6.898	20.826	52	9.886	92-271
Bluegill (*Lepomis macrochirus*)	5.525	16.682	133	25.285	51-191
Brown bullhead (*Ameiurus nebulosus*)	0.573	1.728	3	0.570	195-303
Yellow bullhead (*Ameiurus natalus*)	0.734	2.215	13	2.471	112-195
Cutthroat trout (*Oncorhynchus clarki*)	1.071	3.232	13	2.471	175-209
Steelhead trout (*Oncorhynchus mykiss*)	0.687	2.074	6	1.141	200-233
Coho salmon (*Oncorhynchus kisutch*)	1.588	4.794	26	4.943	126-181
Total	33.122		526		

C P U E

While electrofishing, catch rates were highest for bluegill. Stock-length largemouth bass and yellow perch were captured at similar rates (Table 6). With the exception of brown bullhead, the catch rates for stock-size forage fish were much lower when gill netting compared to electrofishing. Catch rates for stock-length brown bullhead were similarly low between gear types. The CPUE for coho salmon, cutthroat trout, and steelhead trout were calculated for all sizes and were correlated with the relative abundances measured in the outmigration the previous spring.

Table 6. 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 and juvenile salmonids collected from Sunset Pond (Whatcom County) while electrofishing, gill netting, and fyke netting during early fall 1997.

Species	Gear type					
	Electrofishing (fish/hr)	n (shock sites)	Gill netting (fish/hr)	n (net nights)	Fyke netting (fish/hr)	n (net nights)
Largemouth bass	41.81 ± 23.36	3	0	2	0	2
Yellow perch	41.80 ± 35.06	3	11[a]	2	0	2
Bluegill	203.15 ± 37.55	3	1[a]	2	10.50[a]	2
Brown bullhead	1.99 [a]	3	0	2	1	2
Yellow bullhead	7.96 ± 6.75	3	1[a]	2	2.00 ± 1.28	2
Cutthroat trout	21.88 ± 6.77	3	2.50 ± 1.92	2	0	2
Steelhead trout	1.99[a]	3	1[a]	2	0	2
Coho salmon	33.88 ± 14.24	3	4.50 ± 1.92	2	0	2

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

Stock Density Indices

Large numbers of stock length bluegill were captured in Sunset Pond. Quality and preferred size largemouth bass, and bluegill were captured in modest numbers whereas quality and preferred size yellow perch were captured in high numbers. No memorable or trophy fish were captured. PSD and RSD for bluegill and yellow perch (Table 7) were close to, or within, the stock density index objective ranges for a body of water managed for a panfish fishery. A balance between predator and prey species may be obtainable with active management such as a maximum length limit, but currently PSD for largemouth bass is below the 40 to 60 value range for a balanced population (Willis et al. 1993).

Table 7. Traditional stock density indices, including 80% confidence intervals, for warmwater fishes and stock length trout collected from Sunset Pond (Whatcom County) while electrofishing, gill netting, and fyke netting during late fall 1998. PSD = proportional stock density, whereas RSD = relative stock density of preferred length fish (RSD P), memorable length fish (RSD M), and trophy length fish (RSD T). EB = electrofishing, GN = gill netting, and FN = fyke netting.

Species	Gear Type	n	PSD	RSD-P	RSD-M	RSD-T
Brown Bullhead	EB	1	100a	100	0	0
	GN	0	0	0	0	0
	FN	2	0	0	0	0
Bluegill	EB	102	18 ± 5	0	0	0
	GN	2	0	0	0	0
	FN	21	52 ± 14	0	0	0
Cutthroat Trout	EB	4	0	0	0	0
	GN	5	0	0	0	0
	FN	0	0	0	0	0

Table 7 (continued). Traditional stock density indices, including 80% confidence intervals, for warmwater fishes and stock length trout collected from Sunset Pond (Whatcom County) while electrofishing, gill netting, and fyke netting during late fall 1998.

Species	Gear Type	n	PSD	RSD-P	RSD-M	RSD-T
Largemouth Bass	EB	21	24 ± 12	19 ± 11	0	0
	GN	0	0	0	0	0
	FN	0	0	0	0	0
Yellow Bullhead	EB	4	0	0	0	0
	GN	2	0	0	0	0
	FN	4	0	0	0	0
Yellow Perch	EB	21	76 ± 12	19 ± 11	0	0
	GN	22	91 ± 8	9 ± 8	0	0
	FN	0	0	0	0	0

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

Largemouth Bass

Largemouth bass ranged from 50 to 445 mm (age 0+ to 6+) (Table 8, Figure 3). Age 0+ and age 1+ fish were abundant. Fish older than 2+ were relatively rare, no age 4+ fish were sampled, and age classes older than 6+ were absent from our samples. Growth of largemouth bass collected from Sunset Pond was well above the western Washington State average. Relative weights were generally consistent with or below western Washington State averages for most size classes (Figure 4). However, fish in the three largest size classes exhibited relative weights above those of largemouth bass in Western Washington.

Table 8. Age and growth of largemouth bass (*Micropterus salmoides*) captured at Sunset Pond (Whatcom County) during late fall 1998. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

		Mean total length (mm) at age					
Year class	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**
1997	43	73.2					
		84.8					
1996	7	87.0	186.7				
		100.0	191.7				
1995	1	80.1	173.6	269.3			
		95.5	183.5	273.7			
1994	0						
1993	1	106.9	178.2	225.7	269.3	364.3	
		121.5	189.1	234.2	275.5	365.7	
1992	3	95.4	165.1	222.5	313.8	372.3	410.6
		110.9	177.4	232.1	319.1	374.8	411.3
Overall unweighted mean		88.5	175.9	239.2	291.5	368.3	410.6
Weighted mean		89.0	187.2	240.8	308.2	372.5	411.3
State Average		60.4	145.5	222.2	261.1	289.3	319.0

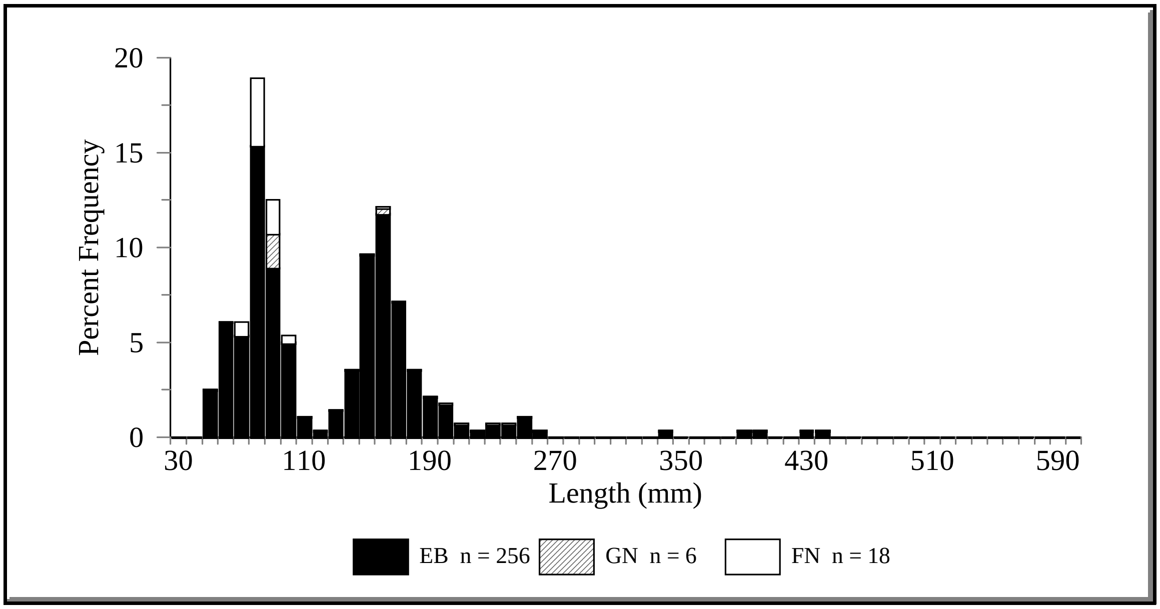

Figure 3. Length frequency histogram of largemouth bass sampled from Sunset Pond in late fall 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB=electrofishing, GN = gillnetting, and FN = fyke netting.

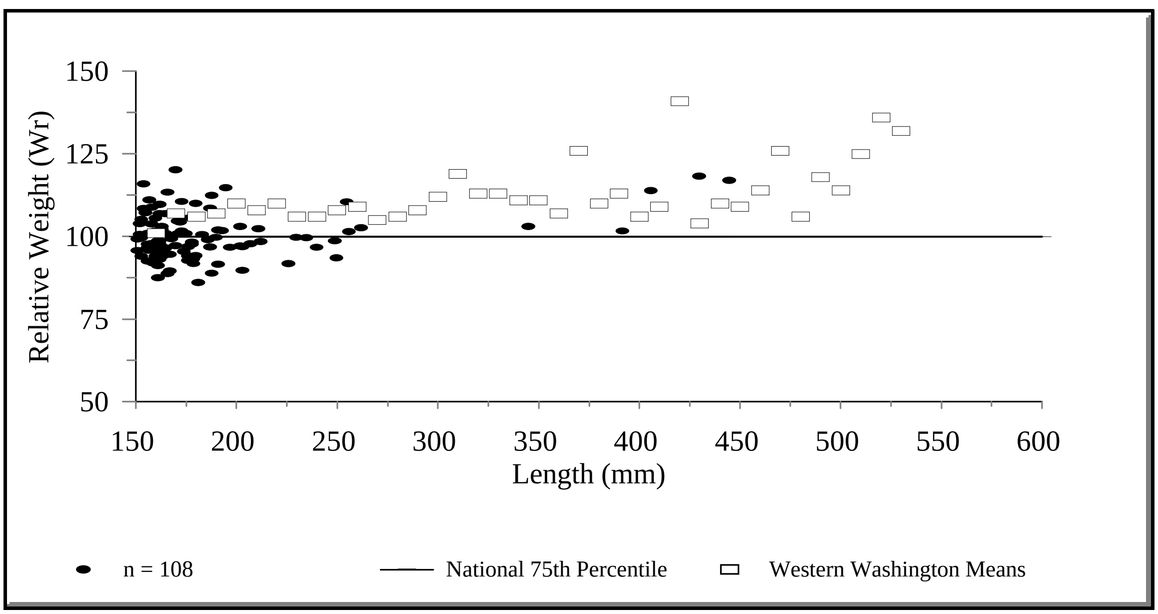

Figure 4. Relationship between total length and relative weight (Wr) of largemouth bass from Sunset Pond, (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75^{th} percentile.

Yellow Perch

Yellow perch ranged from 92 to 271 mm TL (age 0+ to 5+). Individuals measuring ~ 200 to 270 mm TL (age 3+) were dominant (Figure 5). Growth and condition of the moderately abundant yellow perch in Sunset Pond were well above average when compared to yellow perch statewide (Table 9, Figure 6). Very few young-of-year perch were observed.

Table 9. Age and growth of yellow perch (*Perca flavescens*) captured at Sunset Pond (Whatcom County) during late fall 1998. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age				
		1	2	3	4	5
1997	5	70.1				
		88.3				
1996	3	78.0	167.6			
		96.8	173.7			
1995	19	65.5	134.5	191.3		
		86.9	146.8	196.2		
1994	4	59.2	131.0	184.1	227.5	
		81.8	144.8	191.3	229.5	
1993	1	70.5	124.4	181.9	254.3	261.7
		92.7	140.6	191.8	256.1	262.7
Overall unweighted mean		68.7	139.4	185.8	240.9	261.7
Weighted mean		87.6	149.2	195.2	234.8	262.7
State Average		59.7	119.9	152.1	192.5	206

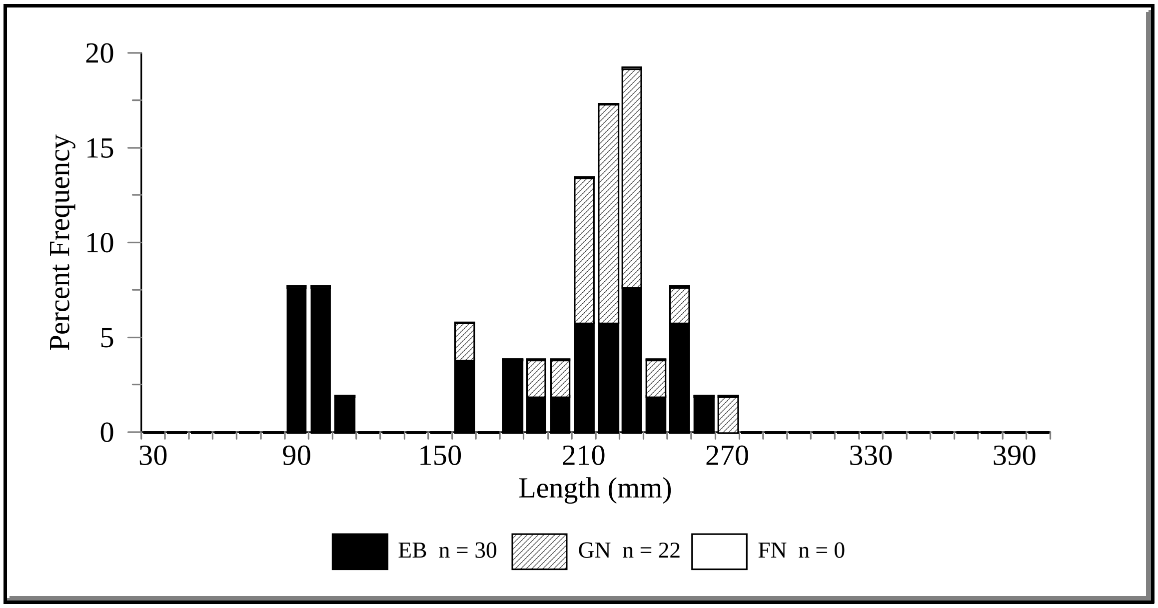

Figure 5. Length frequency histogram of yellow perch sampled from Sunset Pond in late fall 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

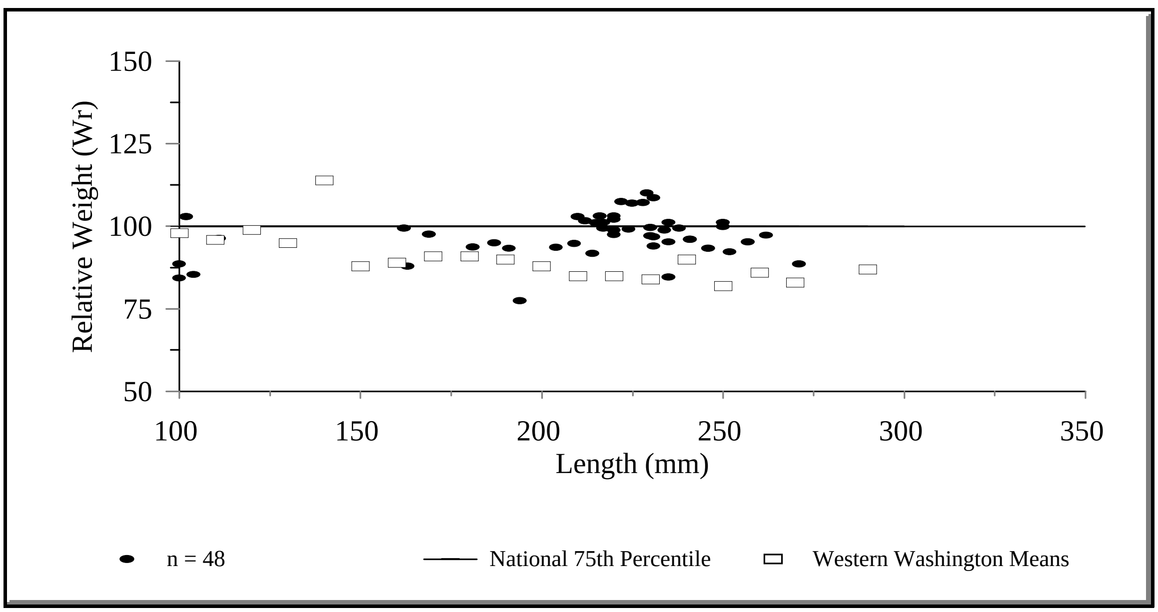

Figure 6. Relationship between total length and relative weight (Wr) of yellow perch from Sunset Pond, (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Bluegill

Bluegill ranged from 47 to 191 mm TL (age 0+ to 5+) (Table 10, Figure 7). Little variability appeared to exist in year-class strength. A steady decline in the numbers of fish in each age class occurred following a classic mortality curve. Growth and condition for bluegill were generally consistent with state averages (Table 11, Figure 8). However, Sunset Pond bluegill appeared to grow very rapidly in their first year.

Table 10. Age and growth of bluegill (*Lepomis macrochirus*) captured at Sunset Pond (Whatcom County) during late fall 1998. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	# fish	Mean total length (mm) at age				
		1	**2**	**3**	**4**	**5**
1997	30	69.1				
		77.1				
1996	7	52.9	107.4			
		65.7	112.6			
1995	7	60.8	105.7	136.1		
		73.2	112.4	139.0		
1994	6	65.5	101.4	127.9	155.4	
		78.1	109.9	133.4	157.7	
1993	3	54.9	100.3	118.5	149.2	174.4
		69.0	109.4	125.7	153.0	175.6
Overall unweighted mean		60.7	103.7	127.5	152.3	174.4
Weighted mean		74.7	111.4	134.4	156.1	175.6
State Average		37.3	96.8	132.1	148.3	169.9

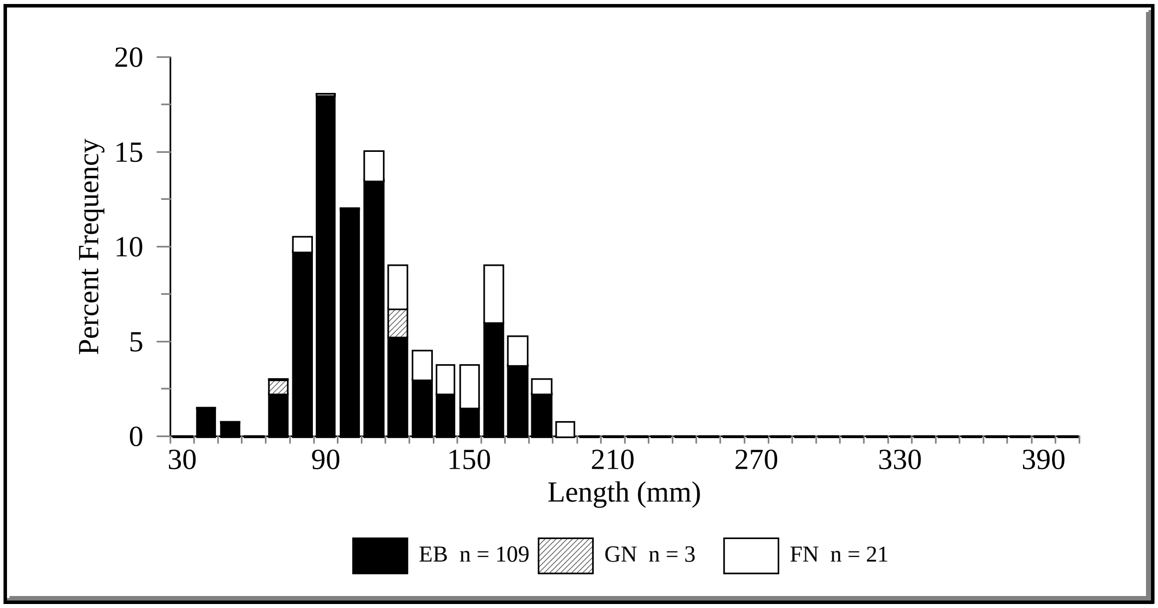

Figure 7. Length frequency histogram of bluegill sampled from Sunset Pond in late fall 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

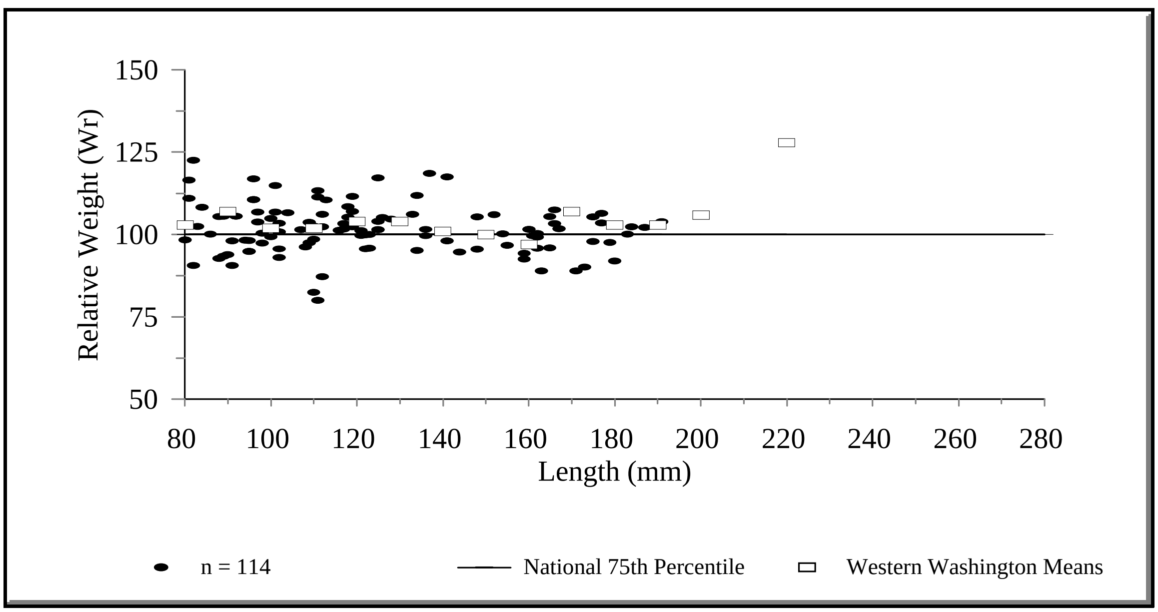

Figure 8. Relationship between total length and relative weight (Wr) of bluegill from Sunset Pond, (Whatcom County) compared with means from up to 25 western Washington lakes and the national 75th percentile.

Brown Bullhead

Three brown bullhead ranging from195 to 303 mm TL were captured in Sunset Pond (Figure 9). While no state average for relative weights currently exists to compare their condition to, they were well below the national 75th percentile (Figure 10).

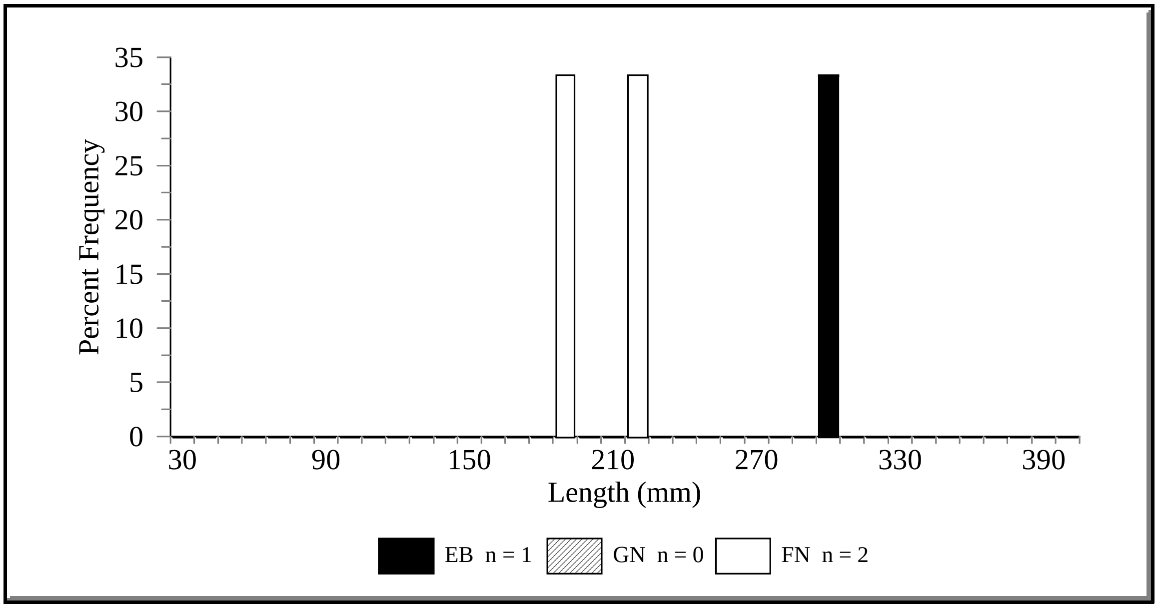

Figure 9. Length frequency histogram of brown bullhead sampled from Sunset Pond in late fall 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

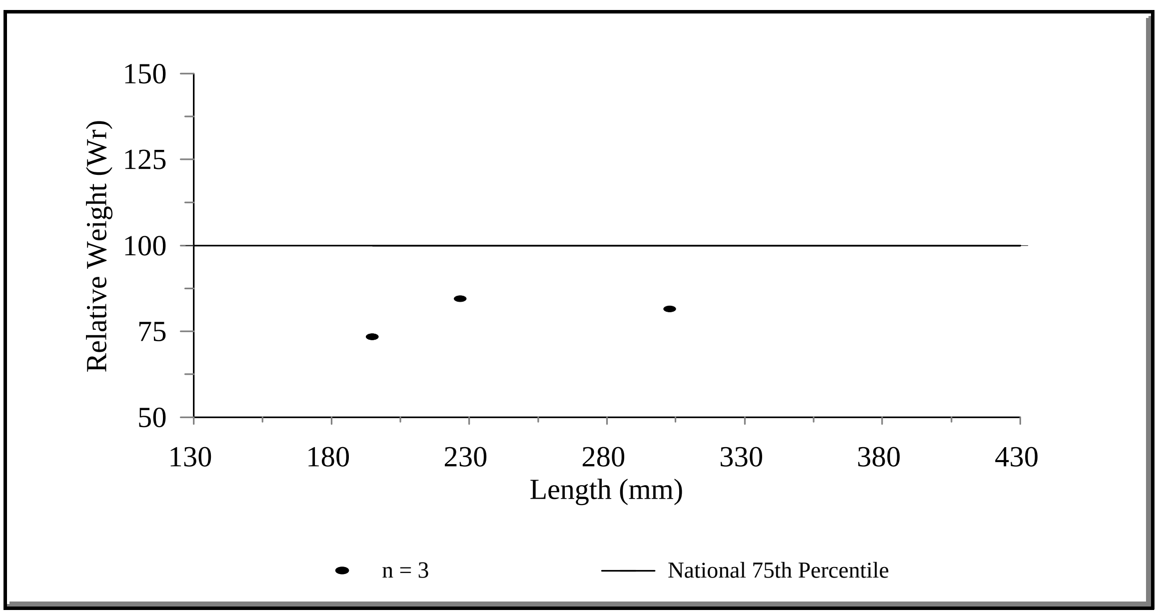

Figure 10. Relationship between total length and relative weight (Wr) of brown bullhead from Sunset Pond (Whatcom County) compared to the national 75th percentile.

Yellow Bullhead

Yellow bullhead made up 2% of the catch by weight and number, ranging from 112 to 195 mm TL (Figure 11). These fish were more abundant and in better condition than brown bullhead sampled (Figure 12).

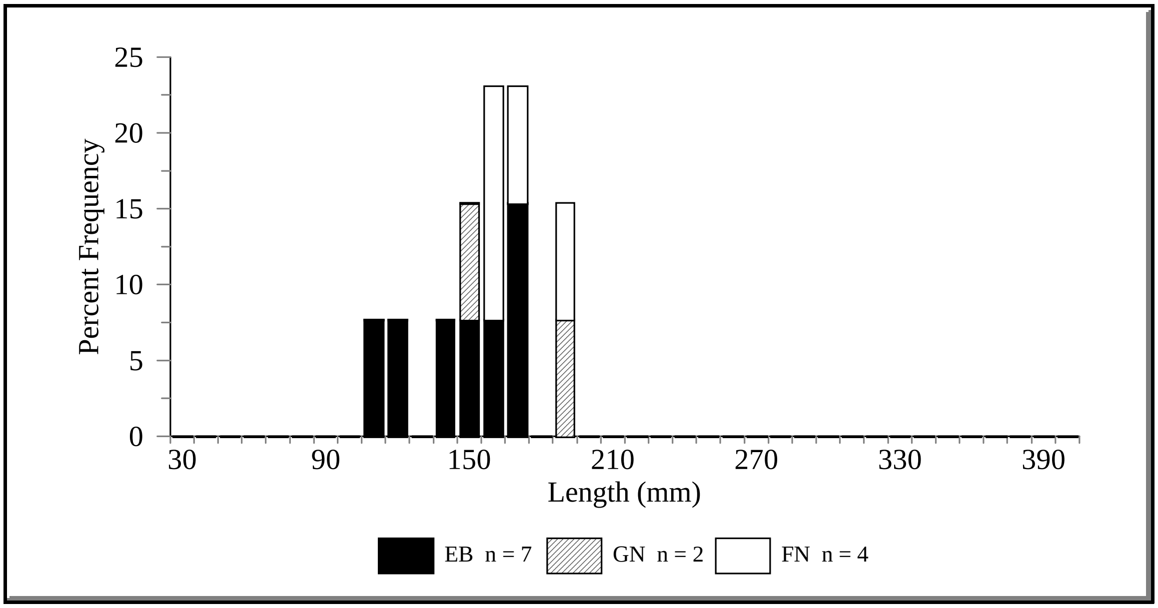

Figure 11. Length frequency histogram of yellow bullhead sampled from Sunset Pond in late fall, 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

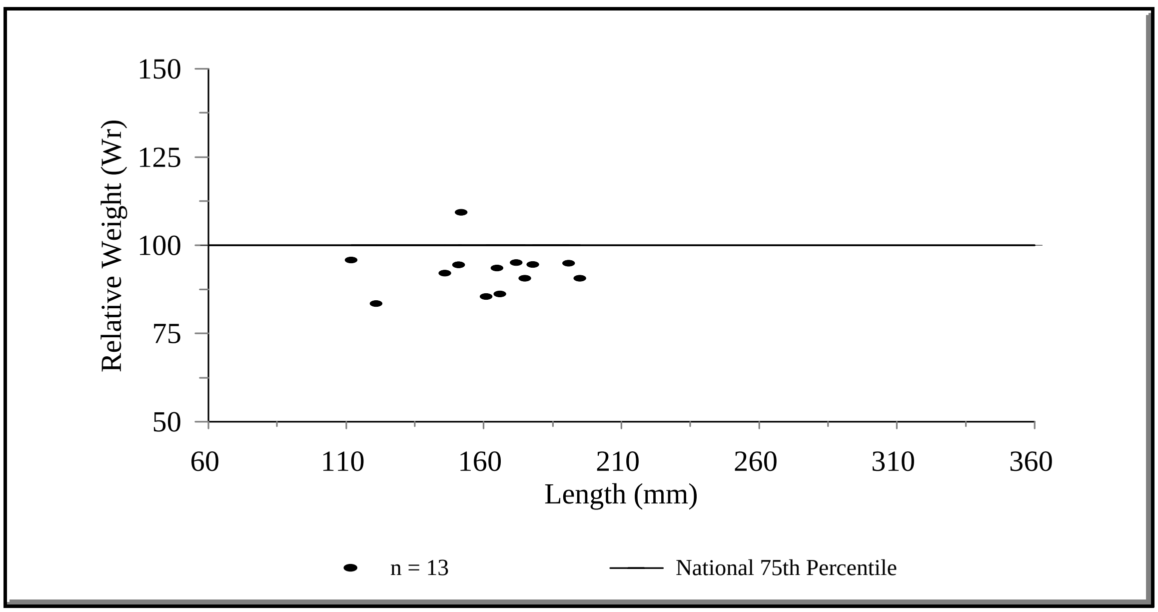

Figure 12. Relationship between total length and relative weight (Wr) of yellow bullhead from Sunset Pond (Whatcom County) compared to the national 75th percentile.

Members of the Family Salmonidae

Coho Salmon

Coho salmon juveniles made up approximately 5% of the catch both by number and by weight during the fall stock assessment, and ranged from 126 to 181 mm in fork length (FL) (Table 5, Figure 13). Twenty-five coho salmon were aged from scales and all were determined to be age 1+ fish. The origin of these fish is believed to be predominantly from unfed fry plants since approximately 126,000 fry/year are planted in the system and little evidence exists for natural spawning (WDFW Hatchery Plant Records 1998, WDFW Spawner Escapement Surveys 1998). The Squalicum Creek outlet from Sunset Pond was dry at the time of our survey, preventing downstream movement of these fish.

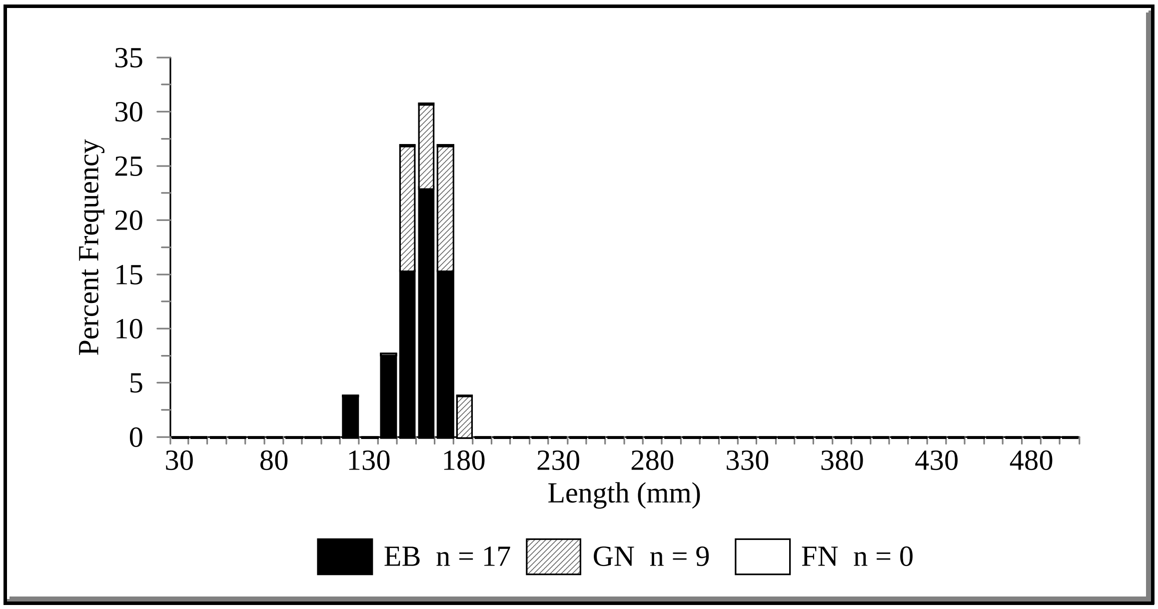

Figure 13. Length frequency histogram of coho salmon sampled from Sunset Pond in late fall 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

Cutthroat Trout

Cutthroat trout made up 3.2% of the catch by weight and 2.5 % of the catch by number, ranging from 175 to 209 mm FL (Table 5, Figure 14). Seven of the cutthroat trout captured were aged from scales. All were determined to be age 2+ except one age 1+ fish measuring 188 mm FL. Relative weights were above the national 75th percentile (Figure 15). The modal length frequency distribution of the sample and ages suggested all these fish were sea-run (Wedemeyer et al. 1980). While both sea-run and resident cutthroat populations are known to inhabit the Squalicum Creek system, these fish should be assumed to have originated from anadromous stock unless determined otherwise due to the tenuous state of the sea-run population (Downen 1999).

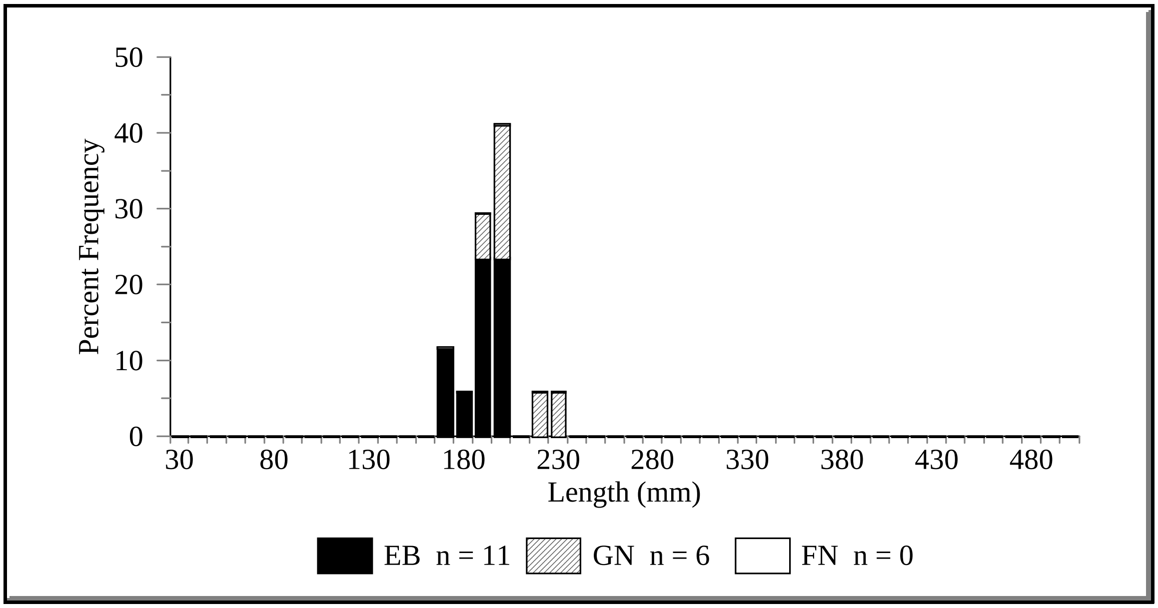

Figure 14. Length frequency histogram of cutthroat sampled from Sunset Pond in late fall, 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

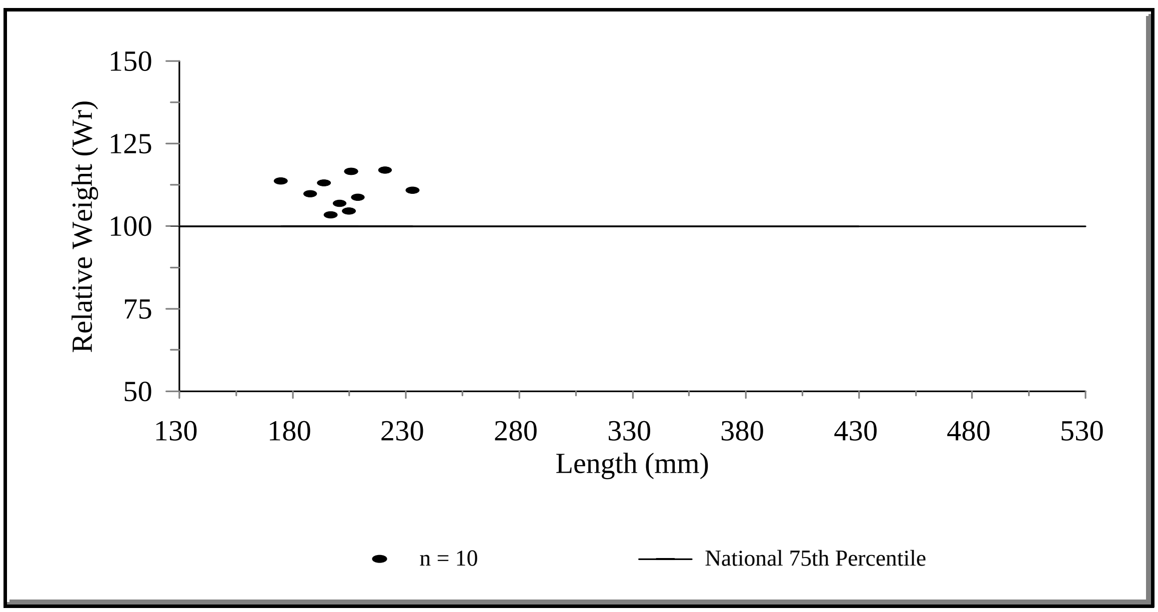

Figure 15. Relationship between total length and relative weight (Wr) of cutthroat from Sunset Pond, (Whatcom County) compared with the national 75th percentile.

Steelhead Trout

Steelhead trout made up 2% of the catch by weight and 1% of the catch by number, ranging in length from 200 to 233 mm FL (Table 5, Figure 16). Two fish aged from scales were age 2+ fish. Again, size, length frequency distribution, ages, and the documentation of a steelhead outmigration the previous spring suggested the *Oncorhynchus mykiss* collected from Sunset Pond were from anadromous stock (Wedemeyer et al. 1980, Downen 1999).

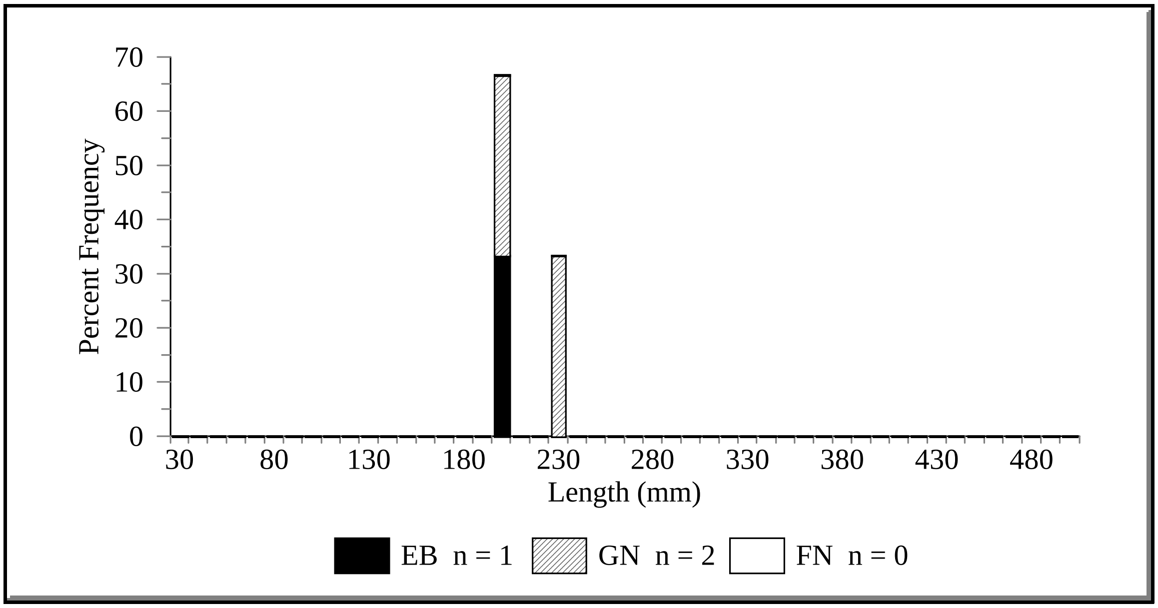

Figure 16. Length frequency histogram of steelhead trout sampled from Sunset Pond in late fall, 1998. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing, GN = gill netting, and FN = fyke netting.

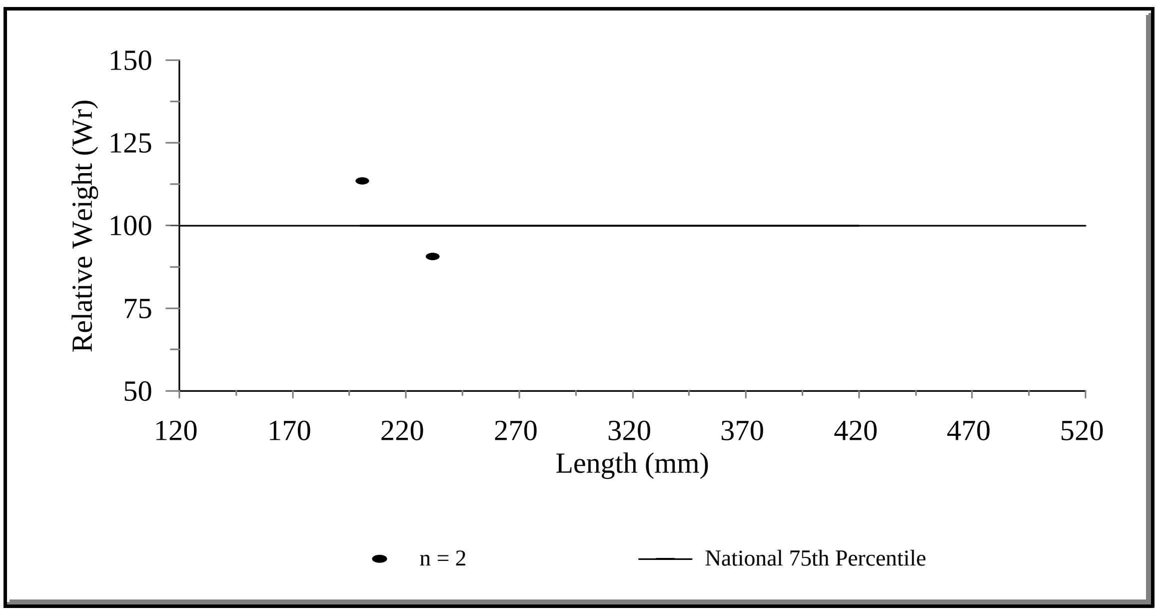

Figure 17. Relationship between total length and relative weight (Wr) of steelhead trout from Sunset Pond, (Whatcom County) compared the national 75th percentile.

Warmwater Enhancement Options

The primary purpose of the Sunset Pond stock assessment was to evaluate warmwater species presence, abundance, size structure, growth, and condition in conjunction with salmonid smolt production the previous spring, to assess the potential for interactions of warmwater species and salmonids and to identify risks to salmonid populations in this disturbed, urban stream. The ecological interaction of introduced fish species with salmonids is not well understood but of some importance with regard to the management of both fisheries. Responsible management of warmwater fisheries requires minimizing the impact of warmwater species on native salmonids (WDFW 1999). Moreover, effective restoration and management of salmonids in disturbed systems would benefit from an understanding of the trophic and competitive relationships of salmonids and introduced species in altered environments. This study examined fundamental characteristics of warmwater fish populations as an environmental condition of salmonid populations inhabiting the system and assessed the potential for interaction in the Squalicum Creek system.

Without accurate population estimates, the annual contribution of salmonids to the diets of predators and water temperatures throughout the entire year we cannot estimate the impact of predation of largemouth bass on salmonids (Reiman et al. 1988; Beamesferder et al. 1990; Poe et al. 1991). Examination of diet overlap and evaluation of subsequent competition would require a similar effort (Hodgeson et al. 1991). Lack of resources precluded a complete diet study of the largemouth bass and yellow perch of Sunset Pond and the Squalicum Creek system. Unfortunately, the cost and effort of such work prohibits carrying out such studies in numerous smaller systems while efforts are focused on larger, more productive systems. Moreover, each system has a unique history, configuration, and set of environmental conditions that prevent inferring the ecology of one based on data gathered from another (Kareiva 1990; Landis et al. 1996; Lancaster 1996). Resource managers are often faced with the dilemma of making management decisions based on the limited available data, risk potential, and probable scenarios generated by management decisions (Suter 1990; Landis and Weigers 1997). Limited evidence of salmonid consumption by largemouth bass; rapid growth rates and abundance of largemouth bass and yellow perch; high, size-selective mortality of outmigrating salmonids; and spatial, temporal, and metabolic overlap of warmwater species and salmonids suggest some degree of interaction does occur in this system. Moreover, the presence of threatened wild steelhead trout and cutthroat trout runs in Squalicum Creek suggest a conservative management strategy with regard to warmwater species may be prudent.

Potential for Interaction Between Salmonids and Warmwater Fish

In order to assess the potential for interaction between warmwater species and salmonids we examined species presence, estimated abundance, size structure, growth, and condition. These factors reflect the potential for interaction since more abundant, robust populations can have greater potential for interaction (Beauchamp et al. 1995, Ruggerone and Rogers 1992) and smaller, weakened populations can be more sensitive to the impacts of interaction (Beamesderfer et al. 1990). The physical configuration of the system, environmental conditions, and flow regimes may also influence interaction potential (Vigg and Burley 1991; Gregory 1993; Peterson 1995; Armstrong 1998). Therefore, we briefly discus the likelihood of spatial, and temporal overlap at water temperatures at which warmwater fish are metabolically active. In this context, we assume smaller salmonid populations would be more vulnerable to any impacts that may occur. However, we cannot infer the degree or extent of interactions based on available data.

Approximately 88% of the 1998 outmigration occurred between 25 May and 1 June at water temperatures between 12.8°C and 15.1°C. Growth and mortality for coho salmon outmigrating from Squalicum Creek were both high (G = 3.6 and Z = 2.3, calculated across 15 months). Age 1 coho salmon migrated from Squalicum Creek at greater mean fork length than have been reported for other systems (Shapovaloff and Taft 1954; Salo and Bayliff 1958; Fraser et al. 1983). Sea-run cutthroat and steelhead trout also demonstrated rapid growth and a tendency to migrate in larger proportions as age 1 and age 2 fish than has been observed in other systems (Shapovaloff and Taft 1954; Johnston and Mercer 1976; Johnson and Cooper 1992). Productive conditions may allow salmonids to reach size thresholds necessary for smoltification sooner than in less productive systems (Wedemeyer 1980). Larger fish may also be the result of system productivity interacting with size selective mortality occurring through predation and displacement (Parker 1971, Downing et al 1990, Martel 1996). Early attainment of threshold size and risk associated with extended residence time may influence outmigration timing of Squalicum Creek salmonids.

Marked coho salmon parr released in Bug Lake and Sunset Pond on 21 March 1998 experienced 42% and 57% mortality, respectively, during outmigration through June 1998. The causes of these high mortality rates remain unknown. Unidentified water quality problems, pathogens, incidental hooking by anglers, predation by birds, otters, native fish species and introduced fish species are all potential sources (Johnston and Mercer 1976; Wood 1987; Vigg et al. 1993; Rugerone and Rogers 1992; Dolloff 1993) and cumulative stressors may be important (Mesa 1994). Limited diet data collected in the spring of 1998 (Downen 1999) suggest warmwater fish contribute to salmonid mortality at early life stages but the degree of this contribution is unquantified.

More than 200 juvenile largemouth bass (80-110 mm TL) were captured both in the ponds and in stream reaches between 30 March and 1 June, and 26% of the individuals sampled contained coho salmon fry (n = 38). Adult largemouth bass were not collected during the outmigration period so their impact on smolts was unknown. While sources of mortality for outmigrating salmonids could not be directly identified, some of the losses were thought to be due to predation since spatial and temporal overlap of largemouth bass with smolts occurred at temperatures where largemouth bass are present and metabolically active. However, warmwater fish species presence, abundance, size structure, and growth were entirely undocumented and largely unknown. Consequently there was no means of assessing interaction potential for these species and salmonids or for assessing risk for salmonids.

We collected 280 largemouth bass from Sunset Pond during our 1998 stock assessment. However, the majority of these were age 0 and age 1, ranging from 50 to 190 mm TL. We captured 21 stock length fish at a CPUE of 42 fish/hr which is only slightly above average for western Washington lakes. Largemouth bass in Sunset Pond demonstrated rapid growth rates well above western Washington State averages. Relative weights were generally consistent with or above western Washington State averages, especially for larger fish. The PSD and RSD were lower than values generally accepted for balanced populations warmwater populations (Willis et al. 1993) but above western Washington State averages.

During our September stock assessment of Sunset Pond we collected several largemouth bass large enough to consume smolts but could not conduct a mark and recapture study to estimate population size. A number of studies in other of parts of the US have developed relationships between CPUE and density (Coble 1992; Edwards et al. 1997). Since 200 mm TL is, conservatively, the minimum size that largemouth bass are capable of consuming forage fish the size of salmonid smolts (Lawrence 1958), Downen (1999) used CPUE for largemouth bass over 200 mm TL collected from Sunset Pond to estimate largemouth bass density and population size. The CPUE for largemouth bass > 200 mm was 42 fish/hour. One density and population estimate of largemouth bass > 200 mm in Sunset Pond was 27.5 fish/ha and 137 fish based on a regression equation derived from mark and recapture data (Cobble 1992). Another estimate yielded 186 fish/ha and 931 fish based on an equation derived from draining experimental ponds (Edwards et al. 1997). These density estimates are higher than those made for other Western Washington waters where densities estimated from mark and recapture data average between 10 and 15 fish/ha (Scott Bonar, WDFW, unpublished data). Therefore, the estimates based on CPUE should be viewed with caution. However, in the absence of similar studies relating mark and recapture data, CPUE and actual population size in the Pacific Northwest and due to the tendency of mark and recapture data to underestimate largemouth bass populations (Swingle 1966; Grinstead and Wright 1973; Edwards et al. 1997) these estimates represent a possible range of largemouth bass numbers in Sunset Pond. A population size in this range may represent a mortality factor during outmigration.

Yellow perch may also interact trophically with salmonids in the Squalicum Creek system. Although yellow perch are commonly characterized as generalists (Keast 1979), they are frequently the most abundant or only piscivore in small lakes (Paszkowski and Tonn 1994). Age-2 and older yellow perch, particularly those over 200 mm total length are functional piscivores and may exert considerable pressure on forage fish and juveniles of a variety of other species (Knight et al. 1984). Smaller yellow perch are particularly sensitive to prey size, and concentrate their prey efforts on benthic invertebrates and seasonally available age-0 fish (Paszkowski and Tonn 1994). Yellow perch in Lake Erie ranging from 152 to 242 mm total length selected and consumed forage fishes ranging from 40 to 70 mm total length (Knight et al. 1984). These studies suggest yellow perch are capable of preying on salmonid fry under circumstances in which both groups overlap spatially, temporally, and metabolically. The yellow perch population in Sunset Pond was characterized by relative weights far above the western Washington State averages and national 75th percentile across all size classes, especially for larger fish. This population also demonstrated trends in growth that were higher than in other western Washington lakes. Moreover, the PSD for yellow perch was dramatically above the Washington State average (Scott Bonar, WDFW, unpublished data). While this could be the result of reduced intraspecific competition through predation or fishing pressure (Paszkowski and Tonn 1994), it may also be the result of piscivory (Knight et al. 1984).

Growth rates for largemouth bass and yellow perch were above the Washington State average suggesting system productivity is effectively transferred to introduced populations. Low *Wr* values are generally interpreted as evidence for competition as a growth-influencing factor or resource limitation (Murphy et al. 1996). Relative Weights for all warmwater species in Sunset Pond were above the national 75th percentile across the entire range of lengths, suggesting these populations are not food limited or stunted. Rapid growth rates of largemouth bass and yellow perch and high mortality of juvenile salmonids may be related. However, we have no evidence for a causal relationship so this correlation should be viewed with caution. Rapid growth of warmwater species may also be the result of the predation of larger warmwater fish on smaller warmwater fish or other prey items.

Despite strong trends in growth, the age class distribution of largemouth bass and yellow perch, and the apparent absence of older individuals suggests mortality is high for fish entering the fishery. The absence of age-4 largemouth bass from the sample may also be evidence of a year-class failure (Murphy et al. 1996). When production and mortality are constant through time the log of fish numbers plotted against age generates a catch curve with a steadily descending right limb (Ricker 1975). The catch curves for all introduced species from Sunset Pond deviate from this pattern, and suggest high variability in one or both of these factors. Due to the central location and accessibility of Sunset Pond, it is frequently fished by a diverse group of fishers. Consequently, hooking mortality and takes are may impact fishable populations, including largemouth bass. Limitations in habitat in Sunset Pond may result in territory-holding by larger fish (Gutreuter and Anderson 1985). Smaller fish that have entered the fishery but are not large enough to hold territories may move more frequently, encounter fishing gear more often, and experience higher mortality. It appears that warmwater fish populations in Sunset Pond exhibit similar trends in growth and mortality as Squalicum Creek salmonids though probably for different reasons.

Lacking resources for collecting quantitative interaction data, Downen (1999) completed an ecological risk assessment for salmonids inhabiting the Squalicum Creek drainage. Ecological risk assessment incorporates environmental variability, stochastic processes, paucity of data, and subsequent uncertainty into evaluations of resources and management decisions (Landis and Weigers 1997). Ecological risk assessment begins with the premise that ecosystems are historical in nature and stochastic events often influence ecosystem dynamics in unpredictable ways (Serrat et al. 1995; Landis et al. 1996; Ruxton 1996). Moreover, risk assessment attempts to account for risk and the consequences of different possible scenarios in the face of uncertainty and unpredictability (Suter 1990, Landis and Weigers 1997). In situations where uncertainty and paucity of data exist, the application of ranking risks based upon temporal and spatial autocorrelation is an appropriate means of assessing risk (Landis and Weigers 1997). When the interactive relationships or magnitudes of risks are variable and unknown, ranking them provides a useful means of establishing management priorities.

Downen (1999) developed a conceptual model based upon life history, habitat use, and spatial, temporal, and metabolic overlap of salmonids and a number of potential stressors including pollution, temperature and oxygen extremes, and predation by and competition with introduced species. He concluded that trophic interaction with introduced species was only one potential source of mortality for salmonids. However, some interaction may occur during the spring when salmonid smolts outmigrate through the ponds and when juvenile largemouth bass disperse into streams. During late summer interactions may also occur if low stream flows and higher water temperatures increase the spatial, temporal, and metabolic overlap of largemouth bass and large yellow perch with salmonid parr in these pond habitats. This can occur if low flows reduce available instream habitat and force the redistribution of fry and parr through density-dependent processes (Bisson et al. 1988; Spalding et al. 1995; Martel 1996).

The potential for warmwater species impacting diminished native and wild salmonid runs in Squalicum Creek precludes active management by the WDFW Warmwater Enhancement Program (WDFW 1999). While the degree to which warmwater fish species impact salmonid population is unknown, any mortality factor may be important where runs such as those in Squalicum Creek are in danger of extirpation. Therefore, a conservative management approach that increases warmwater fishing opportunity and harvest of warmwater fish may be desirable. Measures that might improve access to this popular urban warmwater fishery without adversely impact salmonids include, but are not limited to, the following:

Improve shoreline access to increase fishing opportunities

Currently, the City of Bellingham maintains areas for fishing along the west shore of Sunset Pond. A primitive trail exists around the pond but access can be difficult during spring and summer months, especially for juvenile fishing. Improved access could increase fishing opportunities and subsequently, harvest of largemouth bass and yellow perch. However, increased fishing may also increase incidental hooking and subsequent mortality of juvenile and adult anadromous trout during certain times of the year, even if these populations are protected by closures of these fisheries.

Change existing fishing rules to alter size structure of largemouth bass

Currently, Sunset Pond falls under the statewide general freshwater rules for largemouth bass and yellow perch. Sunset Pond anglers are allowed to harvest five fish daily, including no more than three over 15 inches in total length. Analyses of data from the 1998 stock assessment revealed rapid growth for both largemouth bass and yellow perch, indicating that food was not limiting. While the PSD for largemouth bass for Sunset Pond was above the western Washington State average (Scott Bonar, WDFW, unpublished data) the index and age class distributions still reflect a lack of large fish, and lack of fish in older age classes suggests larger fish are taken at rates that exceed recruitment. A 12"-17" maximum length limit for largemouth bass on Sunset Pond might improve the PSD for bass by increasing the ratio of quality fish to stock length fish. At the same time such a rule might effectively target largemouth bass in the size classes believed to have the greatest impact on forage fish in the size classes of salmonid smolts (Lawrence 1958; Hambright 1991). However, some question still exists as to the relationship between predator and prey size (Bonar et al. 1994). Prey availability seems to play a major role in the diet of larger fish (Hambright 1991). Although larger fish are capable of consuming larger prey than smaller fish, they also consume a wider range of prey sizes depending on prey availability.

Literature Cited

Armstrong, J.D., V.A. Braithwaite, and M. Fox. 1998. The response of wild Atlantic salmon parr to acute reductions in water flow. Journal of Animal Ecology 67: 292-7.

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.

Beamesferder, R.C., Rieman, B.E., Bledsoe, L.J. 1990. Management implications of a model of predation by a resident fish on juvenile salmonids migrating through a Columbia River Reservoir. North American Journal of Fisheries Management 10:290-304.

Beauchamp, D.A., LaRiviere, M.G., Thomas, G.L. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Ozette, Washington. North American Journal of Fisheries Management 15: 193-207.

Bonar, S.A., Fletcher, D., and B. Bolding. 1994. Relationship between forage fish abundance in the diet of largemouth bass (*Micropterus salmoides*). Washington Department of Fish and Wildlife Technical Report No. 94-07. 22p.

Bennett, G.W. 1962. Management of artificial lake and ponds. Reinhold Publishing Corporation, New York.

Bisson, P., K. Sullivan, and J. Nielson. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117: 262-273.

Brown, G.W., and J.T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resources Research 6: 1133-39.

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.

Casper, A.F. 1994. Population and community effects of sediment contamination from residential urban runoff on benthic macroinvertebrate biomass and abundance. Bulletin of Environmental Contamination and Toxicology 53:796-7

Chew, R.L. 1974. Early life history of the Florida largemouth bass. Florida Game and Fish Commission, Fishery Bulletin No. 7, 76 p.

Cobble, D.W. 1992. Predicting population density of largemouth bass from electrofishing catch per unit effort. North American Journal of Fisheries Management 12: 650-652.

Dolloff, C.A. 1993. Predation by river otters (*Lutra canadensis*) on juvenile coho salmon (Oncorhynchus kisutch) and Dolly Varden (*Salvelinus malma*) in southeast Alaska.. Canadian Journal of Fisheries and Aquatic Sciences 50: 312-15.

Downen, M.R. 1999. Relationship of salmonid outmigration to environmental factors in adisturbed, urban stream, Squalicum Creek, WA. Master's Thesis. Western Washington University, Bellingham, Washington, 187 p.

Downing, J.A., C. Plante, and S. Lalonde. 1990. Fish production correlated with primary productivity, not the morphedaphic index. Canadian Journal of Fisheries and Aquatic Sciences 47: 1929-36.

Downing, J.A., and C. Plante. 1993. Production of fish populations in lakes. Canadian Journal of Fisheries and Aquatic Sciences 50: 110-20.

Edwards, C.M., R.W. Drenner, K.L. Gallo, and K.E. Rieger. 1997. Estimation of population density of largemouth bass in ponds using mark-recapture and electrofishing catch per effort. North American Journal of Fisheries Management 17: 719-725.

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.

Fraser, F.J., E.A. Perry, and D.T. Lightly. 1983. Big Qualicum River salmon development project volume 1: a biological assessment 1959-1972. Canadian Technical Report Fisheries Aquatic Sciences 1189: 198pp.

Hambright, K.D. 1991. Experimental analysis of prey selection by largemouth bass: role of predator mouth width and prey body depth. Transactions of the American Fisheries Society 120: 500-508.

Herrera Environmental Consultants. 1991. Squalicum Creek water quality evaluation. *In* Beck and Associates, Squalicum Creek floodplain management plan, final plan. 1994. City of Bellingham Public Works, Bellingham, WA.

Hodgeson, J.R., Hodgeson, C.J., and S.M. Brooks. 1991. Trophic interaction and competition between largemouth bass (*Micropterus salmoides*) and rainbow trout (*Oncorhynchus mykiss*) in a manipulated lake. Canadian Journal of Fisheries and Aquatic Sciences 48: 1704-1712.

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

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile chinook salmon (Oncorhynchus tshawytcha). Canadian Journal of Fisheries and Aquatic Sciences 50: 241-6.

Grinstead, B.G., anf G. L. Wright. 1973. Estimation of black bass, *Micropterus* spp., population in Eufaula reservoir, Oklahoma, with discussion of techniques. Proceedings of the Oklahoma Academy of Science 53: 48-52.

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

Gutreuter, S.J. and R.O. Anderson. 1985. The importance of body size to the recruitment process in Largemouth bass populations. Transactions of the American Fisheries Society 114: 317-27.

Jearld, A. 1983. Age determination. Pages 301-324 *In*: Nielson, L.A., and D.L. Johnson (eds.), Fisheries techniques. American Fisheries Society, Bethesda. MD.

Johnson, T.H., and R. Cooper. 1992. Snow Creek anadromous fish research annual performance report. Washington Department of Wildlife, Port Townsend, WA.

Johnston, J.M., and S.P. Mercer. 1976. Sea-run cutthroat in saltwater pens: broodstock development and extended juvenile rearing (with life history compendium). Fishery Research Report, Washington State Game Department 92pp.

Karieva, P. 1990. Population dynamics in spatially complex environments: theory and data. Phil. Transactions Royal Society of London 330: 15-190.

Keast, A. 1979. Patterns of predation in generalist feeders. Pages 243-255 *in* H. Clepper, editor. Predator-prey systems in fisheries management. Sport Fishery Institute, Washington D.C.

Knight, R.L., F.J. Margraf, and R.F. Carline.1984. Piscivory by walleyes andyellow perch in western Lake Erie. Transactions of the American Fisheries Society 113:677-93.

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.

Lancaster, J. 1996. Scaling the effect of predation and disturbance in a patchy environment. Oecologia 107: 321-31.

Landis, W.G., R.A. Matthews, and G.B. Matthews. 1996. The layered and historical nature of ecological systems and risk assessment of pesticides. Environmental Toxicology and Chemistry 15: 432-440.

Landis, W.G., and J.A. Wiegers 1997. Design considerations and a suggested approach for regional risk assessment and comparative ecological risk assessment. Human and Ecological Risk Assessment 3: 287-297.

Lawrence, J.M. 1958. Estimated sizes of various forage fishes largemouth bass can swallow. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 11: 220-225.

Lenth, J.W.O. 1995. The macroinvertebrate communities in Kamm Creek: a study of the effects of habitat perturbations from agriculture and an evaluation of bioassessment indices. Master's Thesis, Western Washington University, Bellingham, Washington.

Martel, G. 1996. Growth rate and influence of predation risk on territoriality in juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 53: 660-9.

Mesa, M.G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123: 786-93.

Murphy. B.R., D.W. Willis, and T.A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries 16: 30-38.

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.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. Journal of the fisheries research Board of Canada 28: 1503-1510.

Paszkowski, C.A. Tonn, W.M. 1994. Effects of prey size, abundance, and population structure on piscivory by yellow perch. Transactions of the American Fisheries Society 123: 855-65

Peterson, J.H. 1995. Importance of spatial pattern in estimating predation on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 123: 924-30.

Poe, T.P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergrast. 1991.Feeding of predacious fishes on outmigrating juvenile Salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 405-20.

Reiman, B.E., R.C. Beamesferder, S.Vigg, and T.P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River reservoir: part IV. Estimated loss and mortality of juvenile salmonids to northern squawfish, walleye, smallmouth bass. Pages 249-273 *in* Poe and Reiman (1988).

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Board of Canada 191: 382 pp.

Ruggerone, G.T., Rogers, D.E. 1992. Predation on sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management. North American Journal of Fisheries Management 12: 87-102.

R.W.Beck and Associates. 1994. Squalicum Creek flood plan management plan. City of Bellingham Public Works. Bellingham WA.

Ruxton, G.D. 1996. Chaos in a three species food chain with a lower bound on the bottom population. Ecology 77: 317-319.

Salo, E.O., and W.H. Bayliff. 1958. Artificial and natural production of silver salmon *(Oncorhynchus kisutch)* at Minter Creek, Washington. Res. Bulletin Washington Department of Fisheries 4: 76pp.

Serrat, J.A., M. Lewis, and A. Fowler. 1995. Ecological chaos in the wake of invasion. Proceedings of the National Academy of Sciences, USA 92: 2524-2528.

Shapovalov, L., and A.C. Taft. 1954. The lifer histories of the steelhead rainbow trout (*Salmo gairdneri)* and silver salmon (*Oncorhynchus kisutch)* with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish Game Fish Bulletin 98: 375pp.

Spalding, S., Peterson, N.P., and Quinn, T.P. 1995. Summer distribution, survival and growth of juvenile coho ssalmon (*Onchorhynchus kisutch)* under varying experimental conditions of brushy instream cover. Trans. Am. Fish. Soc. 124: 124-130.

Suter, G.W. 1990. Environmental risk assessment / environmental hazard assessment: similarities and differences. Aquatic Technology and Risk Assessment 13: 5-14.

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, W.E., R.O. Smitherman, and S.L. Spencer. 1966. Estimation of bass numbers in a farm pond prior to draining with electro-shocking and angling. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 19(1965): 246-253.

Vigg, S., and Burley, C.C. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychoceilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 48: 2491-8.

Vigg, S., Poe, T.P., Pendergast, L.A. 1993. Rates of consumption of juvenile salmon prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 421-38.

Wagner, H.H. 1974. Photoperiod and temperature regulation of smolting in steelhead trout (*Salmo gairdneri)*.Canadian Journal of Zoology 52: 219-234.

WDFW (Washington Department of Fish and Wildlife). 1998. Squalicum Creek Spawner Escapement Surveys 1985-1998. La Conner WA.

WDFW (Washington Department of Fish and Wildlife). 1998. Squalicum Creek Stock Reports 1934-1998. La Conner, WA.

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

Wedemeyer, G.A., R.L. Saunders, and W.C. Clark. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Marine Fisheries Review 42: 1-14.

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

Wood, C.C. 1987. Predation of juvenile Pacific salmon by the common merganser (Mergus merganser) on eastern Vancouver Island II: Predation of stream resident juvenile salmon by merganser broods. Canadian Journal of Fisheries and Aquatic Sciences 44: 950-959.

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