Lake Sammamish Late Run Kokanee Synthesis Report

Submitted to:

King County
City of Issaquah
City of Bellevue
City of Sammamish
City of Redmond
and
U.S. Fish and Wildlife Service

Submitted by:

HDR Engineering, Inc.
4717 97th St NW
Gig Harbor, WA 98332

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Executive Summary

The authors of this document seek to identify factors that are potentially impacting the late-run kokanee populations in Lake Sammamish, so that local jurisdictions, agencies, tribes, non-profits and citizens can identify and take action to restore and preserve the species. While the data describing the abundance of spawning kokanee now spans a decade and provides a relatively sound picture of at least recent population size, the information and data currently available concerning the potential causes for the population's decline are extremely limited. This circumstance calls for significant caution in drawing definitive conclusions about causes for decline and their cures. It indicates the need for recovery strategies and actions that incorporate a precautionary approach and prioritized data collection activities that will greatly improve the scientific basis for action.

This analysis focuses on the late run kokanee. Of the three historic kokanee runs in the Lake Washington/Sammamish watershed, the late run provides the greatest certainty of native origin and current presence. The early run, which inhabited Issaquah Creek, is believed to be extinct. The middle run, which may have inhabited several streams from Lake Sammamish downstream into Lake Washington, presents a relatively uncertain picture of native origin and current presence. The current status of and limiting factors for middle run kokanee in the Lake Washington watershed need a more thorough assessment, from basic data collection to analyses and conclusions, than this document was intended to provide.

Analysis of existing stream flow data weakly implicates high fall/winter flows and lower spring flows as dominant limiting factors. High flows may act to scour redds reducing egg survival, while lower flows may reduce the survival of fry during the stream to lake migration. As a result, the actions taken to protect and restore stream habitat functions are beneficial to kokanee and should continue.

Adult escapement data for the remaining three late-run spawning aggregations indicate generally uniform trends among populations suggesting that factors limiting the population size likely occur when the populations are co-mingled in the lake. The lake environment may be unfavorable for kokanee survival in the summer period due to low dissolved oxygen in the lower depths and high water temperatures near the surface. Kokanee appear to avoid the upper and lower portions of the lake which may limit access to food or increase predation. Food (zooplankton) does not appear to be limiting and in fact kokanee appear to grow faster in Lake Sammamish than in many other lakes of the Pacific Northwest. The fast growth appears to be due to the bountiful supply of *Daphnia* and the availability and consumption of Mysids by kokanee, and may be confounded by low densities of kokanee in Lake Sammamish. Predation by cutthroat trout and other predators may the most significant factor limiting population, particularly during the summer period when temperature and dissolved oxygen constraints may restrict kokanee into a narrow band within the lake facilitating overlap with pelagic piscivores, such as cutthroat trout.

To address the recent precipitous decline of Lake Sammamish late-run kokanee, we recommend that the Washington Department of Fish and Wildlife implement an emergency supplementation program in the fall of 2008; governments, NGOs and citizens continue with habitat protection and restoration actions; and appropriate entities implement a robust monitoring plan capable of evaluating the benefits of habitat and supplementation actions. Necessary monitoring includes the collection of information to understand the population structure, dynamics and factors playing a primary role in limiting population success.

To be most useful in informing future management decisions, the monitoring program should generate information addressing the following:

- An understanding of age class structure and growth rates for fish in the lake and of returning adults.
- Escapement and egg-to-fry survival at each spawning area, including beach spawning.
- Predation rates of cutthroat and quantification of the impacts to the kokanee population at each life stage.
- Environmental variables including stream flow, bed scour, zooplankton abundance and the physical environment of the lake and correlate with fry, juvenile, subadult and adult kokanee.

An integrated supplementation, habitat restoration and research plan should be created and agreed to prior to implementation, to ensure the supplementation, habitat and research actions are complementary and have the greatest opportunity to 1) further clarify factors limiting the kokanee population and 2) determine which of the factors are the most important obstacle to recovering the population.

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Introduction

Kokanee and sockeye are considered one species (*Oncorhynchus nerka*) that displays different life history characteristics (Burgner 1991). Kokanee are adfluvial (live their entire lives in the freshwater, lake environment) and sockeye are anadromous (go the ocean and back). Further, kokanee and sockeye are considered a species complex: the progeny of kokanee will produce sockeye and sockeye will produce kokanee. Biologists have speculated that the species complex is a mechanism to spread the risk of population failure by keeping part of the population in a lake environment and the other part in the ocean environment. If one environment becomes too hostile to support the species, the fish in the other environment will perpetuate the species (Burgner 1991). The species complex mechanism is not an instantaneous reactive support system that can compensate for a population failure within a generation. Instead, the species complex mechanism operates over numerous generations that span hundreds or thousands of years. As a result, Lake Sammamish kokanee today are considered to be genetically unique and worthy of consideration for protection under the Endangered Species Act (USFWS 2008).

There are seven Evolutionarily Significant Units (ESUs) of sockeye salmon (*O. nerka*) in Washington and Oregon, as well as the sockeye from Big Bear Creek in the Lake Washington/Sammamish Basin, which is provisionally recognized as an ESU (Gustafson et al. 2001). Kokanee salmon are not considered part of any listed sockeye ESU, and are therefore currently afforded no protection under the Endangered Species Act (ESA). However, in 2007, Trout Unlimited, the City of Issaquah, King County, People for Puget Sound, Save Lake Sammamish, the Snoqualmie Tribe, and the Wild Fish Conservancy petitioned the United States Fish and Wildlife Service (USFWS) to define and list all wild, indigenous, naturally-spawned, kokanee in Lake Sammamish, Washington, as a threatened or endangered species under the ESA. In response, the USFWS (2008) stated that,

> “if, as the petitioners suggest, Lake Sammamish kokanee constitute a distinct vertebrate population segment, we find that the petition presents substantial information to indicate that listing Lake Sammamish kokanee under the Act may be warranted due to: (1) The present destruction, modification, or curtailment of the population’s habitat or range; (2) the inadequacy of existing regulatory mechanisms; and (3) other natural or manmade factors affecting its continued existence. In summary, we conclude that the petition has presented substantial information that listing may be warranted for Lake Sammamish kokanee. As such, we are initiating a [one year] status review to determine whether listing Lake Sammamish kokanee under the Act is warranted.”

Kokanee spawn in Lake Sammamish tributaries generally during the fall months. Eggs incubate over the winter and hatch from late winter to early spring. Hatchlings (alevin) absorb their yolk sac then swim out of the gravel as fry to feed on invertebrates on the stream bottom. In March through May, fry migrate out of the river and into the lake.

There, kokanee feed predominantly on zooplankton with a strong preference for *Daphnia*. Three to five years later the fish reach a size of 12 to 24 inches and mature to adults. Adults enter the streams to spawn in the fall and die within days to weeks after spawning (Berge and Higgins 2003).

Native Lake Sammamish kokanee provided a dominant fishery in the 1800s to early 1900s for Native Americans and settlers. Records indicate kokanee were plentiful and well distributed through the lake and tributaries until recently (Connor et al. 2000). The kokanee fishery declined in the mid-1990s to the point where the Washington Department of Fish and Wildlife (WDFW) enforced a harvest moratorium to conserve the species.

This report considers the factors limiting Late-Run Lake Sammamish kokanee (*Oncorhynchus nerka*). Currently available evidence suggests that this run is the last remaining stock of three distinct stocks runs of the Lake Sammamish kokanee stock population that historically occurred in Lake Sammamish and associated its tributaries, in areas downstream of Lake Sammamish, and potentially into Lake Washington. The three runs have been characterized by their unique run timings, and appear to spawn or have spawned in different tributaries (Figure 1). These runs have been divided into early, middle and late-run kokanee (Connor et al. 2000).

The early-run kokanee population declined from an annual escapement estimate in 1970s between 1,000 and 3,000 spawners to 39 or fewer fish from 1992 to 1998. This run is known to have spawned predominantly, if not entirely, in Issaquah Creek in the latter half of the 1900s (Connor et al. 2000). In 2000, the U.S. Fish and Wildlife Service (USFWS) was unsuccessfully petitioned to list the early-run of Lake Sammamish kokanee under the Endangered Species Act (ESA). However, since the 2000 petition, there have not been returns to Issaquah Creek, and by 2003 the run was believed to be extinct.

The middle-run is associated with the Sammamish River and tributaries, and located downstream of Lake Sammamish and upstream of Lake Washington. Given the proximity of the spawning grounds of the middle run to Lake Washington and its location downstream of Lake Sammamish, the middle-run is assumed to rear in Lake Washington. This report does not address whether the existing middle-run is the historic, native run (and therefore potentially related to the native-origin kokanee in Lake Sammamish) or if it is comprised of the offspring of introduced *Oncorhynchus nerka.* This question may be addressed in the status review USFWS is undertaking in response to the 2007 listing petition. Current genetics data (Young et al. 2004) suggests that these fish are the progeny of introduced sockeye to the watershed, which happened as early as 1917 (Connor et al. 2000).

The third run of Lake Sammamish kokanee, the late-run, spawn from late October through January primarily in tributaries to Lake Sammamish including Lewis, Ebright, and Laughing Jacobs Creeks, with a few spawners recorded in Vasa, Pine Lake, and East Fork Issaquah Creeks (Berge and Higgins 2003; Young et al. 2004; Jackson 2006). Lake Sammamish shoreline spawning has been observed, but not quantified (Hans Berge, pers. comm. 2008). Adult fish return to their natal stream or beach at ages 3 to 5 and spawn in late October through January (Berge and Higgins 2003; Jackson 2006). Eggs incubate through the winter, and fry leave the tributaries in April through May (Mark Taylor, unpublished data). Fry through sub-adult life stages occur in the lake and feed primarily on *Daphnia* for 3 to 5 years until reaching adulthood (Hans Berge, unpublished data).

A number of genetic studies have been and continue to be conducted to better understand the origin of late run kokanee and determine if it is a unique population (Young et al. 2004; Warheit and Bowman 2008). For the purposes of this study we assume the late run is a unique population and that each spawning tributary is a unique spawning aggregation within that larger population.

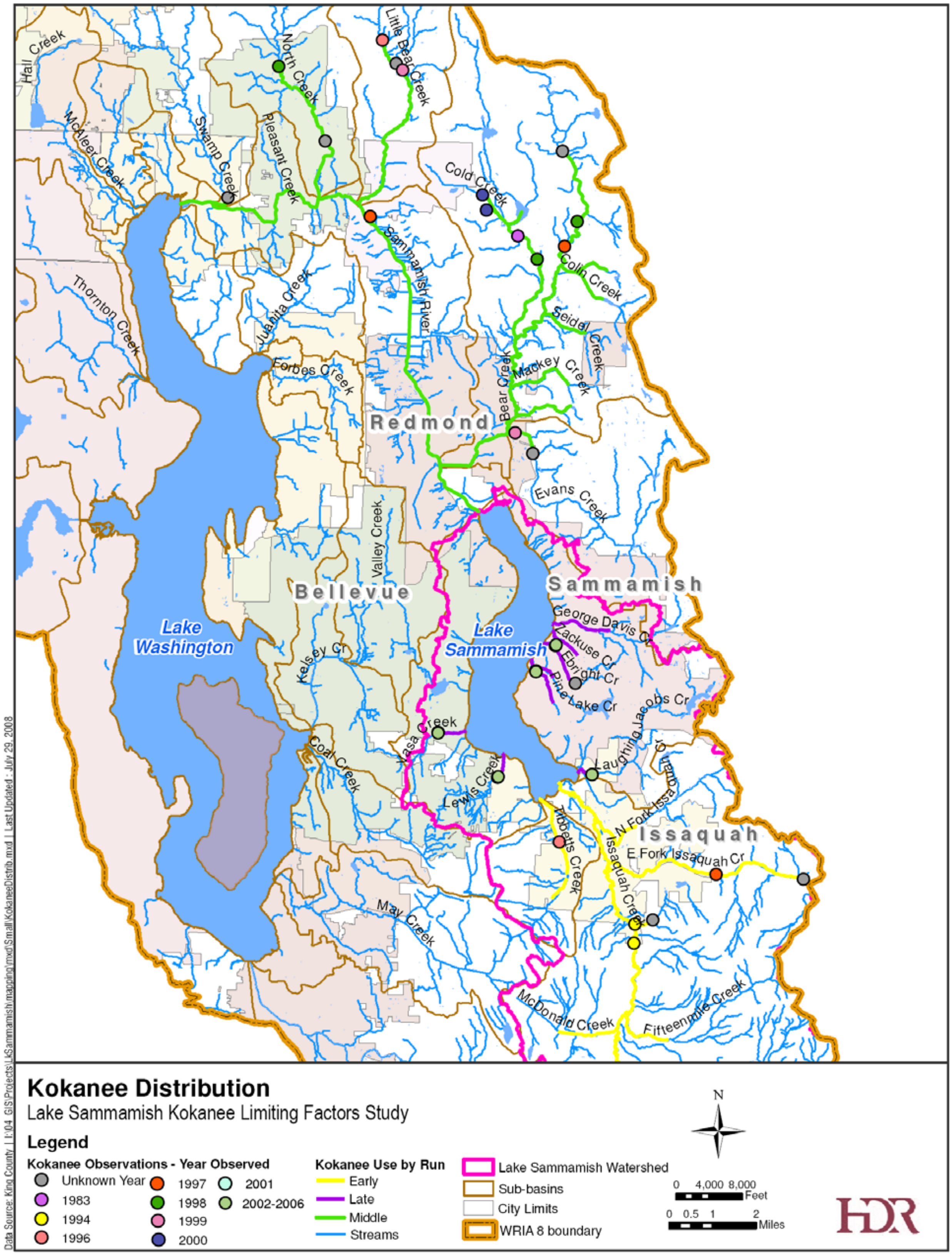

Figure 1. Spawning distribution of early, middle and late-run Lake Sammamish kokanee. (For historic distribution see Berge and Higgins 2003)

Previously Identified Factors of Decline

Many factors have likely contributed to the decline of kokanee in the Lake Sammamish Watershed. A brief summary of the primary factors are discussed in the following paragraphs.

Harvest

According to Trout Unlimited et al. (2007), kokanee were an important sport fish in the past and the USFWS (2008) states that sport fishing may have contributed to initial declines in the population. However, there currently is no intentional fishery for kokanee in Lake Sammamish, as kokanee salmon are prohibited from catch in both recreational and commercial fisheries in Lake Sammamish (Jackson 2006). A harvest ban has been in place since 1986 (Pfeifer 1995).

Although commercial fishing is not a current threat to the kokanee in Lake Sammamish, sport fishing may pose a threat to kokanee through incidental and illegal catch. Kokanee of the size seen historically in Issaquah Creek are likely vulnerable to angler harvest (Rieman and Meyer 1990). Anglers can misidentify kokanee as “trout” and as a result may be illegally keeping captured Lake Sammamish kokanee. Such misidentifications have been observed in Lake Roosevelt creel surveys (Keith Underwood, unpublished data). Whether incidental catch is affecting the Lake Sammamish kokanee population is unknown because creel surveys have not been conducted on this lake and consequently the number of kokanee caught and released is unknown. In Lake Roosevelt, as many as 30% of the kokanee die from the “catch and release” fishery (Keith Underwood, unpublished data).

Sockeye and Kokanee Supplementation

While sockeye and kokanee have not been stocked into Lake Sammamish since the 1970s, sockeye and kokanee were introduced into Lake Sammamish and Lake Washington on numerous occasions over the past century to create fishing opportunities (Gustafson et al. 1997). Pfeifer (1992) reports that about 21 million hatchery-origin kokanee fry were released throughout the Lake Sammamish Basin and 52 million were released in the Lake Washington Basin from 1917 through 1984 (Table 1). Connor et al. (2000) report that hatchery kokanee outplants from stocks originating out of basin occurred from 1917 to the 1970s and may have lead to genetic introgression of native kokanee.

Within the watershed, kokanee were abundant enough to support egg collections in the first half of the century. From 1922 to 1951, the King County and Washington Department of Game (WDG) egg-taking programs in the Lake Washington and Lake Sammamish watersheds harvested millions of eggs (Connor et al. 2000) that were primarily used for supplementation of natural production in various stream systems within the basin (Pfeifer 1992).

A total of 3.5 million kokanee fry were planted into Lake Sammamish from 1976 through 1979. However, since 1979, Lake Washington and Lake Sammamish have been managed for wild kokanee production, and there have been no introductions of hatchery broodstocks or non-native stocks to these systems (Pfeifer 1992). As recently as 1983, an egg-taking operation on Issaquah Creek resulted in the planting of nearly 55,000 kokanee fry into Issaquah Creek to augment the declining early-run population (Pfeifer 1992; Connor et al. 2000). A summary of sockeye and kokanee releases into the Lake Sammamish Watershed is presented in Table 1.

Table 1. Releases of Sockeye and Kokanee in the Lake Sammamish and Sammamish River Basins (from Gustafson et al. 1997).

Release Site	Number	Year	Origin
Sockeye			
Issaquah Creek	112,200	1957, 1961	Issaquah Creek
	1,629,059	1935-1944	Grandy Creek
	1,256,079	1947-1963	Issaquah Creek
	59,613	1950, 1954	Cultus Lake, B.C.
Bear Creek	576,000	1937	Grandy Creek
	23,655	1944	Cultus Lake B.C.
Total	3,656,606		
Kokanee			
Lake Sammamish	5,812,153	1938-1951	Lake Washington/Sammamish
	3,448,184	1976-1979	Lake Whatcom
Issaquah Creek	6,077,000	1923-1938	Lake Washington/Sammamish
	2,963,110	1926-1978	Lake Whatcom
	55,000	1983	Lake Sammamish
Other tributaries	860,000	1924-1925	Lake Washington/Sammamish
Bear Creek	35,077,293	1917-1969	Lake Whatcom
	9,118,368	1923-1939	Lake Washington/Sammamish
Little Bear Creek	1,255,719	1962-1969	Unknown
	483,720	1968-1969	Unknown
North Creek	912,200	1931-1937	Lake Washington/Sammamish
	371,240	1932-1969	Lake Whatcom
Swamp Creek	486,166	1933-1939	Lake Washington/Sammamish
	526,000	1968	Lake Whatcom

A result of the sockeye and kokanee plants may have been increased competitive interactions among hatchery and wild stocks. The fitness of the wild stocks may have been weakened through genetic introgression and outbreading depression. However, analysis by Young et al. (2004) suggests the tested populations showed little to no introgression of nonnative alleles and therefore if the fitness was reduced, as a result of hatchery plants, it was likely a fleeting impact that occurred within a generation or two of the release period. Young et al. (2004) have examined a number of kokanee populations and have observed limited or no genetic contribution of planted stocks to the native wild stocks. The mechanism for the lack of contribution is unknown. However, we suspect it is mostly driven by reduced fitness in comparison to wild fish and an inability for the stocked population to adjust behaviors to the new environment into which they were introduced.

Warheit and Bowman (2008) determined that Ebright, Laughing Jacobs and Lewis creeks were genetically distinct tributary populations that were unique and dissimilar to other out-of-basin stocks. These populations were also strongly related to one another suggesting significant gene flow among the populations. A likely mechanism for gene flow is adults straying from their natal tributary to the others. During years when large numbers of adults return to the tributaries and exceed the available spawning habitat, adults stray to the other tributaries in search of vacant habitat (Young 1999). This probably occurred during the peak adult returns seen in 2003. The Lake Sammamish population appears to be sustained by the Ebright, Laughing Jacobs and Lewis Creek populations. These populations are unique to Lake Sammamish (Warheit and Bowman 2008) and warrant consideration for protection under the Endangered Species Act (USFWS 2008).

In 1982, a supplementation program was considered for the early run and operated for one year This program was quickly discontinued because of the fear that diseased kokanee would enter the hatchery system and reduce coho and Chinook survival in the hatchery. In 1997, the WDFW Inland fish program managers evaluated whether a supplementation program was merited for rebuilding early run kokanee populations in the Lake Washington/Sammamish Basin (Pfeifer 1999). Action was not taken primarily due to a lack of funding and a very low number of detectable early run adults. The use of a supplementation strategy to maintain and enhance the late run kokanee population was explored again in a WDFW management plan (Jackson 2006). Efforts to secure hatchery space and funding were underway during the completion of this report. Warheit and Bowman (2008) confirmed the Lake Sammamish kokanee populations were unique and recommended that if a supplementation program were activated, mechanisms should be put in place to identify and maintain the unique populations and avoid sibling crosses.

Chinook and Coho Supplementation

The Issaquah Hatchery was constructed in the late 1930s. This artificial production facility rears and releases fall Chinook and coho. The purpose of the hatchery was to create and improve fall Chinook and coho harvest opportunities. As part of the hatchery, a weir was placed near the hatchery and fish migration to the upper reaches of Issaquah Creek and its tributaries has been under control by hatchery staff since inception. The fall Chinook program was started with Green River fish and the coho program started with a mix of locally adapted and Green River fish (WDFW 2002, 2003). Release goals include 2 million fingerling Chinook and 450,000 yearling coho. Brood stock collection goals are 1,600 Chinook and 1,000-2,000 coho. In the late

1990s the hatchery was renovated to improve the health and survival of Chinook and coho.

Past management operations at the Issaquah State Salmon Hatchery may have contributed to recent adverse impacts to the kokanee population, particularly the early-run. In the early 1960s and 70s, thousands of summer/early-run kokanee were reportedly trapped in hatchery ponds and killed because of concerns over potential disease transmission, which was erroneously thought to be a potential threat to hatchery stocks (Coyle et al. 2001). Additionally, the hatchery weir and water intake structure on Issaquah Creek prevented kokanee access to the upper 16 miles of habitat previously used for spawning. This passage barrier was particularly effective during the low flow months of July through September when the early-run was returning to spawn. The Issaquah Creek weir is still in operation, although the removal of kokanee is no longer practiced (USFWS 2008). The late-run may have also been affected by these practices. Chinook and Coho likely prey on kokanee fry and may have contributed to the population declines. It is not known whether late-run kokanee historically spawned in Issaquah Creek because they would have entered the creek and spawn during the sockeye run making it difficult to differentiate kokanee from sockeye. Currently, the late-run is not known to spawn in Issaquah Creek.

Habitat Modifications

Significant events have affected the Lake Washington Basin over the last century and have each in turn affected the local kokanee populations. The Lake Washington Ship canal, which opened in 1917, caused a lowering of Lake Washington in 1916 of 8.8 feet, and in turn dried up the Black River where it used to drain Lake Washington. The gradient of the Sammamish River was increased from the lowering of the lake. The U.S. Army Corps of Engineers channelized the river by widening and deepening to improve navigation. Extensive land filling of nearshore areas of Union Bay and northern Lake Washington from the early- to mid-1900s caused significant habitat loss. In the 1950s the Sammamish River was modified for flood control, which included dredging. In the 1970s and late 1980, upstream passage access in some Lake Sammamish tributaries was blocked by local residents. Natural passage barriers due to channel aggradation and widening, as well as reduction of summer flows, have also hindered kokanee migration (Connor et al. 2000).

Until the late 1960s, Issaquah Creek carried effluent to Lake Sammamish from several pollutant sources including a wastewater treatment plant, a milk processing plant, a hatchery, and mining operations (King County 2005). In 1968, the effluent from the wastewater treatment plant was diverted away from Lake Sammamish in an effort to limit the amount of phosphorus entering the lake and contributing to eutrophication and blue-green algae blooms (King County 1995). These actions slowed the eutrophication process, but urbanization and development in shoreline areas have significantly increased the amount of surface water runoff through a reduction in upland forest cover and riparian vegetation, leading to increased non-point-source pollution and increased streamside temperatures.

In continued efforts to stop the eutrophication process in-lake goals have been set for phosphorous and chlorophyll-a concentration. Background information about these goals can be found at http://green.kingcounty.gov/lakes/LakeSammamish.htm. Over the last ten years, two years have exceeded phosphorus in 2004 and 2006 and seven have exceeded chlorophyll-a goals from 1999 to 2006. The lake is mesotrophic, indicating a moderately productive system. Kokanee populations are typically healthy in meso- and oligotrophic systems. However, the lake environment in Lake Sammamish is less than ideal for kokanee survival due to low oxygen and high summer temperatures (see the following limiting factors section). As reported by Trout Unlimited et al. (2007), non-traditional pollutants known as “Endocrine disrupters” such as caffeine, endocrine disrupters, and other drugs escape treatment at wastewater plants and are found in storm water discharges. These pollutants have been given limited consideration by the scientific community and only recently have studies begun to determine the effect of these pollutants on fish. Endocrine disrupters are believed to be responsible for sexual dysfunction in fishes and reduced capability to produce offspring (Kirk et al. 2003). It is unknown whether fish in Lake Sammamish are being affected by these pollutants.

The Lake Sammamish/upper Sammamish River watershed is essentially bisected by King County’s Urban Growth Boundary, with the headwaters of Issaquah Creek and Bear/Evans Creek the major watershed areas outside of the Urban Growth Area. The incorporated and unincorporated areas of the watershed show varying intensity of development, with the main land uses in incorporated areas including residential and commercial development and road infrastructure to support them. Land use in unincorporated areas is primarily residential, small-scale commercial and road infrastructure. The level of impervious surface in the watershed has greatly increased as these land uses have intensified over recent decades. Urbanization has removed forests and reduced pervious surfaces thereby changing the hydro dynamics of streams: the ground absorbs less water causing increased intensity and frequency of peak stream flows (Shuster et al. 2005; Corbett et al. 1997, King County 1990). Peak flows may impact kokanee populations by scouring and entombing redds with fine sediments, displacing spawning adults, reducing productivity and ultimately population size as has been observed for other fishes (Craig 1997; Harvey and Lisle 1998; Nawa and Frissell 1993). The subsequent limiting factors section explores whether these potential impacts correlate with kokanee population size in Lake Sammamish

The body of this report relates quantified environmental conditions with population measures, such as stream flow rates and annual number of adults returning, in an attempt to identify factors limiting kokanee success. City and county jurisdictions adjacent to Lake Sammamish are moving to improve the stream and lake habitat, actively through projects and passively through regulation. These actions have undoubtedly benefited kokanee habitat; however, there is insufficient information to correlate kokanee population responses to specific habitat improvements. Further, based on the available data, tributary habitat does not appear to be the driving limiting factor due to relatively good fry survival, as will be discuss further in the subsequent section.

Current Limiting Factors Assessment

The goal of this study was to identify factors most likely to be limiting population success, using the data that could be assembled within the timeframe of this project. The analyses contained within this document are relatively weak due to limited information on the late run kokanee populations within Lake Sammamish. By no means should the hypotheses presented herein be construed as proven. Too little information was available to use multiple lines of evidence and generate a sound argument that is highly certain to withstand scrutiny over time. Instead, the intent of this study was to identify factors likely to limit the population and attempt to demonstrate why. Additional empirical data is required to adequately manage late run kokanee and build a comprehensive and highly certain recovery strategy.

Spawning, Egg Incubation and Fry Migration

The WDFW has summarized recent spawning escapement information for three kokanee spawning tributaries of Lake Sammamish: Lewis, Ebright, and Laughing Jacobs Creeks (Jackson 2008). These tributaries have been systematically monitored to estimate the number of late-run kokanee spawning since 1996 (Figure 2, Table 2). The number of adults entering the tributaries to spawn (escapement) provides us two separate observations: 1) escapement increases and decreases correspond closely among tributary populations, and 2) the total escapement began increasing dramatically in 2002-03, reached its peak in 2003-04, fell sharply in 2004-05, and has remained low ever since.

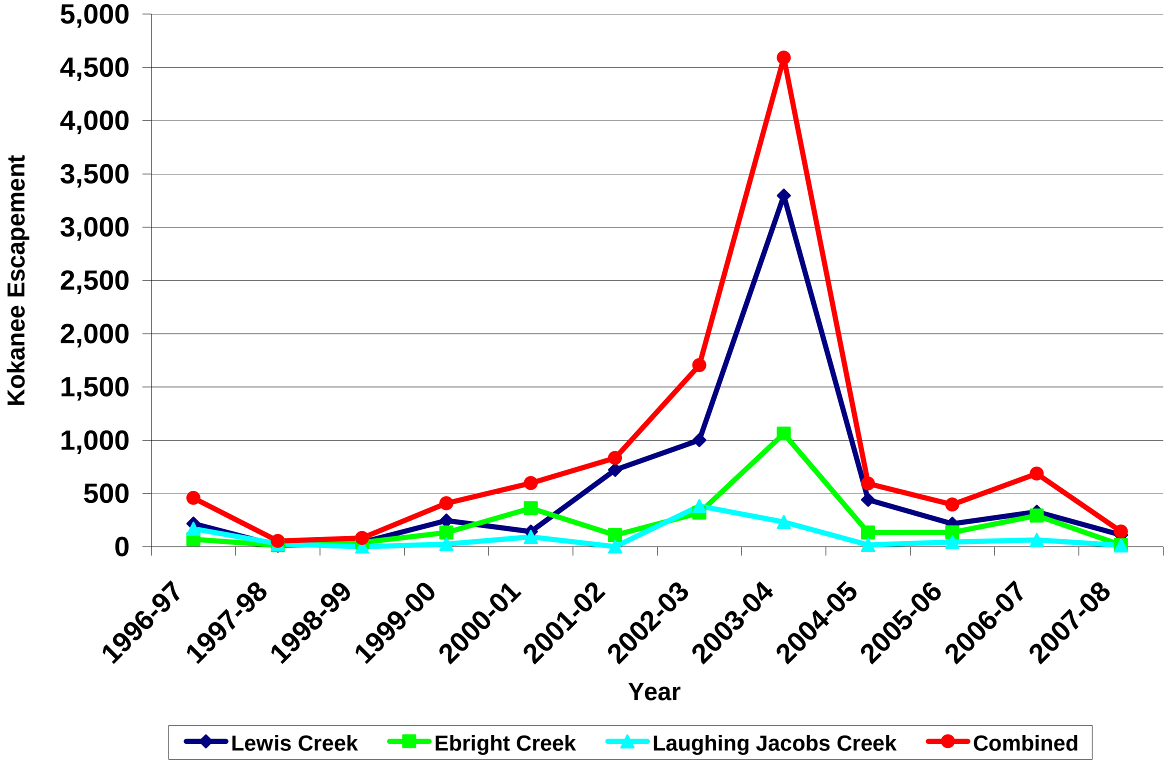

Figure 2. Kokanee Escapement estimates for 1996 through 2007 in Lewis, Ebright and Laughing Jacobs Creek (Jackson 2008)

Table 2. Kokanee escapement estimates for1996 through 2007 in Lewis, Ebright and Laughing Jacobs Creek (Jackson 2008).

LATE-RUN KOKANEE ESCAPEMENT TRENDS				
YEAR	**Lewis**	**Ebright**	**Laughing Jacob**	**Combined**
1996-97	219	70	170	459
1997-98	10	15	29	54
1998-99	43	40	0	83
1999-00	247	134	27	408
2000-01	143	362	92	597
2001-02	722	110	2	834
2002-03	1,002	319	384	1,705
2003-04	3,296	1,063	232	4,591
2004-05	442	134	18	594
2005-06	217	135	44	396
2006-07	330	292	65	687
2007-08	111	17	15	143
Average	565	224	90	879

Salmon in general (including kokanee) express high spawning site fidelity to their natal stream, which means fish that hatched and reared in a particular stream will return to the same stream to spawn as adults, and will often spawn at the exact site they were born (Hasler and Scholz 1983). Based on this natal site fidelity, it is assumed the Lewis, Ebright and Laughing Jacobs fish are unique populations that commingle in the lake, but separate and spawn in their natal streams. Since these populations appear to be synchronized (e.g. uniformly increase and decrease over time), it is hypothesized that the dominating factor(s) controlling population size occur when the population is mixed, such as when the fish are in the lake, affecting all kokanee. Alternatively, factors directly effecting kokanee population size could be due to similar hydrologic occurrences and/or conditions that uniformly affect all spawning streams equally (such as rain events), although the magnitude of bedload transport will be different within each channel due to site specific differences in land-use, riparian habitat, and gradient. Rain events can cause flooding, which results in bedload movement and in some instances bed scour and deposition (Devries 1997). In Western Washington, the typical rainy season overlaps with the period when late-run kokanee eggs are incubating in the gravel.

Before we consider these potential limiting factors, we must first contemplate the second observation. The population began increasing in 2002-03, peaked in 2003-04 and crashed in 2004-05. What was the cause for this pattern? This type of pattern is generally consistent with observations of salmon biology. Conditions become favorable for high survival typically during an early life stage that results in the production of many adults. Age at maturity is typically spread over two to three years and this is why the population builds and peaks over a few years and then declines. We will attempt to identify the environmental conditions creating favorable and then unfavorable conditions for Lake Sammamish kokanee.

Our first approach to answering this question was to correlate hydrologic conditions with spawning and early stream rearing conditions. To do that, we first needed to understand the age structure of the spawning populations in order to relate the hydrologic conditions to the year the fish was born. Two data sets were available to determine the age class structure. The first was of spawned and dead or dying kokanee in three spawning streams during the 2003-04 run. The otoliths (bony ear structure used for aging) were excised from the kokanee and submitted to the WDFW aging lab (Figure 3 and Table 3). In 2003-04, the age-3 adults were on average longer than the age-4 fish and closer in size to age-5 fish. How could age-3 fish be longer than age-4 fish? This is a perplexing question because, age-3 and age-4 are believed to live in the same lake environment and therefore have the same opportunity to exploit food and grow at similar rates. Perhaps the age-4 and age-5 fish grew in girth and not in length. Weight data did not accompany this length data and so we were unable to determine if the older aged fish were heavier.

Table 3. Average fork length by otolith determined age of adults kokanee collected at four Lake Sammamish Tributaries during the 2003 spawning period (raw data from Hans Berge, pers. comm. 2008).

Fork Length (mm) at Age		**Age**			**All**
Stream	**Measure**	**3**	**4**	**5**	
Ebright Creek	Average	400	388	402	396
	Range	330-427	320-426	385-421	320-427
	Number	23	13	3	39
Laughing Jacobs Creek	Average	402	371	410	386
	Range	381-423	336-382	384-436	336-436
	Number	2	5	2	9
Lewis Creek	Average	406	380		387
	Range	336-550	354-425		550
	Number	4	10	0	14
Pine Lake Creek	Average	394	356	403	392
	Range	394	356	387-432	356-432
	Number	1	1	3	5
All	Average	400	381	404	392
	Range	330-550	320-426	384-436	320-550
	Number	30	29	8	67

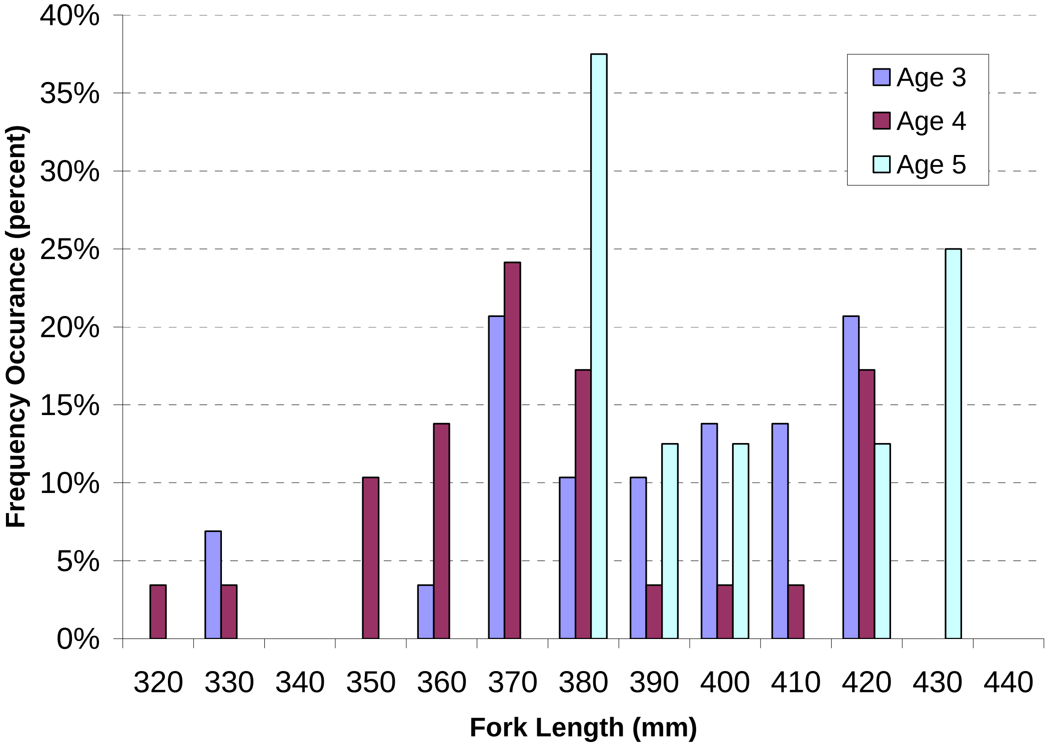

Figure 3. Size class frequency distribution of adult kokanee collected in four Lake Sammamish tributaries during 2003-4 spawning period (raw data from Hans Berge, pers. comm. 2008).

Typical kokanee populations express strong growth patterns that allow age differentiation by fish length; there is always some length overlap among ages, but infrequently to the degree observed here (Stockwell and Johnson 1997). In addition to the returning adults, in 2002-2003 kokanee were collected throughout the year by gill net and aged (Hans Berge pers. comm. 2008). Figure 4 and Table 4 present the age class structure and average length at age. These data confirm substantial size overlap among ages. These data were accompanied with fish weight information providing us an opportunity to determine if weight could be used to identify age. The condition factor (a measure of length to weight) was compared among age classes and presented in Figure 5 to determine if age classes could be identified by weight. There was not a notable difference among age classes and so it does not appear as if older fish are putting on more weight than length in comparison to younger fish.

Table 4. Kokanee age and average fork length (mm) of fish gillnetted in Lake Sammamish throughout 2002 and 2003 (raw data from Hans Berge, pers. comm. 2008)**.**

Age	0	1	2	3	4	5	All
Average	57	137	199	293	367	378	310
Range	57	137	165-292	125-386	260-422	358-389	57-389
Number	1	1	17	25	42	3	89

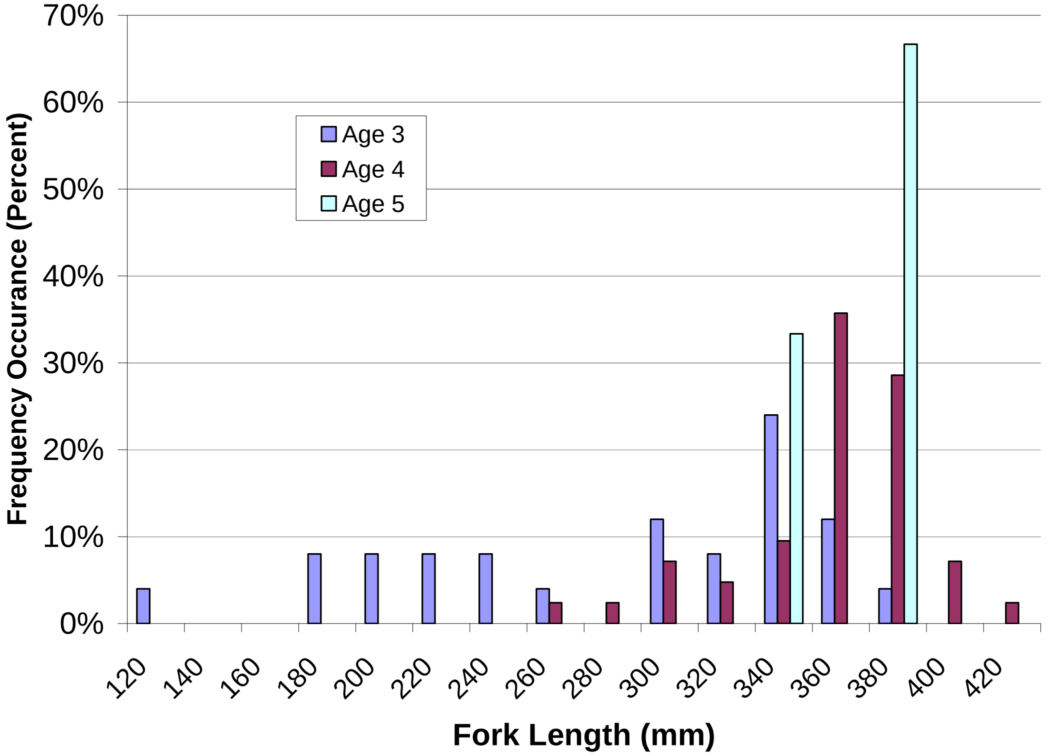

Figure 4. Frequency of occurrence by fork length and otolith determined age, n=89 (raw data from Hans Berge, pers. comm. 2008).

Table 5 compares the Lake Sammamish length at age data to regional kokanee populations provided by Peone et al. (1990). Lake Sammamish age-3 and -4 fish appear to be growing to longer lengths than 9 of the 13 populations indicating that Lake Sammamish kokanee grow fast and are not likely to be food limited. Greater attention will be placed on growth and food later in the document.

Table 5. Comparison of kokanee length at age (adapted from Peone et al. 1990).

Location	n	Average total length (mm) at annulus formation					Reference
		1	2	3	4	5	
Cultus Lake, BC (M)	31	74	163	224	--	--	Ricker (1938)
Cultus Lake, BC (F)	198		163	249	--	--	Ricker (1938)
Moore Creek, BC	--	--	170	237	245	--	Lorz and Northcole (1965)
Granby Lake, CO	--	130	224	264	--	--	Finnell (1966)
Coeur d'Alene Lake, ID	--	--	220	237	295	--	Cochnauer (1983)
Pend Oreille Lake, ID	237	74	160	202	229	--	Riemann and Bowler (1979)
Pend Oreille Lake, ID	--	92	178	216	244	--	Riemann and Bowler (1980)
Priest Lake, ID	205	79	180	216	239	--	Bjorn (1957)
Priest Lake, ID	--	81	175	216	246	--	Bjorn (1961)
Priest Lake, ID	--	195	255	320	--	--	Mauser et al. (1988)
Round Lake, ID	--	93	157	201	--	--	Howser (1966)
Spirit Lake, ID	--	--	215	267	283	--	Cochnauer (1983)
Upper Priest Lake, ID	96	89	193	264	297	--	Bjorn (1957)
Upper Priest Lake, ID	--	91	203	269	307	--	Bjorn (1961)
Libby Reservoir, MT	--	189	265	330	--	--	Chisholm and Fraley (1985)
Elk Lake, OR	--	147	196	249	--	--	Chapman and Fourtune (1963)
Odell Lake, OR	--	178	259	356	--	--	Chapman and Fourtune (1963)
Odell Lake, OR	--	190	255	305	--	--	Lewis (1975)
Lake Roosevelt, WA	55	113	262	251	365	--	Stober et al. (1977)
Mean		121	205	256	275	--	
Lake Sammamish Adults In Tributaries	67	--	--	400	381	404	Hans Berge (pers. comm. 2008)
Lake Sammamish Throughout year in lake	87	137	199	293	367	378	Hans Berge (pers. comm. 2008)

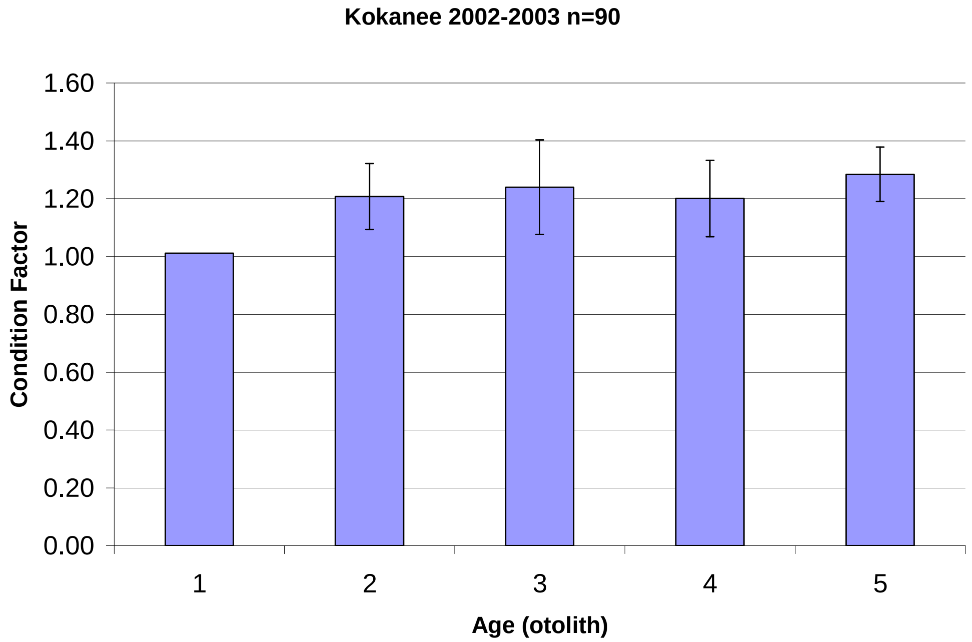

Figure 5. Average condition factor of kokanee collected by gillnet 2002-2003 by otolith determined age with standard deviation error bars (raw data from Hans Berge, pers. comm. 2008).

We were unable to differentiate age classes based on length or weight, which reduces the likelihood of correlating environmental affects with the number of returning adults. We had to include all age classes that returned in the analyses, since there was not means of differentiating age classes. The identification of factors that affect eggs through fry life stages in spawning tributaries is specific to the year of an age class. Therefore, when age classes are mixed, so are the environmental conditions. As a result, the analysis is diluted, because the full number of returning fish from different age classes were included. At any rate, an attempt was made to discover the effect of hydrologic conditions on the number of returning adults. We conducted correlation analyses of precipitation and stream discharge against the number of returning adults with a 3 and 4 year lag time to be consistent with aligning environmental conditions with age-3 and age-4 kokanee, which are the dominant age classes of spawning kokanee. We began the correlation analyses with monthly precipitation 3 and 4 years prior to the adult returns over a 12 year period. This method aligned the conditions the eggs and fry experienced 3 or 4 years prior to their return to the streams as adults to spawn.

These analyses test for uniform effects on the kokanee populations of Lake Sammamish while in the stream. Continuous gauge-generated stream flow data from spawning streams would provide the optimal foundation for an array of useful, detailed analyses relating aquatic habitat conditions to kokanee health. Lacking that, available precipitation data can be used to support analysis of annual environmental conditions such as stream discharge. For example, in years with high precipitation one would expect to observe high stream discharge. On the other hand, although one may expect to see higher stream discharge with greater precipitation, the relative change in stream discharge among spawning streams may differ due to specific watershed characteristics such as catchment size and proportion of impervious surface. This is why annual precipitation was used to screen for factors uniformly affecting the Lake Sammamish kokanee population. For example, years with higher than average precipitation are the years when the streams experience extreme peak flows and floods occur. The peak flow events increase bed load movement and possibly affect egg survival. Figure 6 depicts the number of adults returning to spawning streams (Laughing Jacobs, Ebright and Lewis creeks) three years prior to their return to align the birth of this generation with the total annual precipitation during the year of their birth.

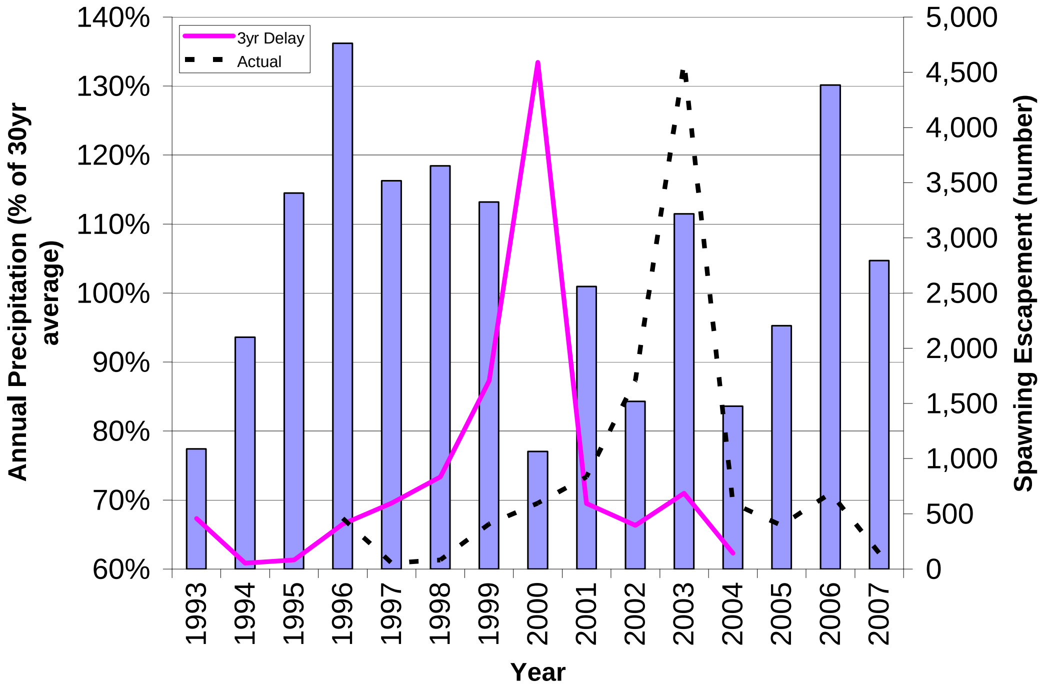

Figure 6. Total annual adult returns to monitored spawning streams (Lewis, Ebright and Laughing Jacobs Creeks) delay three years to align annual precipitation with the birth of the age-3 returning spawners.

There were no obvious patterns presented by this graph. The number of kokanee spawners does not appear to be dependent on annual precipitation recorded during their birth year. Figure 7 presents the scatter graph with the same data as Figure 6 and a linear regression line for ages-3 and -4. The R^2 is 0.125 for age-3 and 0.004 for age-4 suggesting that 12.5% and 0.4% of the points are described by the regression line. This is not considered a good correlation according to scientific standards for data analysis, and as a result we concluded that based on current data annual precipitation could not be used alone to predict the number of spawners produced 3 or 4 years later.

In addition the number of days that the precipitation exceeded the 30 year average of the 10%, 20% 30% and 40% exceedance precipitation was correlated with adult returns. December indicated a negative relationship for age-3 at the 30% exceedance (R^2=0.30, p=0.05), and November indicated a positive relationship in November

(R^2=0.30, p=0.10) for age 4 fish. This suggests that the magnitude of high rain events on a monthly basis did not relate to adult returns 3 and 4 years later for all months. However the frequency of high flow events as evidence by exceedance flows was benefit fish in November and a detriment to the number of adults returning in December. The more frequent the event in November the better and the less frequent in December the better. An interpretation of these relationships may be November precipitation which would turn into additional stream flow benefit adults as they migrate into the streams and may be a detriment to egg survival during December.

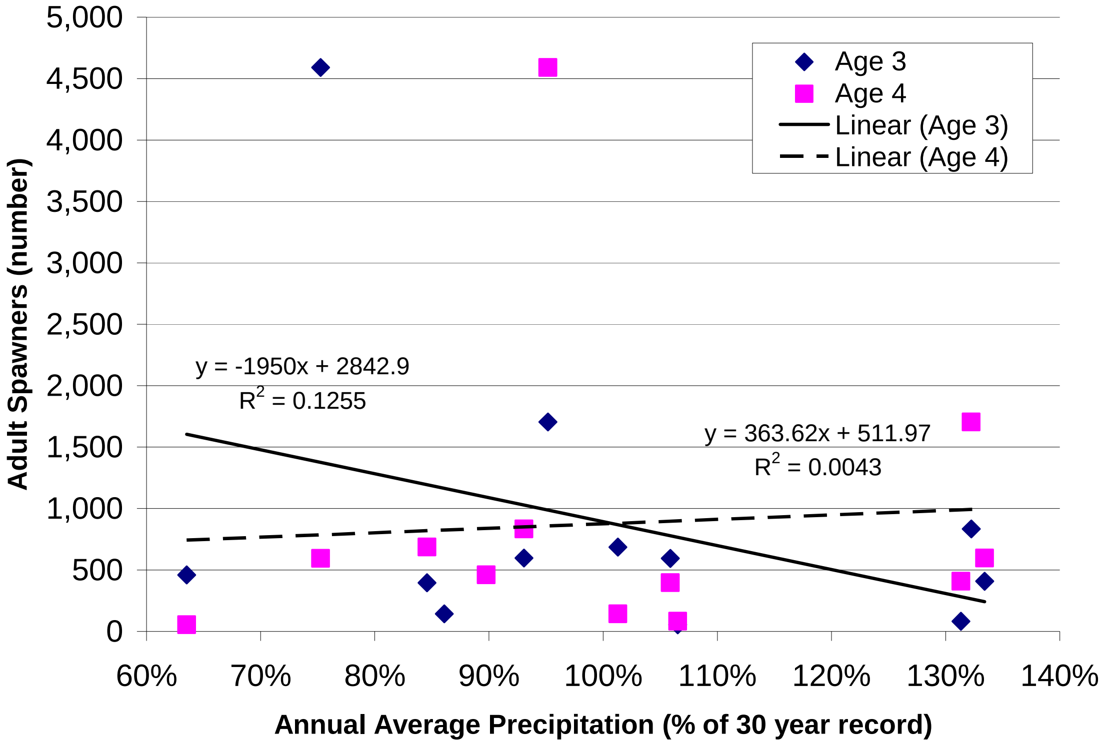

Figure 7. Regression Analysis of Annual Precipitation and Adults Spawners three years prior to their return.

Additional precipitation analysis was conducted by month, meaning the annual number of fish returning to spawn was correlated against each corresponding monthly precipitation, because each month has a potential effect on a different life stage of the fish. The periods and life stages are as follows:

Period	**Kokanee Life Stages**
September - October	Adults hold at stream mouth
November – January	Adults enter stream and spawn
November – March	Eggs incubate
February – April	Yolk-sac fry (alevin)
March – May	Fry outmigration to lake
March - June	Fry convert to lake life

The monthly correlations were very weak but better than those for annual precipitation. When we assume all returning adults were age -3 fish then a positive correlation was detected in June (R^2=0.579, p=0.004, n=12) and when we assumed all returns adults were age-4 fish a positive correlation was detected in May (R^2=0.376, p=0.034, n=12; Appendix A). These results mean that the higher the monthly precipitation in June or May, the greater the number of adults returning 3 and 4 years later. A possible explanation for this correlation is that fry migrate out of the streams and into the lake during April through May. The additional precipitation may provide additional stream flow allowing the fry to avoid being preyed on by sculpin, hatchery coho presmolts, bass, cutthroat, yellow perch and other potential predators. In Lake Sammamish, smallmouth bass were observed feeding on salmonid fry in the spring during the migration out of the streams and into the lake (Pflug and Pauley 1984). Beauchamp (1995) estimated that about 15% of the sockeye fry migrating towards Lake Washington were consumed by steelhead and Tabor et al. (2004) identified sculpin as a significant sockeye fry predator in the Cedar River.

When we tested average, variance, maximum and minimum monthly discharge relative to returning spawners 3 and 4 years later in Lewis Creek, age-3 fish did show a weak positive correlation with monthly average and minimum discharge in Lewis Creek (R^2=0.65, p=0.05, n=5; R^2=0.59, p=0.75, n=5) and age-4 did show a weak positive correlation with monthly variance and monthly maximum discharge (R^2=0.85, p=0.025, n=5; R^2=0.81, p=0.037, n=5). These relationships suggest higher monthly stream flows in June resulting in a greater number of returning adults 3 and 4 years later. Increased stream flow in Laughing Jacobs Creek did not correlate with an increased number of returning adults, probably due to the relatively low numbers of spawning adults.

These analyses resulted in relatively weak statistical relationships either because of low R^2, p or n values. While the analyses implicate potential relationships, they also require further testing to verify that a relationship does exist. With that said, the May –June period maybe a vulnerable period for kokanee fry. Years with higher flow may provide the fry with a survival advantage by providing better migratory conditions and quicker entry into the lake or in some way beneficially altering the lake environment.

Precipitation and returning adult simple regression analyses did identify one other weak negative correlation for the January period. When precipitation increased, age -3 adult returns decreased (R^2=0.25, p=10, n=12). In Lewis Creek, age-3 adult returns correlated negatively with average discharge (R^2=0.602, p=0.06, n=5), and in Laughing Jacobs Creek, age-3 adult returns correlated negatively with minimum monthly discharge (R^2=0.25, p=0.10, n=12). These weak correlations suggest that the higher the stream flow in January, the fewer the number of adults returning 3 years later. We speculate that January is the period during which a majority of spawning has occurred and high flows may scour kokanee redds, uncovering eggs and increasing rates of mortality. High flow events cause streambed movement and can be a significant limiting factor for salmonids (Nawa and Frissell 1993).

A final observation on stream flow and adult returns is a positive correlation in Laughing Jacobs for age-4 returns with November average (R^2=0.28, p=0.08, n=12), variance (R^2=0.32, p=0.05, n=12) and maximum (R^2=0.28, p=0.08, n=12) stream flow (Appendix A). As the stream flow increases, the number of adults returning 4 years later increased; however, it is unclear as to why. Additional flow in November may cause less pre-spawn mortality or encourage spawning earlier in the year. In summary simple regression analysis of escapement compared to precipitation and stream discharge suggests the following:

Period	**Kokanee Life Stages**	**Summary**
Sep-Oct	Adults hold at stream mouth	No clear relationship
Nov–Jan	Adults enter stream and spawn	Laughing Creek during November increased flow increases return size
Dec–Mar	Eggs incubate	Decreased flow increases returns
Feb–Apr	Yolk-sac fry (aleven)	No clear relationship
Mar–May	Fry outmigration to lake	Increased flow increases returns
Mar–Jun	Fry convert to lake life	Increased flow increases returns

With these results it is useful to revisit the two original observations when contemplating Figure 2 and Table 2: 1) escapement increases and decreases correspond closely among tributary populations and 2) the total escapement began increasing dramatically in 2002-03, reached its height in 2003-04, fell sharply in 2004-05, and has remain low ever since. Precipitation and stream discharge appear to have detectable effects on spawning escapement, but the relationships are relatively weak. Although stream flow can limit kokanee spawning success as well as egg and fry survival, it is not a strong enough relationship to implicate stream conditions as the primary factor limiting the kokanee population. Precipitation and stream flow magnitude are two of the many factors contributing to limiting the populations of kokanee in Lake Sammamish; however, they do not appear to be the overriding causes for kokanee decline. As demonstrated in Figure 6, there is no obvious relationship between annual or seasonal precipitation and the large escapement increase observed in 2002-2003. The large escapement in 2002-2003 should have given rise to another large year class three years later; however, this was not the case. The 2005-2006 escapement increased slightly, but not nearly to the proportion that it should have, particularly considering that 2006 was an above-average precipitation year.

Perhaps the number of spawners returning to tributaries during the 2002-2003 overwhelmed the streams, causing density dependent mortality because there were more spawners than spawning gravel, resulting in redd superimposition and reduced egg to fry survival. This may be the case, but we were unable to find estimates of current spawning gravel area or other habitat based analysis that would provide an accurate description of spawning capacity of the stream. However, kokanee typically spawn in the lower 0.75 of a mile of Lewis Creek and over 3,000 fish spawned in this reach - that equates to roughly one redd per lineal foot of stream. This suggests there was a lack of spawning habitat, and redd superimposition was witnessed by Hans

Berge (pers. comm. 2008). Thus, density dependent mortality was likely present, but not likely at a level sufficient to result in the low numbers returning in 2006.

In the spring of 2007, a fry trap was operated near the mouth of Lewis Creek. An estimated 13,942 fry migrated out of Lewis Creek from March through May (Hans Berge pers. comm. 2008). The adult escapement in 2006-07 was 330 adults. If we assume 60% of the adults were female and the fecundity of each female was 656 eggs (based on Pfeifer 1995), then roughly 129,882 eggs were deposited in redds during 2007 and the apparent egg to fry survival was roughly 11%. Hyatt et al. (2005) documented egg to fry survival rates of 2.2 to 11.3% in British Columbia. This information suggests that egg to fry survival in Lewis Creek during that year was toward the upper end of expected survival rates and further complicates an argument suggesting the tributary environment is limiting kokanee production. Rainfall during the spawning and incubation periods was near average annual precipitation, suggesting average precipitation years provide fairly good habitat during the egg to fry stage in Lewis Creek.

However, there are years where the stream conditions appear to profoundly affect the populations. From December 2-5, 2007, the above average volumes of precipitation (155% of normal) created bed scour conditions, which likely contributed to the low fry survival observed during the spring of 2008. Data show that while 111 adults escaped into Lewis Creek only 1,045 fry migrated out. The apparent egg to fry survival was 2.2% (raw data from Hans Berge, pers. comm. 2008). Although the survival rate was low, it still was within the survival rates observed in British Columbia further suggesting that even during the poorest hydraulic conditions, Lewis Creek, had suitable habitat capable of producing fry.

Spawning escapement of beach spawners is unknown and an important gap in our understanding of this population. Hans Berge (pers. comm. 2008) has observed large congregations of kokanee along the eastern shoreline of the lake during the spawning period (November). The absolute number of beach spawners and survival rates of the progeny are unknown, as are the specific habitat conditions that are drawing spawners.

Lake Environment

The lake environment may challenge kokanee survival during the summer months. Lake Sammamish stratifies beginning in May through October. During the summer months the upper 10 meters warm to above optimal temperatures, while the lower 5-10 meters falls below optimal dissolved oxygen levels (4 mg/l O_2). Hans Berge (*in press*) reviewed the potential effects of this environmental condition on Lake Sammamish kokanee, and argued that during these months only 20% of the lake meets kokanee sublethal standards of 17°C and 4mg/L as depicted in Figure 8. Sublethal standards suggest fish will avoid temperatures above and oxygen below the standard and if forced to reside in waters not meeting the standard may incur injury, but would survive. This environmental condition has come to be known as the temperature-DO “squeeze” (Berge, pers. comm. 2008). Berge hypothesizes that the squeeze may crowd kokanee into a limited space that is suitable to their needs, making them more susceptible to predation or partitioning them from their primary food source *Daphnia*. During other seasons of the year much more area of the lake appears to meet kokanee minimum requirements for temperature and oxygen.

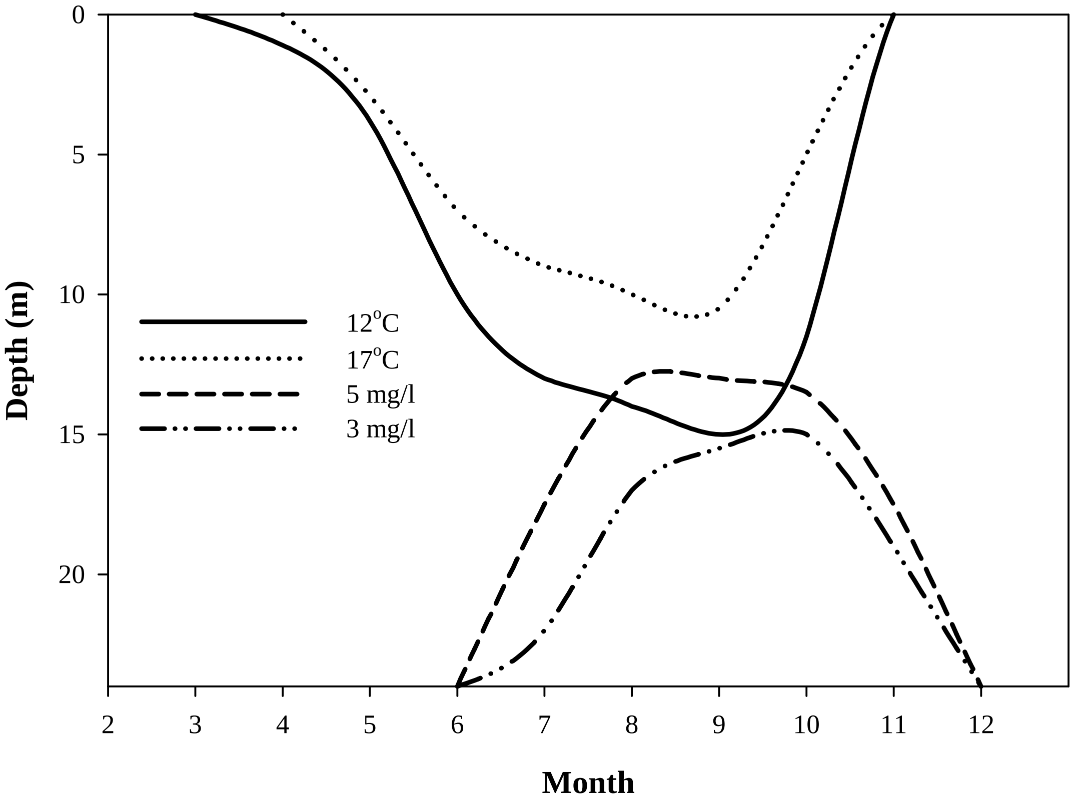

Figure 8. Annual temperature and dissolved oxygen isopleths for Lake Sammamish (2002 - 2003) from Berge (*in press*).

Food

The length of late-run kokanee returning to Lake Sammamish tributaries was above average, when compared to other kokanee populations within the Pacific Northwest (Table 4). Kokanee are zooplanktivores that selectively feed on *Daphnia* (Hampton et al. 2006), and are such highly effective *Daphnia* predators and have such strong selection for *Daphnia* that many populations express density dependant growth attributed directly to *Daphnia* abundance (Figure 9; Stockwell and Johnson 1997). In lakes where *Daphnia* are not prevalent, kokanee populations do not grow as long as fish with ample food. Frequently, shorter-than-average kokanee populations are the direct result of competition for *Daphnia* (Rieman and Myers 1992). Based on kokanee length at age data alone, the Lake Sammamish kokanee population does not appear to be food limited.

Hampton et al. (2006) demonstrated that sockeye fry in Lake Washington will feed on *Daphnia* when the density exceeds 0.4 *Daphnia*/L. *Daphnia* densities have been observed to be 8 *Daphnia*/L in April when fry leave the creeks for Lake Sammamish and therefore food appears to be adequate during the fry migration, as well as the rest of the year (Figure 10).

Neomysis mercedis is a “shrimp-like” crustacean native to Lake Sammamish. Kokanee diet analysis indicates that *N. mercedis* is the second most frequently encountered food item in stomachs and therefore appears to be an important food source (raw data from Hans Berge, pers. comm. 2008). Mysids are a nutritious food source and are probably one of the reasons kokanee grow to a larger than average size in Lake Sammamish. However, a close relative, *Mysis relicta,* typically out-competes kokanee for *Daphnia* and has contributed to the collapse of kokanee populations where it has been introduced (Martinez and Bergersen 1991). Nesler and Bergersen (1991) demonstrated that kokanee do not feed on mysids because their habitats do not overlap. When kokanee are at the surface, mysids are at depth and visa versa due to their unique diel migration behavior and unique reactions to environmental cues. However, the Lake Sammamish “squeeze” during the summer may create conditions where *N. mercedis* and kokanee habitat use overlaps and therefore an opportunity for kokanee to feed on *N. mercedis*. Mysids have low tolerance for warm water temperatures forcing them to occupy the same lake depths as kokanee in Lake Sammamish.

The density of *N. mercedis* in Lake Sammamish is unknown because they are not susceptible to the sampling gear used to collect zooplankton and studies have not been directed at this invertebrate. Due to the high density of *Daphnia* it is not likely that kokanee are being out-competed for food, although the possibility cannot be completely discounted.

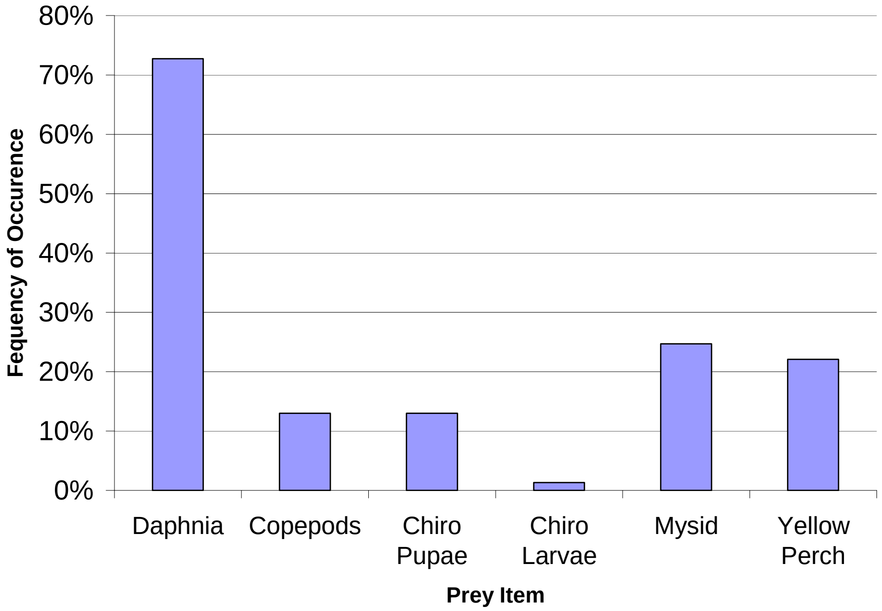

Figure 9. Kokanee diet described by frequency of occurrence based on 77 stomachs with prey items May 2002 through November 2003 and captured by gill nets (raw data from Hans Berge, pers. comm. 2008).

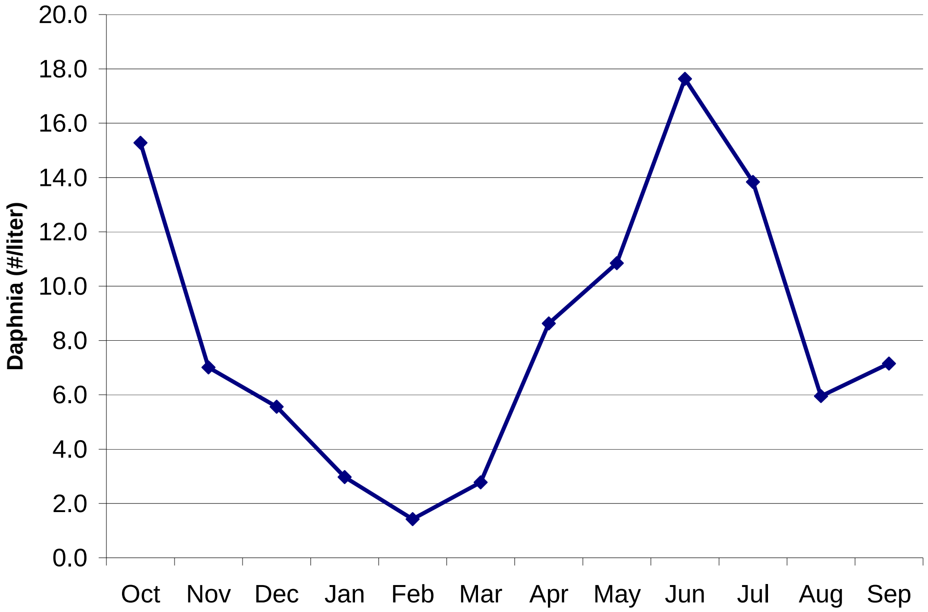

Figure 10. Average Monthly density of Daphnia from 1989 to 2003 (raw data from Hans Berge, pers. comm. 2008)

Competition and Predation

The Lake Sammamish fish community is diverse with a mix of native and non-native species. Based on data collected by Hans Berge with gill nets in the pelagic zone, cutthroat trout, yellow perch, and kokanee were the most dominant fish. The nets were not set near the shoreline and therefore likely under represents species with a strong affinity for the littoral zone such as northern pikeminnow, smallmouth bass, and suckers. Table 6 presents species relative abundance and importance of *Daphnia* as a prey item by fish species. Although a number of species used *Daphnia* as a food source, kokanee did not appear to have experienced a food shortage that had resulted in slowed growth. As a result, competition for *Daphnia*, kokanee's primary food source, is not likely.

On the other hand, Lake Sammamish does support fish species known to be piscivorous and the kokanee population may be impacted by these predators. Based on diet data collected by King County (Hans Berge, pers. comm. 2008), Chinook, cutthroat and northern pikeminnow were observed with kokanee/sockeye in their stomachs (Table 7). Based on frequency of occurrence and percent of relative weight in the diet, cutthroat appears to be a significant kokanee predator within the pelagic zone. However, due to the sampling methodology pikeminnow and other known predators in the littoral zone such as bass and sculpin were likely underreported and may play a significant role in limiting kokanee survival through predation. However, bass habitat preference is for the littoral area where kokanee spend very limit time. The limited habitat overlap likely limits predation by bass and other littoral-oriented fish.

When looking at cutthroat alone, their numbers may be high enough to severely limit the kokanee population without considering the other piscivores. Kokanee fry are vulnerable to predation as they leave the creeks and enter the lake during May and June. This is the period where kokanee are learning to forage and avoid predators in the lake environment. Footen (2003) identified cutthroat and yellow perch as significant salmonid predators in Lake Sammamish. This is similar to Lake Washington where cutthroat, yellow perch, northern pikeminnow, bass and sculpin prey on sockeye fry in Lake Washington and its tributaries (Nowak et al. 2004, Tabor et al. 2004, Tabor et al. 2007, Tabor et al. 2007a, and McIntyre et al. 2006). Other regional lakes with kokanee and sockeye such as Lake Ozette have demonstrated that cutthroat trout can consume up to 17% of the kokanee/sockeye age-0 production per 1,000 cutthroat and that cutthroat had a 25 times greater predation on kokanee/sockeye than did pikeminnow (Beauchamp et al. 1995). In addition, Cartwright et al. (1998) estimated that between 32 and 100% of the sockeye fry planted into an Alaskan lake were consumed by cutthroat trout. The available data from Lake Sammamish appear to be consistent with these findings.

Cutthroat may impose a significant impact to the kokanee population size. Additional research should be focused on this potential limitation by focusing on kokanee fry and juvenile predation in the lake and stream environment. The study should be designed to determine when and where predation is occurring and by which fish species. For instance, although coho were not identified as a predator by Berge's work, Ruggerone and Rogers (1992) documented substantial sockeye fry predation by coho juveniles in Chignik Lakes, Alaska. Understanding the prey dynamics will provide decision makers with the information necessary to cause a change in fisheries management. For example, managers could decide to increase harvest rates on predatory fishes and/or decrease the release number of hatchery fish if found to be preying on kokanee in Lake Sammamish.

Table 6. Relative abundance by pelagic fish species and importance of the prey item Daphnia based on relative weight to the fish population based on fish captured by gill nets, and hook and line during May 2002 through November 2003 (Unpublished data provided by Hans Berge, pers. comm. 2008). Note: relative abundance is only reflective of the pelagic zone in Lake Sammamish.

Species	Number Captured	Relative Abundance	Daphnia Importance
Chinook	4	2%	5%
Coho	3	1%	18%
Cutthroat trout	129	50%	15%
Kokanee	39	15%	56%
Large Scale Sucker	2	1%	0%
Northern Pikeminnow	1	<1%	15%
Peamouth Chub	7	3%	11%
Prickly Sculpin	1	<1%	24%
Smallmouth Bass	1	<1%	10%
Sockeye	1	<1%	-
Yellow Perch	73	28%	39%

Table 7. Frequency occurrence and relative weight of the prey item kokanee/sockeye in the stomachs of Lake Sammamish fish collected by gill net, seine and hook and line during May 2002 through November 2003 (raw data provided by Hans Berge, pers. comm. 2008)

Species	Stomachs with Prey	Frequency Occurs		Importance by Weight
		Number	Percent	
Black Crappie	1		0%	0%
Brown bullhead	5		0%	0%
Chinook	7	1	14%	6%
Coho	9		0%	0%
Cutthroat trout	174	22	13%	11%
Kokanee	77		0%	0%
Large Scale Sucker	17		0%	0%
Largemouth Bass	2		0%	0%
Mountain Whitefish	5		0%	0%
Northern Pikeminnow	26	2	8%	8%
Peamouth Chub	58		0%	0%
Prickly Sculpin	9		0%	0%
Pumpkinseed	2		0%	0%
Smallmouth Bass	18		0%	0%
Sockeye	0			
Yellow Perch	238		0%	0%
Total	648	25	4%	4%

Summary and Recommendations

The goal of this study was to identify factors most likely to be limiting the population success of Lake Sammamish late-run kokanee, using the data that could be assembled within the timeframe of this project. This last remaining run of kokanee in Lake Sammamish is in decline and in jeopardy of extinction. Information on this population is sparse, and actual historic and recent data relatively more sparse, and as a result our understanding of what limits the population is restricted to 12 years of adult escapement data and a few years of other population dynamics data. The analyses contained within this document are relatively weak due to these information constraints. By no means should the hypotheses presented herein be construed as proven. Too little information was available to use multiple lines of evidence and generate a sound argument that is highly certain to withstand scrutiny over time. Instead, the intent of this study was to identify factors likely to limit the population and attempt to demonstrate why. Additional empirical data is required to adequately manage late run kokanee.

Given the uncertainty inherent in the conclusions drawn from existing data and presented in this report, a precautionary approach should be employed as a guide for strategies to conserve and recovery this population. In practice this means the focus of actions should be on protecting areas of intact spawning and rearing habitat and the habitat processes that create and sustain those areas. It also means that effort must be directed at preventing the immediate extinction of the population itself, through artificial propagation measures that will protect and sustain the genetic material of the population and improve the abundance and distribution of the population as a hedge against further impacts of limiting factors.

Similar trends in escapement data for the kokanee populations that spawn in three separate tributaries suggest that conditions limiting population size occur while the populations are co-mingled in the lake. Further evidence of this hypothesis includes trends in adult escapement. The dramatic increase in the number of adults escaping to the tributaries in 2003-04, followed by the dramatic decrease a year later, coupled with the lack of rebuilding returns one generation later indicate that lake conditions may be uniformly affecting populations.

Annual and monthly precipitation and stream flow indicated weak correlations when compared with adult returns 3 or 4 years earlier. This suggested that the stream environment did not have a profound affect on the population because these conditions did not appear to be the overriding factor that could explain the uniform adult return pattern among populations. Stream flow also did not appear to be the primary factor affecting the escalated 2003-04 adult return. Stream flow during January, April, May and June appeared to relate to adult returns. When stream flow increased in January, the subsequent number returning adults a generation later decreased. This relationship may be explained by stream bed scour: increased stream flow caused the stream bed to move, scouring redds and subsequently killing eggs. However, increased flows during the months of April, May and June correlated with increased adult returns 3 or 4 years later. Increased stream flow during this period may improve migratory conditions for kokanee, which typically outmigrate from tributaries to the lake during these months. Increased stream flow may improve migratory conditions and fry survival by decreasing the time it takes to migrate to the lake and avoid stream predators such as sculpin and cutthroat.

The lake environment may be unfavorable for kokanee survival in the summer period due to low dissolved oxygen in the lower depths and high water temperatures near the surface. Kokanee appear to avoid the oxygen or temperature-limited upper and lower portions of the lake and such avoidance may limit access to food or increase predation. However, food does not appear to be limiting, and in fact kokanee appear to grow faster in Lake Sammamish than in many other lakes of the Pacific Northwest. The fast growth appears to be due to the bountiful supply of *Daphnia* and availability of Mysids. Predation by cutthroat trout may be a significant limitation to the population. Cutthroat are known predators on sockeye fry in Lake Washington and Ozette Lake (Nowak et al. 2004; Beauchamp et al. 1995). The summer environment forces kokanee into a narrow band within the lake and perhaps makes kokanee more vulnerable to cutthroat predation than they were historically. Eggers (1978) hypothesized that sockeye in Lake Washington spent the day at depth and migrated to the surface at night to feed as an avoidance measure against northern pike minnow predation. The avoidance behavior is not possible in Lake Sammamish due to the water quality.

Existing data are not sufficient to thoroughly test hypotheses about the effects of predation on kokanee in Lake Sammamish. For example, predation rates could not be assigned to the many known predators (i.e. sculpin, yellow perch, bass and northern pikeminnow), thus limiting understanding. A comprehensive predation study would provide fish managers with the information needed to determine appropriate management actions. Such a study would inform consideration of options, for example, to liberalize cutthroat bag limits or modify the release strategy for hatchery coho to minimize overlap with kokanee. Without the predation study, action to reduce predation may be counterproductive or just not succeed, because the uninformed action may focus on the wrong species or temporal-spatial periods.

We were unable to convincingly link stream habitat conditions with kokanee success. All kokanee spawning streams should be monitored with fry traps to estimate the egg to fry survival over many years, and with flow gauges to track hydrologic conditions at a finer resolution than annual or monthly precipitation. This will allow for a long term data set that will allow hydrologic and hydraulic conditions to be correlated with survival and, as habitat improvements continue, provide sufficient data to link habitat improvements with fry survival improvements. More importantly, a fry escapement estimate would benefit a comprehensive predation study to determine when, where and by whom a majority of the kokanee fry predation occurs.

Exploring the origin and genetic purity of Lake Sammamish kokanee has occupied a substantial portion of available staff resources. Expenditures on genetic analyses have reached the point of diminishing returns in terms of informing recovery strategies.

These analyses should be a lower priority compared to expenditures to understand what will drive the population toward sustainable health and actions that will accomplish this. The late run kokanee are so poorly understood that we could not provide a good assessment as to how strong the population is, or in other words, how likely the population is to go extinct. If the early run is any indication, the population of concern is nearing extinction and heroic efforts should be put forth to give this population a fighting chance while countable numbers of adults continue to exist.

Climate change could result in changes to precipitation patterns and could change the intensity of peak stream flows, thereby exacerbating bed scour conditions while kokanee eggs are in the gravel and reduce egg survival. Climate change could also increase the surface temperature of the lake, further degrading the lake environment. These changes in habitat conditions would likely decrease kokanee survival and select for fish species and communities of fish who spawn in tributaries outside to of the peak flow periods and are adept at surviving high lake temperatures with low oxygen demands. This type of selection pressure would select for fishes like northern pikeminnow and against fishes like kokanee. The shift in environment along with continued urbanization will likely intensify negative pressures on the late run kokanee making recovery unlikely without intervention. A monitoring and evaluation program that measures not only habitat variables, but also the fish community's response to the changing environment, will allow more effective management of the fish community and improve the chances of rehabilitating the kokanee population during a period when climate change may be affecting Lake Sammamish habitats. Such a monitoring and evaluation program would annually track fish harvest, relative abundance, age class structure, adult escapement, feeding behavior and fry production.

In a preemptive effort to ensure the late run kokanee stock does not go extinct, we recommend WDFW follow through with their proposal to implement an emergency conservation supplementation program as outlined by Jackson (2006). The Lake Sammamish kokanee appear to be declining and may not have time for the fish managers to determine the cause for the decline. In order to guard against extinction and provide adequate numbers of fish to test hypotheses regarding the causes for decline, a supplementation plan will be needed. The multiple-generation supplementation plan would need to provide guidance on 1) hatchery production goals, 2) whether the fish would be reared as one group or multiple groups, 3) target sizes at release, 4) the minimum number of fish released in each group (if separate groups are warranted) and 5) a marking strategy that is compatible with Lake Sammamish and other programs in Lake Washington.

Supplementation actions should be undertaken with a complementary commitment to collect information vital to understanding the population structure, dynamics and factors playing a primary role in limiting population success. Therefore, the supplementation plan should be coupled with a study plan to guide evaluations of overall action effectiveness and hypothesis testing. The study plan should be created and agreed to prior to implementation of a supplementation program, to ensure the supplementation and research actions are complementary and have the greatest opportunity to 1) further clarify factors limiting the kokanee population and 2) determine which of the factors are the most important obstacle to recovering the population.

To be most useful in informing future management decisions, the study plan should generate information addressing the following:

- Age class structure and growth rates for fish in the lake and of returning adults.
- Escapement and egg-to-fry survival at each spawning area, including beach spawning.
- Predation rates of cutthroat and quantification of the impacts to the kokanee population at each life stage.
- Environmental variables including stream flow, bed scour, zooplankton abundance and the physical environment of the lake, and how they correlate with fry, juvenile, subadult and adult kokanee condition and survival.

The results of the study plan should inform management decisions regarding when, at what size, and the best fry release strategy for the hatchery program. It would also inform consideration of fisheries management actions to limit cutthroat and other fish populations in order to reduce predation, through passive techniques such as harvest regulations or active techniques such as gill netting.

A supplementation project could also produce sufficient number of fry to test whether the cutthroat and other predators are driving fry to adult mortality. The study would need to address several key related questions, including

- When the fry are eaten and at what rate?
- Is the predation in the spring when the fry leave the rivers and enter the lake?
- Is the bulk of the predation in the summer during the lake “squeeze”?

Habitat-focused studies should be an integral part of the study plan. These studies would inform recovery goal setting and identify attributes of the habitat requiring improvement to reach recovery goals. Whereas the supplementation studies would focus on improving population health immediately, the habitat studies would guide setting expectations and goals. Both types of information are necessary to successfully manage the population.

Habitat studies could include, for example:

- Surveys able to determine the spawning gravel quality and quantity to produce a carrying capacity estimate.
- Determine the kokanee carrying capacity of the lake, based on bioenergetics or other means.
- Conduct scour chain studies to determine the frequency and extent bed scour destroy eggs.

- Estimate egg to fry survival in all significant kokanee spawning streams to define whether habitat is limiting fry survival.

The first step in building a study plan should be a critical path analysis to prioritize which hypotheses should be tested experimentally or refined through data collection. There is never enough funding or time to answer all the questions that one would like to answer before making decisions. Critical path and hypothesis testing are proven techniques that will maximize investments in knowledge procurement. Given the perilous state of the population, it is probable that a critical path analysis would prioritize the studies that help address immediate, extinction-avoidance issues over other studies.

A critical path analysis of study needs could play out as follows. Available data, while limited, suggest that egg-to-fry survival is reasonable and not likely the current reason for the species decline. As a result, egg-to-fry survival is a lower study priority than in-lake survival. However, availability of adequate spawning habitat that results in low egg-to-fry survival may become a limiting factor in the future, once kokanee population size increases and spawning habitat becomes limited. This is not the case today and should not be addressed immediately. The driving limitation appears to occur during the period from fry to adult. Fry to adult life stages occur in the lake and reasons for the low survival are debatable. Hypotheses for the apparent in-lake survival could include:

- Predation by cutthroat and other fish species.
- Lake environment is inhospitable and kills kokanee due to high temperature or lack of oxygen.
- Kokanee migrate out of the lake into Lake Washington and do not return.
- Unknown disease causes high mortality during the fry to adult stage.

This limiting factors report suggests predation may be the greatest impact to the population. Evidence for the second hypotheses was less compelling than the first, and the data were insufficient to address the third and four hypotheses in this report.. With that said, none of these hypotheses could be ruled out entirely. Our recommendation is to first test the predation hypothesis. Predation is a significant controlling mechanism in Lake Washington and limited data for Lake Sammamish appears to point to predation as well.

A study should be conducted that quantifies predation by predator, location, life stage of predator and prey and time of year. If a majority of the mortality can not be described by predation, then the other hypotheses should be updated, reviewed and then the next strongest hypothesis should be tested. Ideally this would continue until sufficient understanding is gained to further tailor and improve the effectiveness of recovery actions.

References

Beauchamp, D.A. 1995. Riverine predation on sockeye salmon fry migrating to Lake Washington. North American Journal of Fisheries Management. 15:358-365.

Beauchamp, D.A., M.G. LaRiviere, G. L. Thomas. 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.

Berejikian, Barry, and Michael Ford. 2003. A review of relative fitness of hatchery and natural salmon. preliminary review draft, Dec. 19, 2003. Available at: http://www.salmonrecovery.gov/remand/analysis_reports/fitness_paper_external_review_draft_121903.pdf

Berge, Hans B. and Kollin Higgins. 2003. The current status of kokanee in the Great Lake Washington Watershed. King County Dept. of Natural Resources and Parks. Seattle, WA. October 2003. 49 pp.

Berge, Hans. In Press. The relationship of temperature, dissolved oxygen and salmonid distribution in Lake Sammamish. Thesis submitted to the School of Fisheries, University of Washington.

Berge, Hans. 2008. Personal Communications, King County.

Booth, D.B. and C.R. Jackson. 1997. Urbanization of aquatic systems: Degradations, thresholds, stormwater detection, and the limits of migration. Journal of the American Water Resources Association 33(5): 1077-1090.

Bowles, E.C. B. E. Rieman, and G.R. Mauser. 1991. Effects of introductions of *Mysis relicta* on fisheries in Northern Idaho. Mysids in Fisheries Hard Lessons learned AFS Symposium 9:65-74.

Burgner, R.L. 1991. Life history of sockeye salmon. *In* Pacific salmon life history, [ed} C. Grout and L. Margolis. UBC Press. Vancouver.

Cartwright, M.A., D.A. Beauchamp, and M.D. Bryant. 1998. Quantifying cutthroat trout (*Oncorhynchus clarki*) predation on sockeye salmon (*Oncorhynchus nerka*) fry using a bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences. 55:1285-1295.

Connor, E., B. Kvam, and L. Mighetto. 2000. Historic and current status of kokanee in the Lake Washington Basin (Discussion Draft). Prepared for King County Department of Natural Resources, Seattle, WA, by R2 Resource Consultants, Inc. with historical research by Historical Research Associates, Inc.

Corbett, C.W., M. Wahl, D. E. Porter, D. Edwards and C. Moise. 1997. Nonpoint source runoff modeling a comparison of a forested watershed and an urban watershed on the South Carolina Coast. Journal of Experimental Marine Biology and Ecology. 213(1):133-149.

Coyle, M., J. Jorgensen, L. Robinson, S. Rullman, T. Seamons. 2001. Status review for the early-run Issaquah Creek kokanee. Student Paper for University of Washington.

Craig, S.D. 1997. Habitat conditions affecting bull trout, Salvelinus confluentus, spawning areas within the Yakima River Basin, Washington. Master's Thesis. Central Washington University. Ellensburg,

David Evans and Associates, Inc. 2007. predator fish monitoring at installed large wood structures – Sammamish River habitat enhancement projects. Prepared for the City of Redmond.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1685-1698.

Eggers, D.M. 1978. Limnetic feeding behavior of juvenile sockeye salmon in Lake Washington and predator avoidance. Limnology and Oceanography. 23(6): 1114-1125.

Entranco. 1996. Lake Sammamish Water quality management plan. Prepared for King County, City of Bellevue, City of Redmond and City of Issaquah.

Entranco. 2005. City of Sammamish Inglewood Basin plan. Prepared for the City of Sammamish.

Footen, B. 2003. Piscivorous impacts on Chinook (*Oncorhynchus tshawytscha*) in the Salmon Bay Estuary, the Lake Washington Ship Canal and Lake Sammamish. http://www.seattle.gov/util/about_spu/management/spu_&_the_environment/salmonfriendlyseattle/spu01_002680.asp

Gustafson, R.G., T.C. Wainwright, G.A. Winans, F.W. Waknitz, L.T. Parker and R.S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U.S. Dept. of Commerce, National Marine Fisheries Services, Seattle, Washington. NOAA Technical Memorandum NMFS-NWFSC-33. available at: <http://www.nwr.noaa.gov/Publications/Biological-Status-Reviews/upload/SR1997-sockeye.pdf>

Gustafson, R. Waples, S.T. Kalinowski, G.A. Winans, A.P. Hendry, J.K. Wenburg, P. Bentzen, E. Volk, and T.P. Quinn. 2001. Evolution of sockeye salmon ecotypes. Science 291(5502):251-252.

Hampton, S.E., R. Romare and D. Seiler. 2006. Environmentally controlled Daphnia spring increase with implications for sockeye salmon fry in Lake Washington, USA. Journal of Plankton Research 28(4):399-406.

Hasler, A.D. and A.T. Scholz. 1983. Olfactory imprinting and homing in salmon. investigations into the mechanism of the imprinting process. Springer-Verlag. New York.

Harvey, B.C., and T.E. Lisle. 1998. Effects of suction dredging on streams: a review and an evaluation strategy. Fisheries 23(8): 8-17.

Herrera Environmental Consultants, Inc. 1988. Evaluation of urban runoff impacts to Lewis Creek and Lake Sammamish from the proposed High Park Development.

Hey, Jody (Chair), E.L. Brannon, D.E. Campton, R.W. Doyle, I.A. Fleming, MT. Kinnison, R. Lande, J. Olsen, D.P. Philipp, J. Travis, C.C. Wood, H. Doremus. May 16, 2005. Considering life history, behavioral, and ecological complexity in defining conservation units for pacific salmon: An independent panel report, requested by NOAA Fisheries. 28pp.

Hyatt, K.D., K.L. Mathias, D.J. McQueen, B. Mercer, P. Milligan, D.P. Rankin. 2005. Evaluation of hatchery versus wild sockeye salmon fry growth and survival in two British Columbia lakes. North American Journal of Fisheries Management 25:745-762.

Independent Scientific Advisory Board (ISAB). 2003. Review of salmon and steelhead supplementation. Northwest Power and Conservation Council pp. 120. Available at: http://www.nwcouncil.org/library/isab/isab2003-3.htm

Jackson, C. 2006. Lake Sammamish Watershed native late-run kokanee stock assessment and management plan. Washington Department of Fish and Wildlife. Region 4 Fish Program. September, 2006. 9pp.

Jackson, C. 2008. Lake Sammamish Watershed native late-run kokanee stock assessment and management plan. Washington Department of Fish and Wildlife. Region 4 Fish Program.

Kerwin, J. 2001. Salmon and steelhead habitat limiting factors report for the Cedar - Sammamish Basin (Water Resource Inventory Area 8). Washington Conservation Commission Olympia, Washington.

King County Department of Metropolitan Services, Water Pollution Control Department and King County Surface Water Management Division. 1995. Lake Sammamish total phosphorus model. King County.

King County Department of Natural Resources. 2006. Preliminary feasibility analysis for the Lewis Creek fish passage improvement at the Spooner property.

King County Surface Water Management Division. 1990. East Lake Sammamish Basin conditions report – Preliminary analysis. King County.

King County. 2005. Draft. development of a 3-dimensional hydrodynamic model of Lake Sammamish. Prepared by Curtis DeGasperi, Water and Land Resources Division. Seattle, Washington.

King County. 2007. Lake Sammamish - Overview and Detailed Graphs website. Accessed June 25, 2008. http://dnr.metrokc.gov/wlr/waterres/lakes/LakeSammamish.htm

King County. 2008. Stream and River Water Quality Monitoring website. Accessed June 25, 2008. http://green.kingcounty.gov/WLR/Waterres/StreamsData/

Kirk, C.J., K. Bottomley, N. Minica, H.. Carpenter, S. Shaw , N. Kohli, M. Winter, E. Taylor, R. Waring, F. Michelangeli and R. Harris. 2003. Environmental endocrine disrupters dysregulate estrogen metabolism ad Ca^{2+} homeostasis in fish and mammals via receptor-independent mechanisms. Comparative Biochemistry and Physiology. 135(1):1-8.

McIntyre, J.K., D.A. Beauchamp, M. M. Mazur and N.C. Overman. 2006. Ontogenetic trophic interactions and benthopelagic coupling in Lake Washington: Evidence from stable isotopes and diet analysis. Transactions of American Fisheries Society 135:1312-1328.

Martinez, P.J. and E.P. Bergersen. 1991. Interactions of zooplankton, Mysis relicta, and kokanees in Lake Granby, Colorado. Mysids in Fisheries hard lessons learned AFS Symposium 9:65-74.

Nawa, R.K. and C. A. Frisssell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management. 13(3):634-638.

Nesler, T. P. and E.P. Bergersen. 1991. Mysids in fisheries: Hard lessons from headlong introductions. American Fisheries Society Symposium 9. Bethesda.

Nowak, G.M., R.A. Tabor, E.J. Warner, K.L. Fresh and T.P. Quinn. 2004. Ontogenetic shifts in habitat and diet of cutthroat trout in Lake Washington, Washington. North American Journal of Fisheries Management 24:624-635.

Oosterhout, G. R., C.W. Huntington, T. E. Nickelson, and P.W. Lawson. 2005. Potential benefits of a conservation hatchery for supplementing Oregon Coast coho salmon (Oncorhynchus kisutch) populations: a stochastic model investigation. Can. J. Fish. Aquat. Sci. 62:1920-1935.

Ostergaard, E., C. Young, and K. Ludwa. 1995. Abundance of spawning kokanee in the Sammamish River Basin: 1994 Status Report. King County Surface Water Management Division, Seattle, WA.

Parametrix. 2003. stream inventory and habitat evaluation report including Issaquah Creek, East and North Forks of Issaquah Creek, Tibbetts Creek, and the shoreline of Lake Sammamish. Prepared for the City of Issaquah.

Peone, T.L., A.T. Scholz, J.R. Griffith, S. Graves and M.G. Thatcher Jr. 1990. Lake Roosevelt fisheries monitoring program. Prepared by the Upper Columbia United Tribes Fisheries Center for Bonneville Power Administration. Portland, Oregon. Project No. 88-63.

Pfeifer, B. 1992. Fisheries investigations of Lakes Washington and Sammamish: 1980-1990. Part V. Wild cutthroat in Lakes Washington and Sammamish. Washington Department of Fish and Wildlife, Mill Creek, WA.

Pfeifer, B. 1995. Decision document for the management and restoration of indigenous kokanee of the Lake Sammamish/Sammamish River basins with special emphasis on the Issaquah Creek stock. WDFW, Mill Creek, WA.

Pfeifer, B. 1999. Recovery options and plan for early-entry Issaquah Creek kokanee in Lake Sammamish. Draft report. Washington Department of Fish and Wildlife, Mill Creek, WA.

Pflug, D.E. and G.B. Pauley. 1984. Biology of smallmouth bass (micropterus dolomieui) in Lake Sammamish, Washington. Northwest Science. 59(2)118-130.

Rieman, B.E. and D. Meyer. 1990. Status and analysis of salmonid fisheries. Kokanee population dynamics. Idaho Dept Fish and Game. DJ Job Pref. Rep. Proj. F-73-R-12.

Rieman, B.E., and D. L Myers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society. 121:178-191.

Ruggerone, G.T. and D.E. Rogers. 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.

Shuster, W.D. J. Bonta, H. Thurston, E. Warnemuende, D.R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. Urban Water Journal. 2(4): 263-275.

Stockwell, J.D. and B.M. Johnson. 1997. Refinement and calibration of a bioenergetics-based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences. 54:2659-2676.

Tabor, R.A., G.S. Brown and V.T. Luiting. 2004. The effect of light intensity on sockeye salmon fry migratory behavior and predation by cottids in the Cedar River, Washington. North American Journal of Fisheries Management. 24:128-145.

Tabor, R.A., E.J. Warner, K.L. Fresh, B.A. Footen, and J.R. Chan. 2007. Ontogenetic diet shirts of prickly sculpin in the Lake Washington Basin, Washington. Transactions of the American Fisheries Society. 136:1801-1813.

Tabor, R.A., B.A. Footen, K.L. Fresh, M.T. Celedonia, F. Mejia, D. L. Low, and L Park. 2007. Smallmouth bass and largemouth bass predation on juvenile Chinook salmon and other salmonids in the Lake Washington Basin. North America Journal of Fisheries Management. 27:1174-1188.

Trout Unlimited, City of Issaquah, King County, People for Puget Sound, Save Lake Sammamish, Snoqualmie Tribe, and Wild Fish Conservancy. 2007a. Petition to list the Lake Sammamish Kokanee (*Oncorhynchus nerka*) as threatened or endangered under the Federal Endangered Species Act. Accessed on June 25, 2008. http://www.scn.org/savelake/Kokanee.Petition.pdf

USFWS. 2008. Endangered and threatened wildlife and plants; 90-Day finding on a petition to list kokanee (Oncorhynchus nerka) in Lake Sammamish, Washington, as threatened or endangered. 73 FR: No. 88: 24915-24922.

USFWS. No date. Biological Opinion for Proposed Interstate I-90 Sunset Interchange Modifications and South Sammamish Plateau Access Road. USFWS Reference: I-3-99-F-0642.

Warheit, K.I. and C. Bowman. 2008. Genetic structure of kokanee (Oncorhynchus nerka) spawning in tributaries of Lake Sammamish, Washington. Report

Submitted to King County Department of Natural Resources and Parks, Water and Land Resources Division, and Trout Unlimited – Bellevue/Issaquah as partial Fulfillment for Contracts 07-2047 (king County) and 07-2098 (trout Unlimited. 49pp.

WDFW. 2002. Hatchery genetic management plan – Issaquah Creek fall Chinook program.

WDFW. 2003. Hatchery genetic management plan – Issaquah coho program.

Young, K.A. 1999. Managing the decline of Pacific salmon: Metapopulation theory and artificial recolonization as ecological mitigation. Canadian Journal of Fisheries and Aquatic Science. 56(9): 1700-1706.

Young, S.F., M. R. Downen, and J.B. Shaklee. 2004. Microsatellite DNA data indicate distinct native populations of kokanee, *Oncorhynchus nerka*, persist in the Lake Sammamish Basin, Washington. Environmental Biology of Fishes. 69: 63-79.

Appendix A

Appendix A-1. Summary of regression analysis (R^2, p and direction of correlation) comparing Lake Sammamish adult returns to monthly precipitation, and stream discharge. N = no apparent relationship.

Regression Analysis	Age	n	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	All
Average Precipitation vs. All Adult Returns	4	12	N	N	N	N	N	N	N	N	R^2=0.38 p=0.03 Positive	N	N	N	N
	3	12	N	N	N	N	R^2=0.25 p=0.10 Negative	N	N	N	N	R^2=0.58 p=0.01 Positive	N	N	N
Days Greater than 30 year average Exceedance 10,20,30,40% vs. All adult returns	4	12	N	N	R^2=0.30 p=0.10 Positive 30% for exeed	N	N	N	N	N	N	N	N	N	N
	3	12	N	N	N	R^2=0.33 p=0.05 Negative 10% for exeed	N	N	N	N	N	N	N	N	N
Laughing Jacobs Average monthly discharge vs. adult returns	4	12	N	N	R^2=0.33 p=0.05 Positive	N	N	N	N	N	N	N	N	N	N
	3	12	N	N	N	N	N	N	N	N	N	N	N	N	N

Regression Analysis	Age	n	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	All
Laughing Jacobs Variance monthly discharge vs. adult returns	4	12	N	N	R^2=0.32 p=0.05 Positive	N	N	N	N	N	N	N	N	N	N
	3	12	N	N	N	N	N	N	N	N	N	N	N	N	N
Laughing Jacobs Maximum monthly discharge vs. adult returns	4	12	N	N	R^2=0.28 p=0.08 Positive	N	N	N	N	N	N	N	N	N	N
	3	12	N	N	N	N	N	N	N	N	N	N	N	N	R^2=0.26 p=0.09 negative
Laughing Jacobs Minimum monthly discharge vs. adult returns	4	12	N	N	N	R^2=0.30 p=0.06 Positive	N	N	N	N	N	N	N	N	N
	3	12	N	N	N	N	R^2=0.25 p=0.10 Negative	N	N	R^2=0.28 p=0.07 negative	N	N	N	R^2=0.26 p=0.09 negative	N
Laughing Jacobs Days Greater than 10 year average flow exceedance 10,20,30,& 40% vs. All adult returns	4	11	N	N	N	N	N	N	N	N	N	N	N	N	N
	3	11	N	N	N	R^2=0.30 p=0.07 Negative 10% exeed	R^2=0.34 p=0.05 Negative 20&30% exeed	N	N	R^2=0.28 p=0.07 negative	N	N	N	R^2=0.26 p=0.09 negative	N
Lewis Cr. Average monthly discharge vs. adult returns	4	5	N	N	N	N	N	N	N	R^2=0.75 p=0.06 positive	N	N	N	N	N
	3	5	N	N	N	N	R^2=0.60 p=0.07 negative	N	N	N	N	r^2=0.65 p=0.05 positive	N	N	N

Regression Analysis	Age	n	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	All
Lewis Cr. Variance monthly discharge vs. adult returns	4	5	N	N	N	N	N	N	N	N	N	r^2=0.85 p=0.03 Positive	N	N	N
	3	5	N	N	N	N	N	N	r^2=0.27 p=0.895 negative	N	N	N	N	N	r^2=0.34 p=0.08 Negative
Lewis Cr. Maximum monthly discharge vs. adult returns	4	5	N	N	N	N	N	N	N	N	N	r^2=0.81 p=0.04 Positive	N	N	N
	3	5	N	N	N	N	N	N	N	N	N	N	N	N	N
Lewis Cr. Minimum monthly discharge vs. adult returns	4	5	N	N	N	N	N	N	N	N	N	N	N	N	N
	3	5	N	N	N	N	N	N	N	N	N	r^2=0.59 p=0.07 Positive	N	r^2=0.52 p=0.11 Positive	N