SEATTLE'S AQUATIC ENVIRONMENTS

Lake Washington

The following write-up relies heavily on the *Lake Washington Subarea Chapter* by Kurt Fresh in the *Draft Reconnaissance Assessment – Habitat Factors that Contribute to the Decline of Salmonids* by the Greater Lake Washington Technical Committee (2001).

Overview

Lake Washington is the largest lake in Washington State west of the Cascade Mountains, with a surface area of 22,138 acres. It is about 20 miles long with over 50 miles of shoreline (at an elevation of 22 feet). Mercer Island is a large island in the southern part of the lake that has an additional 30 miles of shoreline. The city of Seattle borders the west side of the lake with approximately 20.1 miles of shoreline within the city limits. Of these 20.1 miles of shoreline, approximately 11 miles are public land managed by the Seattle Department of Parks and Recreation. Maximum depth of the lake is 214 feet, mean depth is 108 feet, and the lake is shallowest at its north and south ends. The lake has a mean width of 1.5 miles and drains to Puget Sound through Seattle via the Lake Washington Ship Canal, an artificial waterway 8.6 miles long.

The main inflow to the system is the Cedar River which is the city of Seattle's major source of drinking water. The Cedar River flows into the southeast corner of Lake Washington and contributes about 53 percent of the lake's mean annual inflow. The Sammamish River flows into the northeast corner of Lake Washington and contributes approximately 27 percent of the inflow. Numerous other small tributaries, including Thornton Creek in northeast Seattle, Juanita Creek, Kelsey Creek, Lyon Creek and May Creek, also drain into Lake Washington.

The lake stratifies once each year, typically between April through October (Anderson 1954; Beauchamp 1990). Mean epilimentic (0-70 feet) temperatures range from 8°C to 16-18 °C with a maximum of about 23 °C (Beauchamp 1990). During the last decade, the mean temperature in August at 15 feet has ranged from 19.8°C to 22.4°C (Daniel Schindler, UW, personal communication). The lake is homothermal from about December through April with mean temperatures typically ranging from 6 to 8°C (Beauchamp 1987). For the last decade, the mean temperature at 15 feet during the January-February period has ranged from 6.7°C to 8.1°C (Daniel Schindler, UW, personal communication).

Historical Modifications

Physical Changes

Lake Washington has experienced a series of major physical and limnological changes that began in 1916 when the natural outlet of the lake, the Black River, was blocked, and the outlet was changed to the Ballard Locks in Seattle. At the same time, the Cedar River was redirected into Lake Washington to increase the amount of inflow. These actions lowered the lake's level by about 10 feet, exposed 5.4 km^2 of previously shallow water habitat, reduced the lake's surface area 7.0 percent, decreased the shoreline length by about 12.8 percent, and eliminated much of the lake's wetlands (Chrzastowski 1983). Lake level is regulated by the release of water at the Ballard Locks and is not allowed to fluctuate more than about 2 feet. Historically, lake level varied by up to 6.5 feet during flood events.

The shoreline of the lake has been extensively altered. Historically, more commercial development was located on the lakeshore, but as the population in the watershed has grown, the demand for residential waterfront property increased significantly. The majority of the shoreline is now urban, residential (Weitkamp et al. 2000), with the exception of a few commercial and industrial developments (e.g.,

Partially restored Lake Washington shoreline. Note low gradient bank, fine gravel, and shallow water habitat.

Kenmore Air at the north end and the Boeing Company in the south end). Seattle and twelve cities now border the lake. Seattle's and other lakefront parks provide the only substantial exception to this highly developed shoreline condition. Park shorelines are relatively undeveloped, although riparian vegetation is often absent. City parks bordering Lake Washington include Seward Park together with Lake Washington Boulevard, as well as Leschi, Madison, Magnuson and Matthews Beach Parks. City park ownership accounts for over 50% of the city's shoreline.

As the watershed has developed, dredging, filling, bulkheading, and the construction of piers, docks, and floats have occurred in shoreline areas. Bulkheads and other forms of shoreline armoring and retention are also present along most of the Lake Washington shoreline within the city limits. Of the 20.1 miles of shoreline within the Seattle city limits only 14.4% or 2.9 miles was classified unretained (i.e., not hardened) in 1999 (Weitkamp et al. 2000). In many cases, installation of bulkheads has created a vertical or steep-sloped face next to relatively deep water (4-6 ft).

With the exception of several small marinas, most of the docks along Lake Washington consist of single-family residential docks. The littoral area adjacent to the city has more than 750 residential docks (there are about 2,700 docks around the entire lake) that extend out 30-100 ft from the shoreline and cover an estimated 4% of the lake surface area within 100 feet of the shoreline (Weitkamp et al. 2000). Boats moored at these docks shade additional water surface area.

Much of the large woody debris that was likely associated with the lake's shore (Christensen et al. 1996) has been eliminated. The only "natural" shoreline remaining in Lake Washington is on the northeast shore just south of the city of Kenmore at St. Edwards Park, which represents less then 5 percent of the lake's shoreline. A recent survey of the lake's shoreline under the city of Seattle's jurisdiction indicated that "natural vegetation" was present along only 22 percent of the northern shoreline and 11 percent of the southern shoreline (Weitkamp et al. 2000).

Limnological Changes

The limnological characteristics of Lake Washington have undergone dramatic changes during the last 50 years. Many of these changes have resulted directly from fluctuations in phosphorus loadings. Lake Washington received direct discharges of secondary treated sewage effluent from 1941 to 1963. This dramatically increased phosphorus concentrations in the lake, which led to eutrophication of the lake (Edmondson 1991). As a result, blue-green algae became the dominant phytoplankton taxa and dramatically decreased water clarity in the lake. Blue-green algae also helped to suppress the production of some species of zooplankton such as *Daphnia sp.*

Except for combined sewer overflows, sewage effluent was completely diverted from the lake by 1968 and the lake subsequently reverted to a mesotrophic state (Cooke et al. 1993). The major sources of phosphorus inputs to the lake are now from tributary streams (King County 1993). As a result of the diversion of sewage, several major changes in the zooplankton community occurred. Most notably, beginning in 1976, *Daphnia* became the dominant pelagic zooplankton taxa.

Other changes in the limnological characteristics of the lake have occurred that are not related to fluctuations in phosphorus loadings. Alkalinity levels in the lake increased from an annual mean of 28.6 mg of calcium carbonate/L in 1963 to over 40 mg calcium carbonate/L by 1990 (A. Litt, UW, personal communication). It has been hypothesized that the long-term change in alkalinity in Lake Washington has been caused, at least in part, by urbanization that has altered the chemical output of the land to the streams (S. Abella, UW, personal communication).

In addition, surface water temperatures in the lake have been steadily increasing, probably as a result of global warming (D. Schindler, UW, personal communication). For example, from 1932 to 2000, there has been a significant increase in mean August water temperature at a depth of 15 feet from about 19 °C to 21 °C (Daniel Schindler, UW, personal communication). Finally, pH spikes as high as 9.4 have been observed recently in nearshore areas at night during late spring and summer (Fresh, WDFW, personal observation).

Exotic Plants and Animals

In addition to changes in the lake's littoral zone and limnology, exotic plants and animals (i.e., non-native) have affected the Lake Washington ecosystem. Twenty-three non-native fish species have been identified in Lake Washington (Warner and Fresh 1998). Some of these species are known to prey on juvenile salmon (e.g., smallmouth bass) while others are potential competitors with juvenile salmonids for food (Fayram 1996; Kahler et al. 2000).

Eurasian watermilfoil (*Myriophyllum spicatum*), an exotic aquatic plant, was introduced into Lake Washington in the 1970's. This plant has colonized a large percentage of the littoral zone of the lake and replaced much of the native aquatic vegetation present in littoral areas (Patmont et al. 1981). Milfoil is capable of growing to depths of 30 feet (Aiken et al. 1979). Because distribution of aquatic macrophytes in lakes can be limited by the occurrence of seasonally low water levels (Cooke et al. 1993), the stable (i.e., regulated) lake levels have probably promoted milfoil expansion. The plant has altered the physical characteristics of littoral zone habitats, such as changing substrate characteristics (Patmont et al. 1981), and adversely affected local water quality. Frodge et al. (1995) found that high macrophyte densities can cause localized fish mortalities due to dissolved oxygen depletion.

Chinook Utilization of Lake Washington

Lake Washington is used principally by two life stages of chinook.

☐ Adult upstream migration, and

☐ Juvenile outmigration and rearing

Adults. While adult chinook spawn along shoreline areas in other systems (Healey 1991), there are only unconfirmed reports of adult chinook spawning in littoral areas of Lake Washington. Since 1998, some chinook entering Lake Washington have been tagged with ultrasonic transmitters in order to provide information on movements, timing, and habitat use during their passage through the lake. At present, only results of studies in 1998 are available (Fresh et al. 1999).

Adult chinook salmon enter the lake from at least late July through the end of October (Fresh, unpublished data). Differences in timing between years may reflect differences in water temperature as adult chinook entered the lake earlier during the year when water temperatures were cooler (K. Fresh, WDFW, personal communication). The average time spent by adult chinook in Lake Washington in 1998 was 2.9 days (Fresh et al. 1999); data from 1999 is not yet available. Given the short duration of adults in Lake Washington system we will focus the habitat needs analysis on juvenile chinook.

Juveniles. The migration of juvenile salmon through lakes is little studied. The migration of ocean type juvenile chinook salmon through natural lakes is relatively rare (City of Seattle, 1999). Chinook salmon (*Oncorhynchus tshawytscha*) that spawn in the Greater Lake Washington Watershed are classified as "ocean type" fish because they typically spend less than 6 months in freshwater after emerging from spawning gravels before entering estuarine habitats (Healey 1991). In contrast, "stream type" chinook spend more than one year in freshwater following emergence. While in almost all river basins, the freshwater phase of life for ocean type chinook occurs entirely in

riverine environments, Lake Washington chinook salmon are highly unusual in that they must spend some time between stream and estuarine habitats in a large, natural lake.

Based upon data collected in migrant traps located at the mouths of the Cedar River and Bear/Cottage Lake Creek (in the Sammamish River system near the northern part of the lake) (Dave Seiler, WDFW, personal communication), there are two groups of naturally produced juvenile chinook that enter the lake. The first group consists of chinook fry that enter Lake Washington from at least mid-January through mid-March. These fish spend little or no time rearing in riverine habitats before entering Lake Washington where they rear for a number of months before migrating to Puget Sound. In 1999 and 2000, 85% and 75% respectively, of Cedar River chinook progeny emigrated to the lake as fry. (D. Seiler 2001).

While rearing in the lake, the most important area used by chinook fry appears to be the littoral zone (Kurt Fresh, WDFW, personal communication). Chinook juveniles are rarely found in limnetic habitats until after early May. Portions of the littoral zone that are most heavily utilized by chinook include areas around creek mouths and areas that are not heavily developed. Recent studies of microhabitat use of littoral areas (Roger Tabor, USFWS, personal communication) found that chinook fry prefer areas that have small substrates (sand and small gravel). In the lake, juvenile chinook feed on chironomids (a type of insect) until early spring when they shift to a diet dominated by *Daphnia* (M. Koehler, UW, personal communication). A number of predators consume juvenile chinook including bass, sculpins, and cutthroat trout (Warner and Fresh 1998; Weitkamp et al. 2000).

The second group of juvenile chinook that enter Lake Washington are smolts. Smolts enter the lake from mid-May through at least late July and are of a much larger size then fry at the time they enter the lake. These fish rear for a number of months in riverine habitats before entering the lake where they spend much less time then fry rearing; smolts use the lake primarily as a migratory corridor to exit the watershed. Smolts were caught in screw traps at the mouth of the Cedar River, Bear Creek, and Issaquah Creek. These fish migrated at rates of between 0.5 and 1.5 miles per day and arrived at the Locks in 20 to 40 days (DeVries, 2000)

Based upon observations at the Ballard Locks, juvenile chinook migrate from Lake Washington to Puget Sound from late May through summer. During this period, chinook juveniles can be found using much of the littoral zone of the lake as well as limnetic habitats. Increasing water temperature probably plays a key role in determining when juvenile chinook depart Lake Washington in any given year. Changes in water temperature help regulate the rate of smoltification, the process whereby juvenile salmon convert from freshwater-adapted to seawater-adapted animals (Folmar and Dickhoff 1980). In addition, the littoral zone of the lake eventually warms to the point where water temperatures can be stressful and then eventually lethal to the fish.

Habitat Requirements

Juvenile chinook use Lake Washington for outmigration and rearing. In order for chinook to successfully carry out these activities the habitat must supply sufficient food and refuge from predation. Physical barriers should not block access to the migration corridor and water quality should be of sufficiently high quality that juvenile fish are not directly or indirectly harmed in passing through the Lake. We looked at each of these habitat functions to assess what is known about their condition in the Lake and their effect on salmon.

Predation Avoidance

Predation was identified as a "probable" habitat factor of decline for Lake Washington in the WRIA 8 Draft Reconnaissance report (Greater Lake Washington Technical Committee 2001). Because predation is a natural process that influences the abundance of anadromous salmon populations wherever they are found, salmonids have evolved characteristics that minimize predation mortality. Thus, for predation to be a factor of decline, predation mortality must increase over historic conditions due to some change or changes in the ecosystem (Fresh 1997). Fresh (Greater Lake Washington Technical Committee 2001) lists four changes that have occurred in Lake Washington that have the potential to increase predation mortality.

First, littoral zone habitats have been extensively modified over the last 100 years due to the change in lake level (in 1916); construction of

Developed and degraded Lake Washington shoreline. Note rip-rap, bulkhead, and relative lack of overhanging riparian vegetation.

piers, docks, and bulkheads; removal of large, woody debris (LWD); and the expansion of milfoil (Fresh and Lucchetti 2000). While it is highly probable that the types of changes occurring in the littoral zone of Lake Washington have altered the composition, diversity, and abundance of fish communities in the lake (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Weaver et al. 1997), it is difficult to predict the net effect of these changes on fish populations and predation rates on juvenile salmonids. For example, the amount and spatial patterning of attached aquatic macrophytes can directly affect littoral zone fish abundance (Bryan and Scarnecchia 1992, Weaver et al. 1997). A low density of macrophytes usually increases the abundance of littoral zone fish. While shoreline development and an increased density of macrophytes may result in more habitat for juvenile fish (Beauchamp et al. 1984), these changes may also enhance habitat for predators such as smallmouth bass (Bryan and Scarnecchia 1992). Bass predation could increase if the "new" habitat provided by piers, docks and bulkheads either allows the population to expand due to better spawning habitat or it allows predators a better place to ambush their prey (Kahler et al. 2000). In the case of overwater structures, it is unclear whether it is the structure, the shade, or a combination of both that predators are responding to.

Second, predation mortality of salmonids could increase if there has been a significant increase in the population of one or more predator species. While it is clear that population sizes of non-native predators are larger (there were none historically), it is not clear whether populations of native predators are larger. There is some anecdotal evidence that cutthroat trout are considerably more numerous now than historically (Nowak 2000). A large enough increase in the size of the cutthroat population could have resulted in an increased predation mortality of some salmonid species because cutthroat trout (especially large individuals) are highly piscivorous (Beauchamp et al. 1992). Brocksmith (1999) concluded that the northern pikeminnow population had increased 11-38 percent between 1972 and 1997. Further, Brocksmith (1999) found evidence that larger northern pikeminnows are more numerous then they were historically. Because larger predators consume more prey, this could also increase predation mortality of anadromous juvenile salmonids.

Third, as discussed earlier in this section on Lake Washington, water temperatures in the lake have increased since monitoring began in the 1930s. A similar increase in water temperatures has also been noted in the Ship Canal/Lake Union (Daniel Schindler, UW, personal communication). An increase in water temperature would be expected to increase the metabolic rate of predators, which in turn would increase consumption of prey species. Further, there is also evidence that temperatures are warming earlier than historically. Such an increase in water temperatures in the littoral zone could increase overlap between the littoral zone predators (e.g., smallmouth and largemouth bass) and juvenile salmonids. Bass do not typically enter littoral zones until water temperatures exceed 10°C (Pflug and Pauley 1984). If the littoral zone is warming sooner than it did historically, bass may be present in littoral zones for a longer period and thus capable of eating more salmon because of an increased overlap between predator and prey.

A fourth factor that could increase predation mortality of anadromous salmonids over historic levels is the introduction of non-native, piscivorous fish (Fresh 1997). Non-native piscivores introduced into Lake Washington include smallmouth bass, largemouth bass, rainbow trout (considered an exotic here because it can only be sustained by hatchery releases), hatchery-produced chinook and coho, and yellow perch. All of these species are known to prey on juvenile salmon (e.g., Beauchamp 1987; Fayram 1996; Fresh 1997). The impact of any one of these predators on anadromous salmonids depends on a number of factors such as the specific salmon prey, year, availability of other species of prey, environmental conditions, and so on.

Most of the changes discussed above will increase predation mortality on anadromous salmonids. However, the situation may be more complicated if some predators also eat the young of other predators and actually act to reduce the numbers of those predators, effectively helping to "reduce" predation.

Small fish such as chinook fry may escape predation by seeking out shallow habitat (Greater Lake Washington Technical Committee 2001). Juvenile chinook in Lake Washington have been observed to prefer shallow habitat with small particle substrate (Roger Tabor, USFWS, personal communication). As discussed above, the Lake Washington shoreline has been dramatically altered over the last 100 years. The physical changes that have occurred include lowering of the lake, loss of riparian vegetation, loss of LWD, modification of the substrate composition in front of bulkheads, shading of shallow water areas by overwater structures, the addition of new types of habitats (piers and pilings), and a reduction in the amount of shallow water habitat that is available to juvenile salmon (Warner and Fresh 1998; Kahler et al. 2000).

The addition of bank hardening, bulkheads and overwater structures in shoreline areas of Lake Washington has the potential to increase predation on juvenile salmon. Artificial structures may provide better reproductive habitat for some predators leading to an increase in predator numbers. Presumably, as more overwater structures are built, the smallmouth bass population would increase. For example, R. Malcolm (Muckleshoot Indian Tribe, personal communication) found more smallmouth bass nests associated with artificial structures in Lake Sammamish. Man-made structures in shoreline areas may also provide sites that predators can use to more easily ambush and consume young salmon (Kahler et al. 2000). Finally, the amount of shallow water refuge habitat available for juvenile chinook and other salmon could be reduced making the young fish more vulnerable to predators.

While the physical changes to littoral zone habitats resulting from shoreline development are clear, more information is still needed on: juvenile utilization of shoreline areas, predator responses to shoreline modifications, the effects of milfoil on predator-prey interatctions, and responses of prey communities to shoreline changes. Research is currently underway to address some of these information needs. For example, research on the effects of over-water structures on smallmouth bass distribution is part of ongoing research by WDFW.

Food

While it is clear that physical and limnological changes as well as the introduction of exotic species have altered the food web in the Lake, there is insufficient information to determine whether food availability is a factor of decline for chinook. In the lake, juvenile chinook feed on chironomids until early spring when they shift to a diet dominated by *Daphnia* (M. Koehler, UW, personal communication). Bank hardening, bulkheads, and overwater structures in shoreline areas could affect production of key invertebrate species such as chironomids. This could occur as a result of substrate changes, loss of insect production from a loss of riparian vegetation or shading of littoral habitats by overwater structures.

Competition from introduced species could also reduce food availability to juvenile chinook. Coevolution among species within specific habitats leads to the development of niches and behaviors that can reduce adverse interactions and allow species to share the resources. However, juvenile chinook are exposed to both natural and exotic competitors in Lake Washington in a habitat type (lake) in which they did not coevolve (Weitkamp, *et.al,* 2000). Aggressive competitors may force juvenile chinook into less desirable habitats, including areas where food is more scarce or where fish are more susceptible to predators.

Water Quality

Following the removal of sewage effluent in the 1960's, water quality is generally considered to be good (Edmundson 1991). A number of water quality issues remain including an increase in surface and littoral zone water temperatures, increasing nutrients, high levels of alkalinity, pH spikes, and increased levels of contaminants. Because juvenile chinook congregate at stream mouths, water quality in the tributary streams is of increased importance.

Habitat Access

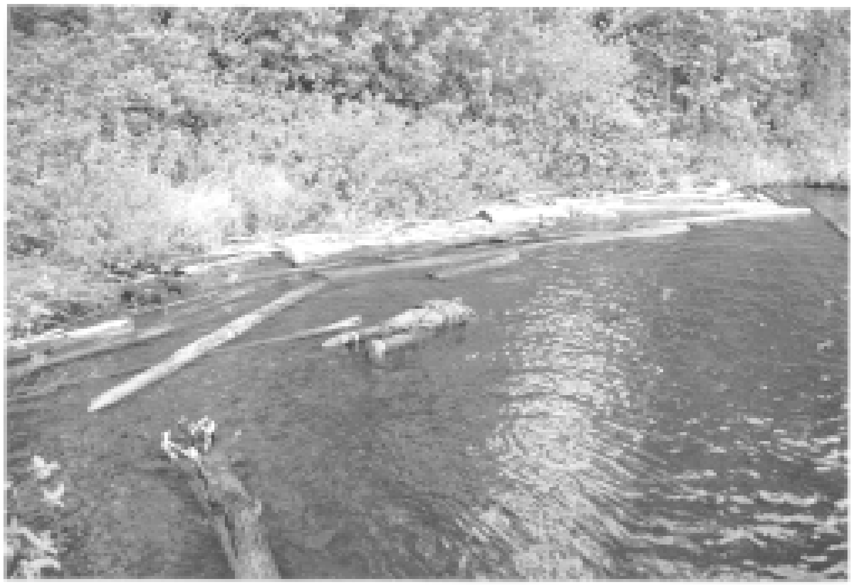
There are no barriers that prevent migration through Lake Washington.

Landscape and Habitat Forming Processes and Trophic Interactions

High quality littoral habitat is important to chinook juveniles for both predator avoidance and food production. Recent studies indicate that chinook fry prefer shallow areas with small substrates (sand and gravel) (Roger Tabor, USFWS, personal communication). Littoral areas may also provide important behavioral cues to juvenile chinook salmon which improve their ability to migrate through Lake Washington to Puget Sound. The formation and maintenance of shallow littoral areas is dependent upon complex interactions among a number of physical and biological processes. These processes can be generally described to be hierarchical with respect to habitat formation, with landscape (watershed) processes driving localized habitat forming processes, and these habitat forming process responsible for creating and maintaining the shallow littoral habitat required for juvenile chinook salmon survival and growth (Figure 4).

The formation of shallow littoral habitat along the shores of Lake Washington is dependent upon three major physical processes: 1) sediment production; 2) mobilization of lake sediments; and 3) sediment deposition along the shore of the lake. The most important sediment sources to Lake Washington are bank erosion (including sloughing), and sediment outflows from streams and rivers entering the lake. The major constraint to bank erosion and sloughing in the Lake Washington system is bulkheading and bank armoring, which occurs along the majority of the shoreline areas to protect lakeside property. The Lake Washington shoreline has been extensively developed for residential and commercial uses. The reduction in sediment inputs to the lake from the shoreline may be partially compensated by increased sediment production from inflowing rivers and lakes, which has resulted from extensive land development and subsequently increased erosion rates within tributary watersheds.

The redistribution of sediments already present in the lake is probably the most important factor responsible for the formation and maintenance of shallow littoral areas. The redistribution of lake sediments is primarily a function of wind-driven surface currents and wave action. The turbulent energy and resulting bed shear created by surface currents and wave action suspends sediment particles in the water column. These suspended sediments are then mobilized by nearshore currents and deposited within areas



Scientist Roger Tabor of the U.S. Fish and Wildlife Service surveys the Lake Washington shoreline looking for juvenile chinook salmon. The City of Seattle has contracted with key scientists to conduct research on the habitat preferences of juvenile chinook salmon in Lake Washington.

having low turbulence. The presence of geologic outcroppings, aquatic vegetation including macrophytes and emergent vegetation, and wood accumulations can produce localized areas along the lakeshore which are well protected from wave action and wind-driven nearshore currents. Sediment deposition and subsequent littoral zone development is enhanced within these areas.

Aquatic vegetation patches and wood accumulations found within the littoral areas of the lake may provide important refuge habitats to juvenile chinook salmon from some predators including northern pikeminnow and largemouth bass. There is some concern that wood accumulation may attract and provide enhanced habitat for predators. The role of woody debris in the predator-prey dynamics in the shallow littoral environment is still under debate. It is possible that in a highly altered and disturbed ecosystem like Lake Washington, minimizing predation by exotic species, may be as beneficial or more beneficial to the survival of juvenile chinook salmon than restoration of some of the natural habitat forming processes (e.g. recruitment and routing of woody debris). The City of Seattle is funding further research on the effect of woody debris on predation in 2001. The lack of natural riparian vegetation communities (especially those possessing late-successional hardwood stands) is an important constraint to the availability of wood in the Lake Washington.

Aquatic vegetation and wood may also play an important role in the production of benthic food for juvenile chinook salmon in the littoral zone of the lake. Besides providing organic matter which serves as a food base for benthic invertebrates such as midge larvae (chironomidae), aquatic vegetation and wood may also provide a complex-textured surface upon which juvenile chinook salmon can efficiently forage. The major constraint to the growth and maintenance of aquatic vegetation in the lake is the scarcity of shallow nearshore areas that are protected from wave action and wind-driven currents. The scarcity of these areas can largely be attributed extensive bulkheading and bank armoring around the lake.

Stream outlets may also provide important feeding areas for juvenile chinook salmon in Lake Washington. Juvenile chinook salmon have been observed to concentrate along stream outlets situated along the lake (Kurt Fresh, personal communication), and are probably feeding on concentrations of invertebrates

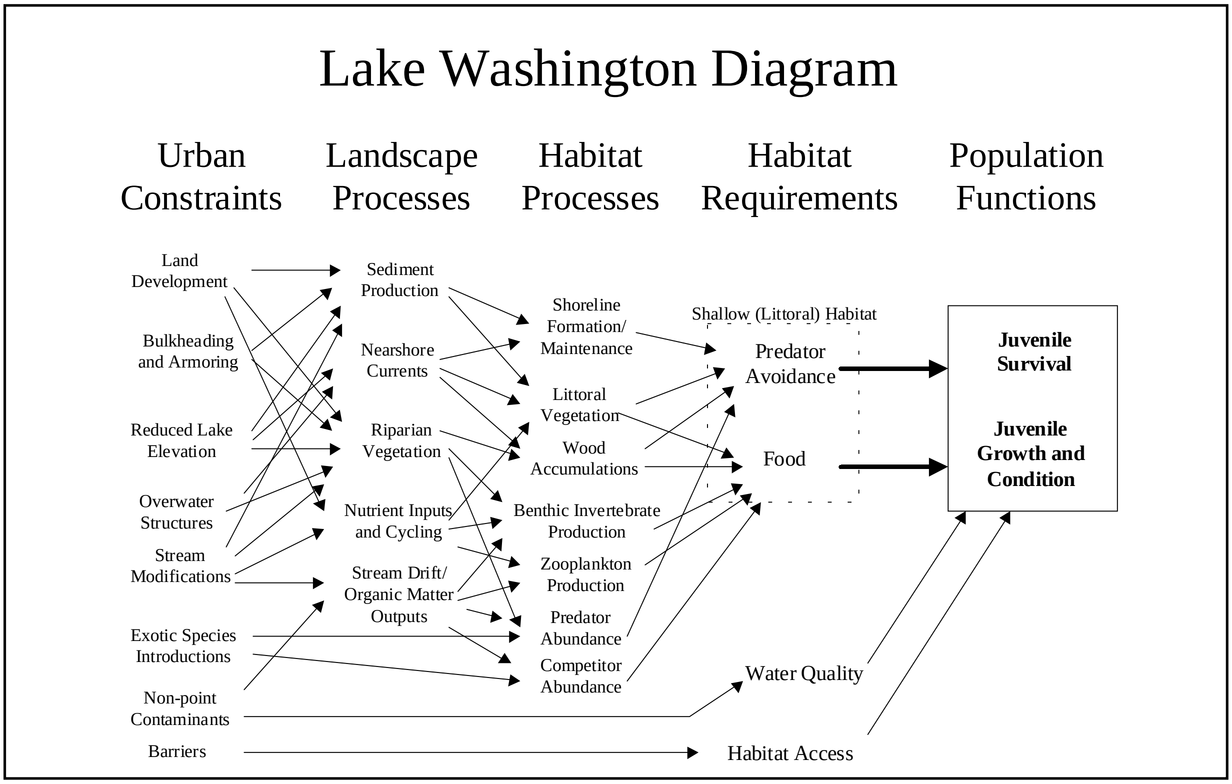


Figure 4. Diagram of Lake Washington ecosystem processes and chinook habitat.

drifting from these streams into the lake. Also, organic matter flowing out of these streams likely results in enhanced food availability for chinook salmon (i.e., high densities of benthic invertebrates) in the stream outlet areas. The major constraints to the amount of invertebrate drift and organic matter produced by these streams are the extensive modifications to the stream corridor (including riparian vegetation) and the surrounding watershed caused by urban development, and non-point contaminants originating from these urban areas.

Other factors potentially affecting the survival and growth of juvenile chinook salmon in Lake Washington include water quality and migration barriers. Water quality is good in Lake Washington, and is therefore not likely a factor limiting the survival, growth, and condition of juvenile chinook salmon migrating through the Lake (Greater Lake Washington Technical Committee 2001). Water temperatures in the lake are cool during the spring outmigration period of juvenile chinook salmon. Outflows from combined sewage outflows (CSOs) in Lake Washington probably have minimal effects on juvenile chinook salmon migrating through this system. There are no known barriers to juvenile chinook migration in Lake Washington. Consequently, access to habitat areas by migrating chinook juveniles is assumed to be unrestricted within the lake. However, overwater structures including docks and piers may delay the migration of juvenile chinook salmon along the lake because of behavioral avoidance of these structures by chinook.

Preliminary Focus Areas

Based on the analysis above, the following table summarizes our understanding of the most significant factors for juvenile chinook survival and fitness in Lake Washington.

Population Function	Habitat Requirements	Habitat characteristic/condition	Habitat forming process	Contraints
Juvenile rearing and outmigration	Predator Avoidance	Shallow Water (< 1 m depth) Shallow gradient (< 1% slope) Fine substrates (sand, mud, small gravel) Spatial distribution of refuge/cover/food	Bank erosion and sloughing Stream sediment output	Bulkheading and bank armoring Stream modifications Historic lowering of lake levels Loss of riparian vegetation Diversions of tributary outflows Overwater Structures
	Food Availability		Riparian vegetation Littoral vegetation Stream drift/organic output	
	Water Qaulity	Generally good, concern with tributary stream water qaulity		
	Habitat Access	need more study No barriers		

Among these factors, the protection and restoration of the shallow littoral habitat emerges as a key area of focus.

Habitat Improvement Projects in Lake Washington

Habitat improvement projects should focus on improving those habitat qualities that the science indicates will likely provide the greatest benefit for fish. The following table notes projects which have already been done and projects which might be considered and notes the benefits for fish which each project may create.

Project Name Project Cost or estimate Status of Project	Project Description	Habitat Requirement	
		Predator Avoidance	Food Availability
Beer Sheva Park No estimate available Planned	An extensive project involving wetland restoration at Lake Washington in Beer Sheva Park as well as daylighting of Mapes Creek and other stormwater and wetland work in the Rainier Beach area is now in the early planning stages by Seattle Public Utilities.	Restoration of the shallow littoral habitat	Riparian vegetation Littoral vegetation Stream drift/ organic output
Colman Park No costs available-old project Completed	The northern portion of the Colman Park shoreline was improved with beach gravel materials and other work in the late 1980's. More recently, a bio-engineering based project has provided native tree and shrub plantings in the shoreline area to the south towards the Mount Baker Park swimming beach.	Restoration of the shallow littoral habitat	Littoral vegetation
Denny: Blaine Park $200,000 (est). Planned	The 200' long shoreline at this park consists of a failing seawall of concrete slabs. A feasibility study of alternative shoreline treatments is underway, with a likely outcome involving development of a new wall inland of the existing wall, and a small beach cove at the.northerly end of the shoreline.	Restoration of the shallow littoral habitat	
Lake Washington Boulevard No estimate available Potential	The shoreline of the boulevard from East Pine Street to the Madrona Drive intersection is littered with concrete debris and blackberry bramble. This stretch of shoreline could benefit from removal of debris, extensive regrading, and re-establishment of native trees and shrubs.	Restoration of the shallow littoral habitat	Littoral vegetation

Lake Washington Boulevard S. I $50,000 Planned	Extensive shoreline restoration was undertaken between 1980 and 1984 in various locations along the southerly portion of the Boulevard. However, control of invasive plants is needed in several locations, along with re-establishment of native vegetation. A limited landscape restoration project, is planned for 2001.	Restoration of the shallow littoral habitat	Littoral vegetation
Lake Washington Boulevard S. II $1,000,000 (est) Potential	In the northerly portion, from Mt. Baker Park to Stan Sayres Park, the water's edge of this shoreline is littered with concrete debris installed years ago to stem erosion problems. This debris could be removed, the shoreline graded and armored with beach gravels, and native riparian shrubs planted to return the shoreline to naturalistic conditions, as was done in the other areas to the south. Such work could be undertaken in stages.	Restoration of the shallow littoral habitat	Littoral vegetation
Magnuson Park $65,000 Completed	An old boat ramp was demolished, and concrete and other debris from the old Navy airfield days were removed from the Magnuson Park shoreline in 1999. Beach areas were renourished as well.	Restoration of the shallow littoral habitat	
Magnuson Park Shoreline $1,000,000 unfunded. Potential	The 1999 work described above only addressed a portion of the Magnuson Park shoreline problem. Much of the southerly portion of the park shoreline is ineffectively armored by concrete pier blocks, rip-rap and concrete walls. Near the north end of the park an old Navy dump area fouls the shoreline with concrete and asphalt debris. Removal of deleterious material and unnecessary shoreline hardening measures, regrading, installation of appropriate beach gravels, and planting with native trees and shrubs is needed.	Restoration of the shallow littoral habitat	Riparian vegetation Littoral vegetation

Matthews Beach $500,000 Completed	The open lawns at the southerly portion of Matthews Beach Park were converted to wetlands in a 1998-1999 project jointly undertaken by Parks and the Seattle District of the Army Corps of Engineers. A small stream was diverted to a new pond, which discharges to Thornton Creek near its mouth at Lake Washington. The pond provides salmon rearing habitat for coho. The areas along the creek channel, the Lake Washington shoreline and the pond were planted with native wetland trees and shrubs.	Restoration of the shallow littoral habitat	Riparian vegetation Littoral vegetation Stream drift/ organic output
Pritchard Beach $400,000+ Completed	The old City Light nursery and Park's storage area at the Atlantic City Park were demolished in 1998 and extensive wetlands restoration undertaken there and into Pritchard Beach Park on the shores of Lake Washington to create the Pritchard Beach Wetlands.	Restoration of the shallow littoral habitat	Riparian vegetation Littoral vegetation Stream drift/ organic output
Sand Point Wetlands >$3,000,000 ($3,000,000 included in PROParks 2000 Levy) Planned	Prior to the construction of the Navy airfield at Sand Point in the 1930's, a small lake and surrounding wetland existed just inland of Lake Washington. Restoration of a portion of these wetlands is proposed in the recent plans for Sand Point. Removal of the old Navy commissary and surrounding buildings and pavements is needed prior to regrading and planting to recreate the wetland. The discharge from the Biological Survey labs and from storm drainage at the southwestern portion of Sand Point could help charge such wetlands.		Riparian vegetation Littoral vegetation Stream drift/ organic output

Seward Park No estimate available Potential	Similar to that noted above, extensive shoreline restoration was undertaken in 1980 and 1984 at Seward. A study is now underway with the Seattle District of the Army Corps of Engineers to evaluate such work, fish utilization of the shoreline, and possibilities for further enhancements. Depending on the study outcome, further work will be planned at Seward. Costs are unknown at this time, since the magnitude of work is not known.	Restoration of the shallow littoral habitat

Addressing Uncertainties

Biological indicators**.** This system is unique in the degree to which the natural system has been altered. It will be important to develop better links between habitat improvements and increased salmon survival and fitness. An important opportunity exists for measuring changes in chinook juvenile survival migrating through Lake Washington and the Ship Canal. Smolts are captured in a screw trap at the mouth of the Cedar River and PIT tagged. Monitoring devices will be placed at the locks to obtain a measure of percent survival. There is no current technology capable of uniquely marking and identifying individual chinook fry.

Key research and assessment issues include:

1. The role of overwater structures (docks and piers) as they influence prey availability and predation on juveniles.
2. The role of woody debris and other structural complexity in predation on juveniles.
3. The role of creek mouths as potential preferred habitat along the lake shoreline and associated water quality impacts on juveniles.
4. Whether prey availability, especially for early migrant chinook fry from January through March, is a factor of decline in the lake and whether competitors are having a significant impact.
5. Methods for altering the balance between juvenile chinook and their predators to favor chinook.

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