PREDATION OF JUVENILE CHINOOK SALMON BY PREDATORY FISHES IN THREE AREAS OF THE LAKE WASHINGTON BASIN

Roger A. Tabor, Mark T. Celedonia, Francine Mejia[1], Rich M. Piaskowski[2], David L. Low[3],
U.S. Fish and Wildlife Service
Western Washington Fish and Wildlife Office
Fisheries Division
510 Desmond Drive SE, Suite 102
Lacey, Washington 98513

Brian Footen, Muckleshoot Indian Tribe
39015 172nd Avenue SE
Auburn, Washington 98092

and

Linda Park, NOAA Fisheries
Northwest Fisheries Science Center
Conservation Biology Molecular Genetics Laboratory
2725 Montlake Blvd. E.
Seattle, Washington 98112

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[1]Present address: U.S. Geological Survey, 6924 Tremont Road, Dixon, California 95620
[2]Present address: Bureau of Reclamation, 6600 Washburn Way, Klamath Falls, Oregon 97603
[3]Present address: Washington Department of Fish and Wildlife, Olympia, Washington 98501

SUMMARY

Previous predator sampling of the Lake Washington system focused on predation of sockeye salmon *(Oncorhynchus nerka)* and little effort was given to quantify predation of Chinook salmon *(O. tshawytscha)*. In 1999 and 2000, we sampled various fish species to better understand the effect that predation has on Chinook salmon populations. Additionally, we reviewed existing data to get a more complete picture of predation. We collected predators in three areas of the Lake Washington basin where juvenile Chinook salmon may be particularly vulnerable to predatory fishes. Two of these areas, the Cedar River and the south end of Lake Washington are important rearing areas. In these areas, Chinook salmon may be vulnerable because they are small and are present for a relatively long period of time. The other study area, Lake Washington Ship Canal (LWSC; includes Portage Bay, Lake Union, Fremont Cut, and Salmon Bay), is a narrow migratory corridor where Chinook salmon smolts are concentrated during their emigration to Puget Sound.

Cedar River.– Within the Lake Washington basin, an important wild run of Chinook salmon occurs in the Cedar River. Juvenile Chinook salmon are present in the Cedar River from January to July. Juvenile Chinook salmon appear to have two rearing strategies: 1) rear in the river and then emigrate to the lake in May or June as a presmolt, and 2) emigrate to the lake as fry in January, February or March and rear in the lake for several months. Both groups then emigrate as smolts to Puget Sound in June or July. The main objectives of this study were to identify important fish predators of juvenile Chinook salmon, estimate total predation by these predators, and begin to understand the spatial and temporal variation in predation.

In 2000, we examined the stomach contents of 599 fish and only 8 juvenile Chinook salmon were found. Most predation was by large rainbow trout *(O. mykiss)*. Predation occurred primarily in large, deep pools ("primary" pools). Because Chinook salmon do not appear to use primary pools as rearing habitat and they must move through these pools when they emigrate downstream, we assumed that predation may occur during this time when they are moving downstream. Thus, there may be some degree of risk in emigrating to the lake as fry. Using a habitat-based model, our estimate of the total predation of Chinook salmon was 24,000 fish, which would be approximately 27% of the natural Chinook salmon production in the Cedar River.

We also reviewed additional data collected in 1995-2000. A consumption estimate was also made for 1998 when we sampled throughout the river. In 1998, predation was observed in secondary pools (small main channel pools and side-channel pools) as well as primary pools. Most of the incidence of predation was observed in stomach samples of cutthroat trout *(O. clarki)* and torrent sculpin *(Cottus rhotheus)*. Most predator sampling in May and June was conducted in the lower 1.7 km of the river as part of the lower Cedar River flood control project. Out of 177 large salmonids and 119 large cottids, only one Chinook salmon was found in the stomach samples; a 238 mm forklength (FL) cutthroat trout had consumed a 88 mm FL Chinook salmon.

South End of Lake Washington.– Once Chinook salmon enter Lake Washington, they inhabit shallow water less a meter deep (January to mid May) and are concentrated in the south end of the lake near the mouth of the Cedar River. To better understand the effect that predators have on the survival of Chinook salmon, we reviewed existing information from 1995-1997 that originally focused on sockeye salmon predation. Nearshore predators were collected from February to June, primarily with electrofishing equipment. In the three years combined, we examined the stomach contents of 1,875 fish. A total of only 15 Chinook salmon were found. The only predators observed to consume Chinook salmon were cutthroat trout, prickly sculpin (*C. asper*), smallmouth bass (*Micropterus dolomieui*), and largemouth bass (*M. salmoides*). Consumption of Chinook salmon by cutthroat trout was observed in February, March and early April. Predation by prickly sculpin was only observed in February. Smallmouth bass consumed Chinook salmon in May and June. Few largemouth bass were collected; however, we did document a largemouth bass that had consumed a Chinook salmon in June. We estimated a total of 1,400 Chinook salmon fry were consumed by littoral predators from February to mid May. Most of the predation loss was attributed to prickly sculpin, who had a substantially larger population size than the other predators. Based on consumption estimates and expected abundance of juvenile Chinook salmon, predatory fishes probably consumed less than 10% of the fry that entered the lake from the Cedar River.

Lake Washington Ship Canal.– In the Lake Washington basin, salmonid smolts must migrate through the Lake Washington Ship Canal (LWSC; includes Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and Salmon Bay) and pass through the Ballard Locks before they reach the marine environment. Within the LWSC, smolts are vulnerable to several species of predatory fishes, including northern pikeminnow (*Ptychocheilus oregonensis*), smallmouth bass, and largemouth bass. Preliminary research done by the Muckleshoot Indian Tribe, U.S. Fish and Wildlife Service, and University of Washington (UW) in 1995 and 1997 indicated that smallmouth bass may be an important predator of salmonid smolts in the LWSC. Sampling was limited to a few dates and many areas of the LWSC were not sampled. In 1999, we conducted a more intensive study to determine the overall consumption of smolts by littoral predators in the LWSC.

Fish were collected at night with boat electrofishing equipment. Stomach contents were removed and fish were tagged for a mark-recapture population estimate. Catch rates of northern pikeminnow were low in comparison to bass. This may be due to their vulnerability to shoreline electrofishing. In other systems, northern pikeminnow appear to inhabit deeper waters than bass. From the end of April to the end of July, we removed the stomach contents of over 900 predators. Consumption of smolts was observed in both bass species and northern pikeminnow from mid-May to the end of July. Predators were collected throughout the sample area, however, few predators were collected in Salmon Bay.

Smallmouth bass of all size categories consumed salmonids. The smallest smallmouth bass observed to have consumed a salmonid was 138 mm fork length (FL). Predation appeared to be highest in June, when salmonids made up approximately 50% of their diet. Consumption rates of salmonids by largemouth bass were generally low. Predation was only observed in fish 148-249 mm FL. Approximately 45% of the diet of northern pikeminnow consisted of salmonids. Identification of smolts was done visually for freshly ingested smolts and by genetic analysis for more digested fish. We identified 90% of all ingested salmonids to species. Of those, 45% were Chinook salmon smolts. The remainder were coho salmon *(O. kisutch)* (40%) and sockeye salmon (15%). Based on the length of ingested salmonids, littoral predators appear to prey mostly on subyearling fish. Even coho salmon and sockeye salmon appeared to be mostly subyearling fish. Coho salmon were likely hatchery fish that were released from the UW Hatchery.

Population estimates were calculated for smallmouth bass and largemouth bass. We estimated there were approximately 3,400 smallmouth bass and 2,500 largemouth bass in the LWSC. Estimates were made for fish that were > 130 mm FL which should include all fish that may consume smolts. A bioenergetics model and a direct meal-turnover model was used to estimate total consumption of smolts. The bioenergetics model predicted smallmouth bass consumed 27,300 salmonids and largemouth bass consumed 8,700. The direct meal-turnover model predicted smallmouth bass consumed 41,100 salmonids and largemouth bass consumed 4,600. The highest consumption occurred in age 2 fish because of their large population size and high growth rates. Incorporating the results of both models, there was little apparent difference in the number of each salmonid species consumed by smallmouth bass. Largemouth bass appeared to consume mostly sockeye salmon and coho salmon and few Chinook salmon. The main salmonid consumed by northern pikeminnow was Chinook salmon (47%), followed by coho salmon (32%) and sockeye salmon (21%).

The abundance of Chinook salmon that migrated through the LWSC in 1999 is unknown. However, if we assume a 50% survival rate of hatchery Chinook salmon from Issaquah Hatchery to LWSC, then approximately 1% of the Chinook salmon would be consumed by smallmouth bass and largemouth bass, combined. No population estimate was made for northern pikeminnow, but because salmonids made up a substantial portion of their diet, they have the potential to be a significant predator if their population size in LWSC is large.

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INTRODUCTION

In freshwater environments, predation by predatory fishes can exert significant mortality on juvenile salmonid populations (Hunter 1959; Foerster 1968; Rieman et al. 1991). Because many populations of anadromous salmonids have been declining in the Pacific Northwest, information on predation can be extremely valuable to resource managers. Information on predation is particularly important for highly altered environments or for areas that contain exotic predators.

Puget Sound Chinook salmon (see Table 1 for scientific and common names mentioned herein of fishes of the Lake Washington basin) have recently been listed as threatened under the Endangered Species Act (ESA). Within the Lake Washington basin, wild Chinook salmon occur in the Cedar River and Bear Creek. Because the Lake Washington system is a highly altered system and is inhabited by several exotic species, losses to predation may be abnormally high. Previous predator sampling of the Lake Washington system focused on predation rates of sockeye salmon and little effort was given to quantify predation of Chinook salmon. Additionally, many ingested salmonids could not be identified to species and thus the amount of predation of Chinook salmon could not be accurately determined.

This report outlines predatory impacts at three areas of the Lake Washington basin where juvenile Chinook salmon may be particularly vulnerable to predatory fishes. Two of these areas, the Cedar River and the south end of Lake Washington are important rearing areas. In these areas, Chinook salmon may be vulnerable because they are small and are present for a relatively long period of time. The other study area, Lake Washington Ship Canal (LWSC; includes Portage Bay, Lake Union, Fremont Cut, and Salmon Bay), is a narrow migratory corridor where Chinook salmon smolts are concentrated during their emigration to Puget Sound. This report presents new information on predation of juvenile Chinook salmon as well as reviews existing predation data to provide a more complete picture of predation.

Table 1.– Scientific and common names of fishes of the Lake Washington basin mentioned in this report.

Family Genus and species	**Common Name**
Salmonidae	
Oncorhynchus tshawytscha	Chinook salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus nerka	Sockeye salmon
Oncorhynchus clarki	Cutthroat trout
Oncorhynchus mykiss	Rainbow trout / steelhead
Prosopium williamsoni	Mountain whitefish
Osmeridae	
Spirinchus thaleichthys	Longfin smelt
Cyprinidae	
Mylocheilus caurinus	Peamouth
Ptychocheilus oregonensis	Northern pikeminnow
Catostomidae	
Catostomus macrocheilus	Largescale sucker
Cobitidae	
Misgurnus anguillicaudatus	Oriental weatherfish
Ictaluridae	
Ameiurus nebulosus	Brown bullhead
Gasterosteidae	
Gasterosteus aculeatus	Threespine stickleback
Centrarchidae	
Lepomis gibbosus	Pumpkinseed
Pomoxis nigromaculatus	Black crappie
Micropterus dolomieu	Smallmouth bass
Micropterus salmoides	Largemouth bass
Percidae	
Perca flavescens	Yellow perch
Cottidae	
Cottus aleuticus	Coastrange sculpin
Cottus asper	Prickly sculpin
Cottus confusus	Shorthead sculpin
Cottus gulosus	Riffle sculpin
Cottus rhotheus	Torrent sculpin

STUDY SITE

We examined predation of juvenile Chinook salmon in the Cedar River, the south end of Lake Washington, and LWSC. The largest tributary to Lake Washington is the Cedar River which enters the lake at the south end (Figure 1). The river originates at approximately 1,220 m elevation, and over its 80-km course falls 1,180 m. Prior to 2003, only the lower 35.1 km were accessible to anadromous salmonids. Landsburg Dam, a water diversion structure, prevented Chinook salmon from migrating further upstream. A fish ladder was completed in 2003 which allows access past Landsburg Dam to an additional 20 km of the Cedar River. Besides Chinook salmon, anadromous salmonids in the Cedar River includes sockeye salmon, coho salmon and steelhead Sockeye salmon are by far the most abundant anadromous salmonid in the river. Adult returns in excess of 250,000 fish have occurred in some years. Because of water quality issues, sockeye salmon are not allowed past Landsburg Dam.

Lake Washington is a large monomictic lake with a total surface area of 9,495 hectares and a mean depth of 33 m. The lake typically stratifies from June through October. Surface water temperatures range from 4-6°C in winter to over 20°C in summer. Over 78% of the shoreline is comprised of residential land use. During winter (December to February) the lake level is kept low at an elevation of 6.1 m. Starting in late February the lake level is slowly raised from 6.1 m in January to 6.6 m by May 1 and 6.7 m by June 1. The Ballard Locks, located at the downstream end of the LWSC, controls the lake level. Within Lake Washington, we sampled predators along a 4.4-km-long shoreline section in the south end of the lake (Figure 2). The shoreline is highly developed with industrial and residential structures. Along the entire west shore and a small part of the east shore are residential homes with private docks and other shoreline structures. The Renton Airport, Boeing plant, and other structures are located on the south shoreline. Most the west and south shoreline is armored. Much of the east shore is contained within Gene Coulon Memorial Beach Park, which is mostly unarmored.

The LWSC is a 13.8-km-long artificial waterway that is located between Lake Washington and Puget Sound. The LWSC consists of five sections, Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and the Salmon Bay waterway (Figure 3). The largest part of the LWSC is Lake Union which is 235 hectares in size and has a mean depth of 9.8 m. The shorelines of Portage Bay, Lake Union, and Salmon Bay are highly developed with numerous marinas, commercial shipyards, and house boat communities. The Fremont Cut and Montlake Cut are narrow channels with steep banks.

Historically, the Duwamish River watershed, which included the Cedar River, provided both riverine and estuarine habitat for indigenous Chinook salmon. Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered (Weitkamp and Ruggerone 2000). Most importantly, the Cedar River was diverted into Lake Washington from the Duwamish River watershed, and the outlet of the lake was rerouted through the LWSC. These activities changed fish migration routes and environmental conditions encountered by migrants.

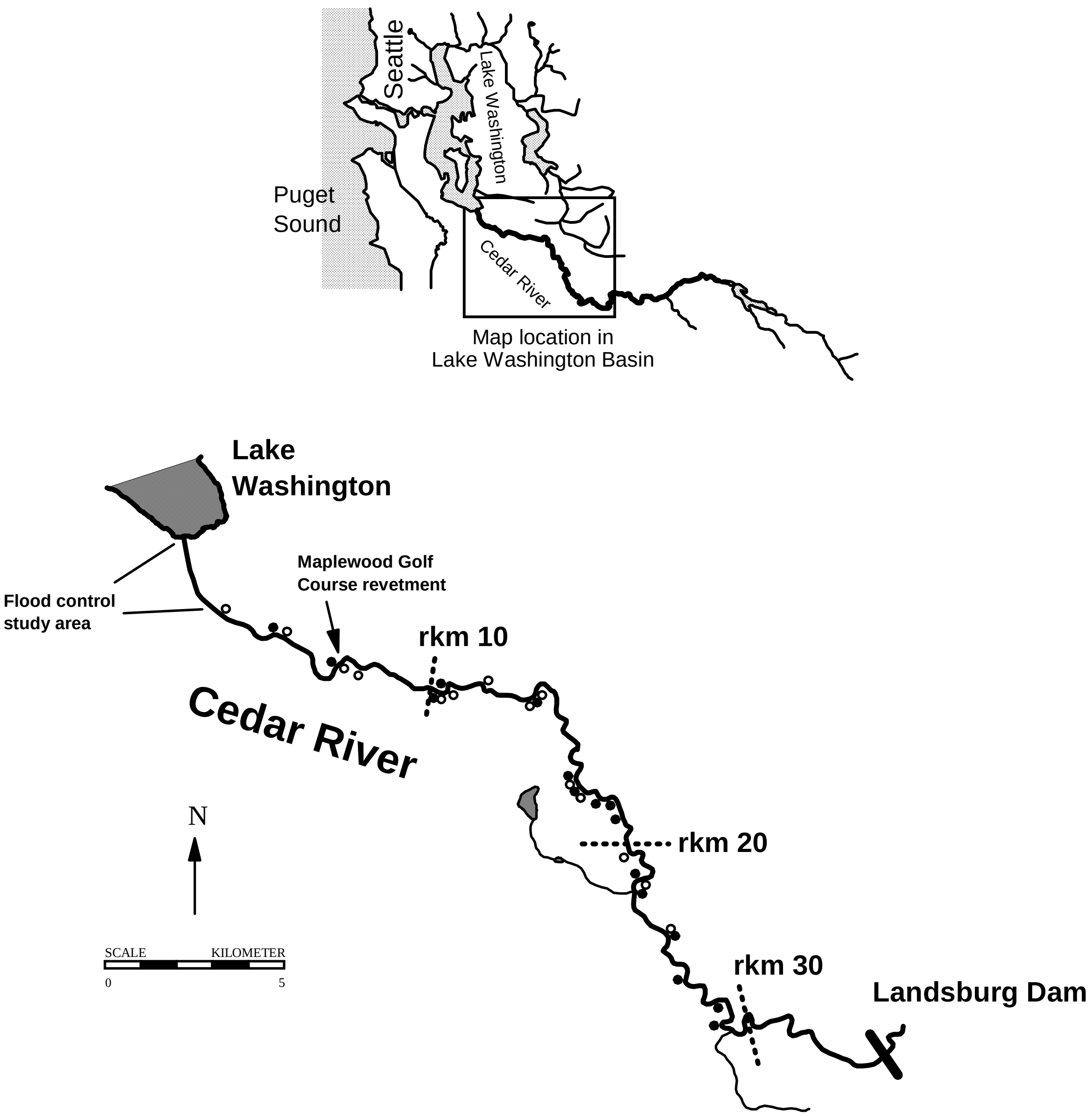

Figure 1. -- Map of lower Cedar River showing various sites used to collect predatory fishes. Open circles are sites used in 2000, solid circles are sites used during the 1997, 1998, and 1999 sockeye salmon predation study. The reach used to sample for the lower Cedar River flood control project is shown (the exact study sites are not shown). The Maplewood Golf Course revetment site is also indicated. rkm = river kilometer.

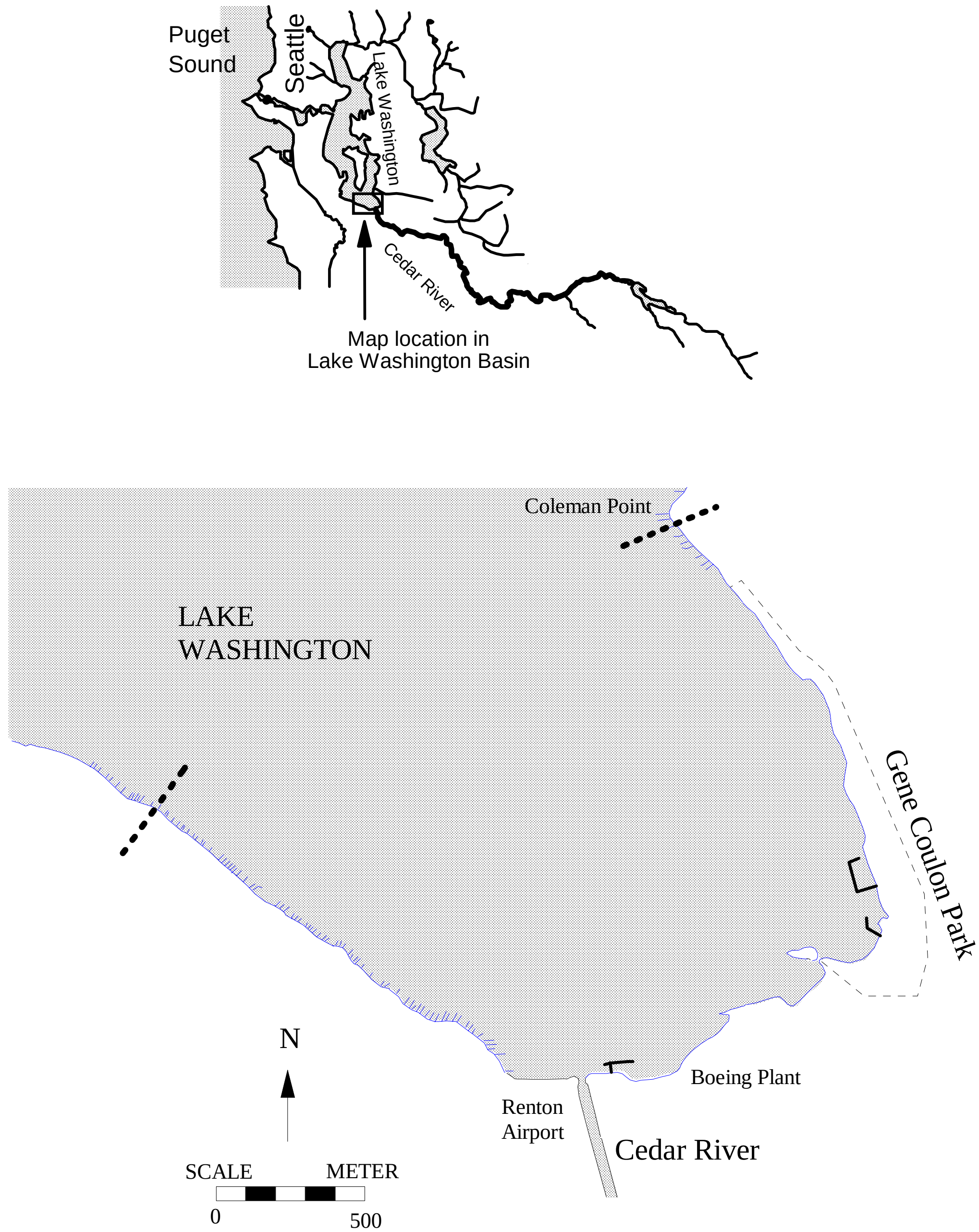

Figure 2. -- Map of the south end of Lake Washington showing the shoreline area used to sample littoral predators, February - June, 1995-1997. The dashed line indicates the northern extent of the sampling.

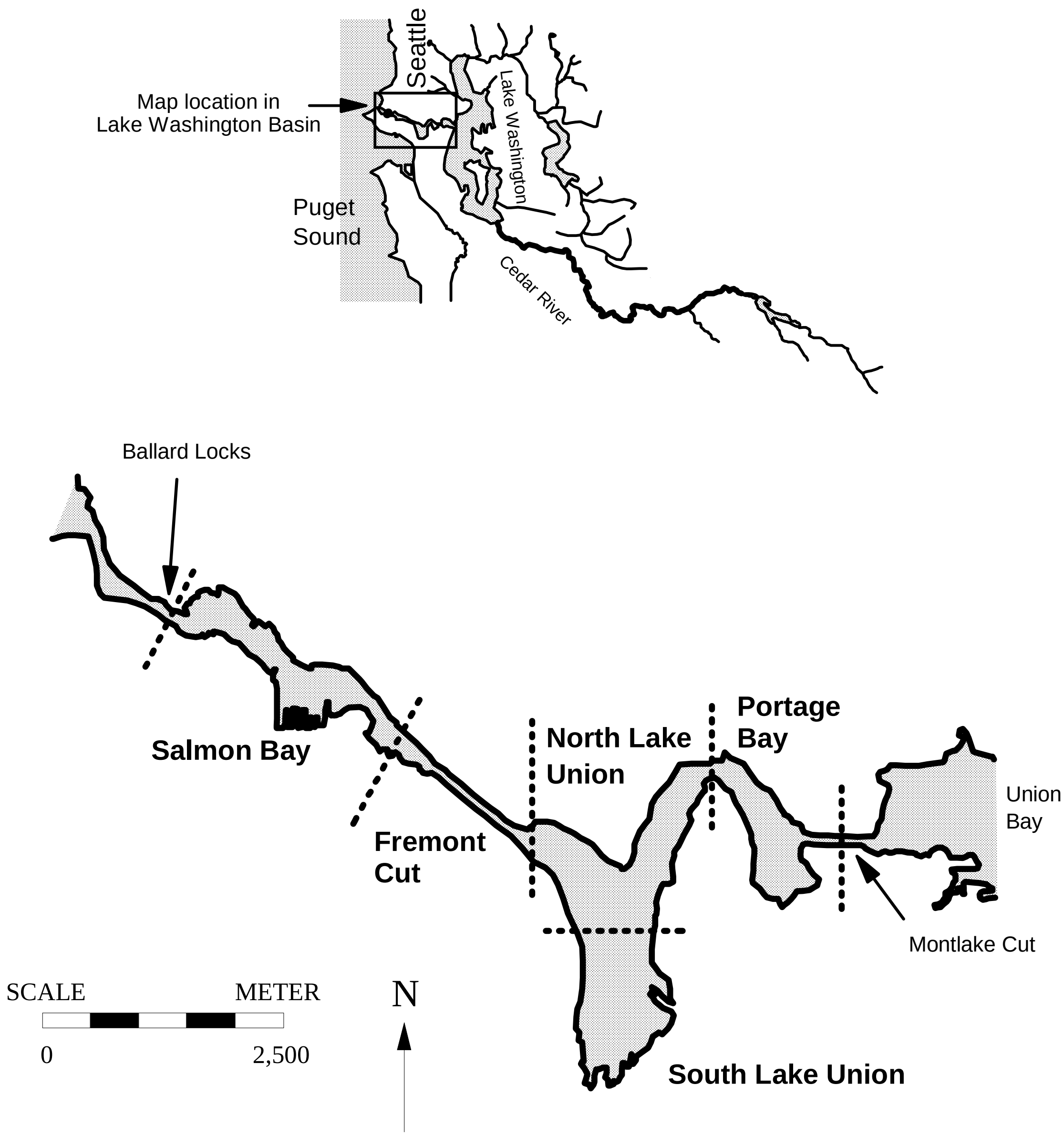

Figure 3. -- Map of the Lake Washington Ship Canal and five zones (bold letters) used to sample littoral predators, April - July, 1999. Union Bay, Montlake Cut and the Ballard Locks are also displayed.

The largest run of wild Chinook salmon in the Lake Washington basin occurs in the Cedar River. Large numbers of adult fish also spawn in Bear Creek. Small numbers of Chinook salmon spawn in several tributaries to Lake Washington and Lake Sammamish. Most hatchery production occurs at the Washington Department of Fish and Wildlife's Issaquah Hatchery. Chinook salmon also spawn below the hatchery and other adults are allowed to migrate upstream of the hatchery if the hatchery production goal of returning adults is met. Additional hatchery production occurs at the University of Washington (UW) Hatchery in Portage Bay.

Adult Chinook salmon enter the Lake Washington system from Puget Sound through the Chittenden Locks in July through September. Peak upstream migration past the locks usually occurs in August. Adult Chinook salmon begin entering the spawning streams in September and continue until November. Spawning occurs from October to December with peak spawning activity usually in November.

Fry emerge from their redds from January to March. Juvenile Chinook salmon appear to have two rearing strategies: rear in the river and then emigrate in May or June as pre-smolts, or emigrate as fry in January, February, or March and rear in the south end of Lake Washington or Lake Sammamish for several months. Juvenile Chinook salmon are released from the Issaquah Hatchery in May or early June and large numbers enter Lake Sammamish a few hours after release (Brian Footen, Muckleshoot Indian Tribe, personal communication). Juveniles migrate past the Chittenden Locks from May to September with peak migration occurring in June. Juveniles migrate to the ocean in their first year, and thus Lake Washington Chinook salmon are considered "ocean-type" fish.

Chapter 1. Predation by Predatory Fishes in the Cedar River

INTRODUCTION

Earlier research on predation of ocean-type Chinook salmon has focused on large rivers (e.g., Columbia River) inhabited by large, coolwater predators such as native northern pikeminnow and exotic smallmouth bass (i.e., Poe et al.1991; Tabor et al.1993). Some work has also been done on predation shortly after hatchery releases of juvenile Chinook salmon (Thompson 1959; Patten 1971; Footen and Tabor 2003). Little research has been done on predation of wild, juvenile Chinook salmon in cold water systems (Hillman 1989, Hawkins and Tipping 1999).

Juvenile Chinook salmon inhabit the Cedar River from January to June. During this time period, juvenile Chinook salmon may be vulnerable to a variety of predators, which include rainbow trout/steelhead (referred to as rainbow trout herein), cutthroat trout, juvenile coho salmon, and four species of sculpin. Each of these species has been documented to prey on sockeye salmon fry, but their consumption of juvenile Chinook salmon is not well known.

The main objectives of this study were to identify important fish predators of juvenile Chinook salmon in the Cedar River, estimate total predation by these predators, and determine the importance that habitat type has on predation rates of juvenile Chinook salmon.

METHODS

We examined the influence of predatory fishes on juvenile Chinook salmon through two approaches: 1) sampling conducted in 2000 which focused directly on predation of Chinook salmon; and 2) review of existing predation data from 1995 to 2000 that originally focused on predation of sockeye salmon fry. We generated consumption estimates for 2000 and 1998 in which samples were collected throughout the river section where juvenile Chinook salmon occur. Consumption rates were developed for different habitat types and then expanded based on habitat survey data. The abundance of adult spawners varied from 227 in 1997 to 681 in 1995 (Table 2). Peak incubation flow was below 3,000 cfs in each year except 1995. Dave Seiler (personal communication) estimates that significant scour of Chinook salmon redds occurs at streamflows above 3,000 cfs. The number of Chinook salmon fry and smolts was only estimated in 1999 and 2000 (Seiler et al. 2003).

Table 2.– Adult escapement, peak mean daily incubation streamflow (cfs), and estimated migration of juvenile Chinook salmon (Seiler et al. 2003), Cedar River. Adult escapement is based on area-under-the-curve estimates (S. Foley, WDFW, unpublished data).

Spawning year	Smolt year	Adult Escapement	Peak streamflow (cfs)	Date	Fry migration	Smolt migration
1994	1995	452	2,730	Dec. 27, 94	--	--
1995	1996	681	7,310	Nov. 30, 95	--	--
1996	1997	303	2,830	Jan. 2, 97	--	--
1997	1998	227	1,790	Jan. 23, 98	--	--
1998	1999	432	2,720	Jan. 1, 99	67,293	12,811
1999	2000	241	2,680	Dec. 18, 99	45,906	18,817

FISH COLLECTIONS

2000 Chinook salmon predation study.– We collected predators from different habitat types in the Cedar River in 2000. Sampling was conducted from late-January to mid-April when Chinook salmon were relatively small and particularly vulnerable to predation. Habitat in the lower river was categorized into four habitat types; primary pools, secondary pools, mid-channel areas of riffles (high velocity areas), and shoreline areas of riffles (low velocity areas). Primary pools were defined as pools that were the dominant habitat type across the main channel and occupied at least 50% of the wetted channel width (Schuett-Hames et al. 1994). We also defined primary pools as pools that had a maximum depth > 1.5 m. At sites where the maximum depth was < 1.5 m and occupied at least 50% of the wetted channel width, water velocities were typically high and the habitat was more glide-like or riffle-like and thus were included with riffles. Secondary pools were either sub-dominant habitat units in the main channel that occupied less than 50% of the wetted channel width or were pools in side channels. We collected predatory fishes in all habitat types except the mid-channel riffle habitat. Juvenile Chinook salmon do not appear to inhabit this area (R. Peters, USFWS, unpublished data) and we have never observed any predation of Chinook salmon or sockeye salmon fry in this area. Large numbers of sockeye salmon fry, which are more vulnerable to predation than Chinook salmon, migrate through this habitat type (McDonald 1960) yet very little predation has been detected (R. Tabor, unpublished data). Additionally, few trout or large sculpin appear to inhabit this area during the winter and early spring (R. Tabor, unpublished data), thus, we feel this is an unlikely location for predation to occur.

At each site, we first snorkeled the site to enumerate the predators and juvenile Chinook salmon. A snorkeler slowly moved upstream at each site and counted all fish observed. A total of two or three passes were done, each by a different snorkeler. All snorkel surveys were conducted at night, since many fish hide during the day in the winter and spring. Snorkel surveys were conducted one to three hours before sunrise. After snorkeling, we returned to each habitat unit and collected predatory fishes. Fish collections began at night, shortly before dawn, and continued through dawn and into the daytime. Because the predators appeared to be only active at night, we assumed that most of their feeding also occurred at night.

We used three gear types to collect predatory fishes: 1) electrofishing, 2) slurp guns or hand-held dip nets, and 3) beach seine. To minimize shocking Chinook salmon, we only used electrofishing equipment in areas (e.g., riprap in pools) where few were present. At locations where Chinook salmon were common, we used slurp guns, hand-held dip nets, or beach seines to collect predatory fish. Slurp guns, hand-held dip nets, and beach seines were only effective at night; while electrofishing could be used either day or night. Slurp guns and dip nets were primarily used to collect sculpin; however, some small salmonids (< 130 mm FL) were also collected.

Review of existing predation data.– In addition to Chinook salmon predation data collected in 2000, we reviewed other predation data collected in the Cedar River from 1995 to 2000 that originally focused on predation of sockeye salmon fry. We examined data from three studies: 1) lower Cedar River flood control project, 1995-2000 (Tabor and Chan 1996a; Tabor and Chan 1996b; Tabor et al. 2001; R. Tabor, unpublished data), 2) sockeye predation study, 1997-1998 (Tabor et al. 1998; R. Tabor, unpublished data); and 3) Maplewood Golf Course revetment study, 2000 (Missildine et al. 2001). Predatory fishes for the lower Cedar River study were collected from the mouth to rkm 1.8 (Logan Street bridge). Samples were generally taken once every three weeks from February or March to June. The study reach was divided into two sections: 1) lower convergence pool (low velocity area) and 2) upper riverine area (higher velocity water). The convergence pool is backed up water from Lake Washington. The size of the convergence pool and other habitats varied within each year depending on lake level and from year to year depending on accumulation of sediments as well as dredging activity that occurred in the summer of 1998. Predatory fish were collected primarily through electrofishing; however, some beach seining was also conducted. Backpack electrofishing equipment was used to sample the riverine area; whereas, boat and backpack electrofishing equipment was used to sample the convergence pool

In 1997-1999, we examined the relationship between habitat type and predation of sockeye salmon fry. Surveys in 1997 were conducted in the lower 20 km of the river. A total of nine sites were selected and surveyed roughly once every three weeks from February to June. In 1998, we sampled predatory fishes shortly after hatchery sockeye salmon fry were released at Landsburg and thus sockeye salmon fry would be abundant at each site. Predatory fishes were sampled on six dates when streamflows were relatively similar (530-611 cfs at Renton gauge station). We began sampling at least one hour after the predicted time the fry would pass a particular site to insure the vast majority of sockeye salmon fry had migrated downstream. Sampling occurred at night until approximately 0300 h. In our review of these data, we did not include sites above rkm 30 because few Chinook salmon spawn upstream of this location (Mavros et al. 2000). During the entire six survey nights, each sample site was only done once. Most 1997 and 1998 sites were sampled with electrofishing equipment; however, beach seines or dip nets were occasionally used.

The Maplewood Golf Course revetment site is located at rkm 7.1. Predatory fish were collected six times between late January and May, 2000. Sculpin were collected primarily with slurp guns or dip nets and salmonids were usually collected with electrofishing equipment or beach seines. Similar to Chinook salmon predation sampling in 2000, snorkel surveys were conducted at this site to enumerate the predators and juvenile Chinook salmon.

FISH PROCESSING AND DIET ANALYSIS

After capture, fish were anesthetized with MS-222, identified to species, and length (fork length or total length) was measured to the nearest millimeter. Stomach contents of fish were removed using a gastric flushing apparatus. Gastric lavage has been shown to be effective in removing stomach contents for many fish species. All stomach contents were put in plastic bags, placed on ice, and later froze. Samples remained frozen until laboratory analysis.

In the laboratory, samples were thawed, examined with a dissecting scope, and divided into major prey taxa. Insects and crustaceans were identified to order, while other prey items were identified to a convenient, major taxonomic group. Each prey group was blotted by placing the sample on tissue paper for approximately 10 seconds. Prey groups were weighed to the nearest 0.001 gram.

Prey fish that were slightly digested were identified to species. Fishes in more advanced stages of digestion were identified to family, genus, or species from diagnostic bones, gill raker counts, pyloric caeca counts, or vertebral columns. The fork length of prey fishes was measured to the nearest millimeter. If a fork length could not taken, the original fork lengths of prey fishes were estimated from measurements of standard length, nape-to-tail length, or diagnostic bones (Hansel et al 1988; Vigg et al 1991). Because ingested salmonids were often too digested to identify to species, analysis was also conducted. Unidentified salmonid samples were sent to the Conservation Biology Molecular Genetics Laboratory at the Northwest Fisheries Science Center (NOAA Fisheries) and molecular genetic (DNA) analysis was conducted. Methodologies were similar to those used by Purcell et al. (2004) except, when available, muscle tissue was analyzed instead of bones. Only salmonid prey greater than 32 mm FL was analyzed because Chinook salmon fry are generally larger than 32 mm FL upon emergence from their redd. The smallest Chinook salmon observed at the fry trap in 1999 or 2000 was 35 mm FL (Seiler et al. 2003). We assumed smaller salmonid prey were sockeye salmon fry which are often commonly consumed.

CONSUMPTION ESTIMATES

Consumption of juvenile Chinook salmon by predatory fishes was calculated two separate ways; a bioenergetics model (Hanson et al. 1997) and a simple meal-turnover method adapted from Adams et al. (1982). Consumption rates were calculated for each habitat type and than expanded based on the population size in each habitat type.

Bioenergetics model.– We used the Wisconsin bioenergetics model 3.0 (Hanson et al. 1997) to estimate predation of juvenile Chinook salmon. The bioenergetics model is an energy mass balance equation in which energy consumed by a fish is balanced by total metabolism, waste losses, and growth. We modeled predation for four fish species: cutthroat trout, rainbow trout, coho salmon, and torrent sculpin. Model parameters have already been developed for cutthroat trout (Beauchamp et al. 1995), rainbow trout (Rand et al. 1993), and coho salmon (Stewart and Ibarra 1991). For torrent sculpin, we used a prickly sculpin model (Moss 2001).

Major inputs into the model include growth, diet, water temperature, and caloric density of the predator and prey. Predation of Chinook salmon by coho salmon was modeled from February to May. The beginning weight was obtained from yearling coho salmon collected in the field in February. Their weight in May was obtained from the Cedar River smolt trap (Seiler et al. 2003). Predation was never observed in older coho salmon and they were not modeled. Consumption by cutthroat trout, rainbow trout, and torrent sculpin was modeled for the entire year. We used length frequency analyses as well as age and growth data from Wydoski and Whitney (2003) to estimate the age and growth of rainbow trout and torrent sculpin. Growth of cutthroat trout was taken from Nowak (2000) who estimated cutthroat trout growth in Lake Washington. Because cutthroat trout appear to move substantially between the lake, the mainstem of the Cedar River, and small tributaries, we felt this may be a reasonable approximation of their growth. Diet information was obtained directly from field data. Mean daily water temperature data was obtained from U.S. Geological Survey. These data were collected at their Cedar River site at Renton (rkm 2.6). Information on prey caloric density was obtained from Cummins and Wuycheck (1971) and various other sources (Appendix A).

Direct meal-turnover method.– The basic formula for the simple meal-turnover method (Adams model) was;

$$C = \frac{n}{N};$$

C = consumption rate of Chinook salmon (number consumed/day), n = number of Chinook salmon consumed within 24 h of capture, and N = number of predators sampled, including those with empty stomachs. Based on the observed water temperatures, and sizes of the predators and prey, more than 5% of the each salmonid consumed would still be present in the stomach 24 h after it was captured. We compared the observed weight of each partially digested Chinook salmon versus the predicted weight if it had been consumed 24 h prior to the time we collected the predator. If the observed weight was larger than the predicted 24 h digestion weight than the salmonid prey was considered to have been consumed within 24 h of sampling. Chinook salmon in more advanced states of digestion were not used to calculate the daily consumption rate. The grams evacuated after 24 h of digestion was estimated from digestion rates of He and Wurtsbaugh (1993);

salmonids: $R_e = 0.053\, e^{0.073\,T}$ and,

sculpin: $R_e = 0.049\, e^{0.072\,T - 0.060 \log_e (PS)}$

where R = evacuation rate (h^{-1}); *T* = temperature (°C); and *PS* = food particle size (g). The salmonid equation was developed for brown trout *Salmo trutta* (0.9-1.6 kg) digesting rainbow trout fingerlings (3.5-7.6 g). The sculpin equation used was a generalized equation developed from digestion rates of 22 fish species. Meal weight was the estimated weight of the Chinook salmon plus the digested weight of all other food items in the stomach (Vigg et al.1991). This assumes that the observed weight of all other food items is the average amount of prey in the stomach while the Chinook salmon was being digested. The predicted weight of each salmonid after 24 h of digestion was then calculated with the following equation;

$$D = (S - E)\frac{P}{S};$$

where D = digested salmonid weight after 24 h; P = original salmonid prey weight; E = grams evacuated; and *S* = meal weight (g). An advantage of this model is that the predation rates are based on digestion of salmonids and are not influenced significantly by differential digestion rates between prey types. Hard-bodied prey such as crayfish can have a significantly different digestion rate than prey fish (Bromley 1994). Other models which incorporate all prey types in the calculations can have large errors if crayfish or other hard-bodied prey make up a large portion of the diet and a digestion equation is used that was developed for digestion of salmonids (He and Wurtsbaugh 1993). Additionally, because predatory fish were not able to digest the Chinook salmon within 24 hours, we did not have to consider diel feeding patterns.

Population estimates.– To estimate the number of Chinook salmon consumed, population sizes of piscivorous fishes were needed. Fish density was estimated for each habitat type and then the total population was estimated based on the total area of each habitat type. We used the bounded count methodology to estimate the abundance of salmonid predators (Regier and Robson 1967). Two or three snorkelers estimated fish abundance along a shoreline transect. Salmonids were divided into two categories; salmonids < 130 and ≥ 130 mm FL. Often it was difficult to get close enough to identify salmonids to species. The estimated fish abundance is calculated by multiplying the highest of the three or two snorkel counts by two and subtracting the second highest count:

$$N = 2N_m - N_{m-1}$$

where N is the estimated fish abundance, N_m is the largest count, and N_{m-1} is the second largest count. To determine the population size of each salmonid species, we used electrofishing catch data to partition the snorkeling count estimate. We did not use snorkel counts to estimate the population size of cottids because they are cryptic and more difficult to count, particularly in complex habitats such as cobble and boulders. Instead we used mark-recapture estimates from 1997 (Tabor et al. 1998).

Habitat survey.-- In 1998, we conducted a habitat survey of the study area to quantify the different habitat types. We rafted the entire study area in late April and early May, 1998 when the streamflow was 381 to 575 cfs (Renton gauge station, USGS, unpublished data). The river was divided into various habitat types. Delineation of habitat types were adapted from Schuett-Hames et al. (1994). We counted and measured the length and width of primary pools and secondary pools. The remainder was considered riffle habitat and was not measured. Pools with logjams were also noted. A logjam is defined as an accumulation of 10 or more large logs or rootwads. At each primary pool and most secondary pools, we also measured the maximum depth.

RESULTS

2000 CHINOOK SALMON PREDATION STUDY

Between January 24 and April 13, 2000, we sampled 15 primary pools, 13 secondary pools and 5 riffle shoreline areas. A total of 445 cottids and 154 salmonids were sampled for the consumption of Chinook salmon. Only eight Chinook salmon were observed in these predators, seven by rainbow trout and one by torrent sculpin (Tables 3 and 4). Streamflow on sampling days ranges from 493 to 800 cfs. Similarly, predation of Chinook salmon occurred within the same range of flows. Seven of the eight Chinook salmon consumed were from predators collected in primary pools (Table 5). The density of Chinook salmon was significantly lower in primary pools than in secondary pools (Mann-Whitney U test = 34.0; $P = 0.049$). Likewise, the density of Chinook salmon at the sites where predation by rainbow trout was observed was significantly lower than sites where predation was not detected (Mann-Whitney U test = 13.0; $P = 0.008$). The exact location where Chinook salmon was consumed is unknown but we assume that the predators did not make extensive movements to forage and probably consumed the fish in the same habitat unit that they were captured.

Chinook salmon made up 1.3% of the overall diet of cottids, 5.7% of the diet of salmonids < 130 mm and 6.1% of the diet of salmonids > 130 mm (Table 6).

Table 3.– Predation of juvenile Chinook salmon in Cedar River (rkm 3-24), January-April, 2000. N = the number of predator stomachs examined; number = the number of Chinook salmon found in the stomachs; min. = minimum; max. = maximum; pred. = predator. Cottid lengths are total length and salmonid length are fork length. Other prey fish included cottids, lamprey, threespine stickleback, and unidentified fish.

Family Species		Predator length (mm)			Predation of Chinook		Other Predation	
	N	min.	max.	mean	number	number/pred.	Sockeye	Other
Cottidae	445	51	149	87.7	1	0.002	18	29
Coastrange sculpin	44	52	111	79.9	0	0	0	1
Prickly sculpin	3	106	149	127.3	0	0	0	0
Riffle sculpin	80	51	113	86.9	0	0	0	2
Shorthead sculpin	3	91	97	94.3	0	0	0	0
Torrent sculpin	315	52	148	88.5	1	0.003	18	26
Salmonidae	154	82	200	116.1	7	0.045	141	2
Coho salmon	20	65	118	92.1	0	0	2	0
Cutthroat trout	20	90	154	123.1	0	0	38	2
Rainbow trout	114	96	228	119.1	7	0.061	101	0

Table 4.– Predation of juvenile Chinook salmon by month in Cedar River (rkm 3-24), January-April, 2000. N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; pred. = predator.

Month	Cottids			Salmonids < 130 mm			Salmonids > 130 mm		
	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.
January	86	1	0.012	26	0	0	6	0	0
February	195	0	0	35	2	0.057	9	1	0.111
March	149	0	0	54	0	0	14	4	0.286
April	15	0	0	3	0	0	7	0	0
Total	445	1	0.002	118	2	0.017	36	5	0.139

Table 5.– Predation of juvenile Chinook salmon in three habitat types in the Cedar River (rkm 3-24), January-April, 2000. N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; pred. = predator.

Habitat type	Cottids			Salmonids < 130 mm			Salmonids > 130 mm		
	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.
Primary pools	200	1	0.005	80	2	0.025	30	4	0.133
Secondary pools	186	0	0	37	0	0	6	1	0.167
Riffle - shoreline	59	0	0	1	0	0	0	--	--
Total	445	1	0.002	118	2	0.017	36	5	0.139

Table 6.– Diet (%) of predatory fish in three habitat types in the Cedar River (rkm 3-24), January-April, 2000. N = the number of predator stomachs examined; Aq. insects = aquatic insects; Other invert. = other invertebrate. Other fish included cottids, lamprey, and unidentified fish.

Predator group Habitat type		Prey category					
	N	Chinook	Sockeye	Other fish	Aq. insects	Other invert.	Other
Cottids							
Primary pools	200	2.6	0.9	28.3	48.8	16.8	2.6
Secondary pools	186	0	5.2	1.1	49.9	40.7	3.1
Riffle - shoreline	59	0	1.0	0.4	78.7	17.0	3.0
Salmonids < 130 mm							
Primary pools	80	8.3	12.9	0	45.3	31.5	2.1
Secondary pools	37	0	1.2	0	94.2	4.6	0
Riffle - shoreline	1	0	0	0	96.5	3.5	0
Salmonids > 130 mm							
Primary pools	30	4.4	38.5	3.3	36.0	17.5	0.3
Secondary pools	6	22.0	20.0	0	56.4	0	1.6
Riffle - shoreline	0	--	--	--	--	--	--

REVIEW OF EXISTING PREDATION DATA

Lower Cedar River flood control project.– Of the 4,346 stomach samples from the lower 2 km of the Cedar River, only 13 juvenile Chinook salmon were observed (Tables 7 and 8). Predation by cottids was low, only three Chinook salmon were observed in 3,260 stomachs examined. Prickly sculpin was the only cottid species observed to predate on Chinook salmon. Consumption of Chinook salmon by salmonids was observed primarily in cutthroat trout but rainbow trout and coho salmon also had consumed Chinook salmon. Overall, 9 of the 13 Chinook salmon consumed were from February and March samples (Table 8). The number of Chinook salmon consumed per salmonid was higher in the convergence pool than the riverine area but the number consumed per cottid was the same for the two locations.

During May and June, when juvenile Chinook salmon migrate downstream to the lake, only large salmonids or large cottids would be expected to be large enough to consume juvenile Chinook. We sampled a total of 177 salmonids > 175 mm FL and 119 cottids > 125 mm TL during this period in the lower river. Only one juvenile Chinook salmon was ever observed in these stomach samples. A 238 mm FL cutthroat trout had consumed a 88 mm FL Chinook salmon (June 8, 1999). In other sampling from other river locations in May and June, only six salmonids > 175 mm FL and three cottids > 125 mm TL were sampled. No juvenile Chinook salmon were found in their stomachs.

Sockeye salmon predation studies.– During the 1997-99 sockeye salmon predation sampling, we observed a total of 18 Chinook salmon in the stomach samples (Tables 9 and 10) ; seven from cottids (N = 1,384) and 11 from salmonids (N = 241). Predation of Chinook was only observed in 1998 samples. In 1997 and 1999 combined, a total of 626 cottids and 84 salmonids were sampled. Fourteen of the 18 Chinook salmon observed were from samples collected on nights when hatchery sockeye salmon fry were released at Landsburg. During this hatchery release sampling, we observed the highest number of Chinook salmon per predator of any study component: cottids: 0.02 Chinook salmon/stomach (N = 346); small salmonids: 0.02 Chinook salmon/stomach (N = 63); and large salmonids: 0.75 Chinook salmon/stomach (N = 8).

Predation of Chinook salmon in 1998 was observed in secondary pools (0.22 Chinook salmon/salmonid; N = 36) as well as primary pools (0.03 Chinook salmon/salmonid; N = 91). Predation by cottids was observed in secondary pools (0.016 Chinook salmon/cottid; N = 258) and primary pools (0.014 Chinook salmon/cottid; N = 219). No predation was detected in riffle shoreline areas (salmonids, N = 8; cottids, N = 156). Additionally, no predation of Chinook salmon was detected in 125 cottids that were sampled in the mid-channel areas of riffles.

Table 7.– Predation of juvenile Chinook salmon and other prey fish in the lower 2 km of the Cedar River, February-June, 1995-2000. N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; min. = minimum; max. = maximum; pred. = predator. Cottid lengths are total length and salmonid length are fork length. Other prey fish included primarily cottids, longfin smelt, lamprey, and unidentified fish (larval fish were not included).

Area		Predator length (mm)			Predation of Chinook		Other Predation	
Family Species	N	min.	max.	mean	#	# / pred.	Sockeye	Other
Riverine								
Cottidae	942	50	163	76.0	1	0.001	361	54
Coastrange sculpin	124	50	111	74.4	0	0	6	5
Riffle sculpin	241	50	118	68.2	0	0	90	7
Prickly sculpin	399	50	163	83.9	1	0.003	218	31
Torrent sculpin	178	50	148	70.1	0	0	47	11
Salmonidae	231	69	398	143.8	2	0.004	304	13
Coho salmon	64	74	141	108.5	0	0	70	1
Cutthroat trout	66	69	398	147.1	2	0.030	179	6
Rainbow trout	101	80	254	164.1	0	0	55	6
Convergence pool								
Cottidae	2,318	50	221	94.0	2	0.001	1,258	269
Coastrange sculpin	151	50	116	69.7	0	0	23	5
Riffle sculpin	179	50	119	71.6	0	0	66	1
Prickly sculpin	1,936	50	221	98.5	2	0.001	1,141	258
Torrent sculpin	52	53	118	75.5	0	0	28	5
Salmonidae	838	72	553	168.9	8	0.010	1,783	93
Coho salmon	308	72	271	111.0	2	0.006	323	4
Cutthroat trout	229	84	553	204.8	4	0.017	687	59
Rainbow trout	301	90	480	200.7	2	0.007	773	30

Table 8.– Predation of juvenile Chinook salmon in two areas of the lower 2 km of the Cedar River, February-June, 1995-2000. N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; pred. = predator.

Area Month	Cottids			Salmonids < 130 mm			Salmonids > 130 mm		
	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.
Riverine									
February	48	0	0	3	0	0	4	0	0
March	222	1	0.005	25	0	0	34	0	0
April	403	0	0	43	1	0.023	42	1	0.024
May	152	0	0	32	0	0	24	0	0
June	117	0	0	0	0	--	24	0	0
Total	942	1	0.001	103	1	0.010	128	1	0.008
Convergence Pool									
February	197	0	0	7	0	0	33	2	0.061
March	779	2	0.003	21	0	0	99	4	0.040
April	702	0	0	96	1	0.010	139	0	0
May	375	0	0	185	0	0	123	0	0
June	250	0	0	11	0	0	124	1	0.008
Total	2,319	2	0.001	320	1	0.003	518	7	0.014

Of the 18 Chinook salmon observed in the stomach samples, six were from one site, a secondary pool (rkm 18.1) at the mouth of the unnamed tributary from McDaniel's Pond. A 146 mm FL cutthroat trout had consumed four Chinook salmon and a 92 mm TL torrent sculpin had consumed two. At this site, we only sampled one cutthroat trout and eight cottids. The site consisted primarily of a back-eddy pool. The upstream part of the site consisted of sand substrate with some small woody debris. The mouth of the tributary was in the middle of the site. Immediately downstream of the tributary mouth was a rip rap shoreline where the predators were collected.

Table 9.– Predation of juvenile Chinook salmon and other prey fish in the Cedar River (rkm 2-26), February-May, 1997-1999. N = the number of predator stomachs examined; number = the number of Chinook salmon found in the stomachs; min. = minimum; max. = maximum; pred. = predator. Cottid lengths are total length and salmonid length are fork length. Other prey fish included cottids, larval fish, and unidentified fish.

Family Species		Predator length (mm)			Predation of Chinook		Other Predation	
	N	min.	max.	mean	number	number/pred.	Sockeye	Other
Cottidae	1,384	50	144	78.7	7	0.005		
Coastrange sculpin	438	50	122	76.4	0	0	138	9
Prickly sculpin	50	55	138	95.6	0	0	110	8
Riffle sculpin	197	50	113	77.6	0	0	62	4
Shorthead sculpin	40	56	112	81.1	0	0	0	0
Torrent sculpin	659	50	144	79.2	7	0.010	457	46
Salmonidae	241	56	470	114.2	11	0.047	106	0
Coho salmon	116	56	123	91.7	1	0.009	377	3
Cutthroat trout	52	98	216	151.4	9	0.173	98	0
Rainbow trout	73	72	470	123.3	1	0.047	20	0

Table 10.– Predation of juvenile Chinook salmon in Cedar River (rkm 2-26), February-June, 1997-1999. N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; pred. = predator.

Month	Cottids			Salmonids < 130 mm			Salmonids > 130 mm		
	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.
February	351	0	0	35	0	0	6	1	0.167
March	426	7	0.005	109	1	0.009	21	5	0.238
April	449	0	0	31	0	0	32	4	0.125
May	125	0	0	0	0	--	4	0	0
June	33	0	0	0	0	--	3	0	0
Total	1384	7	0.001	175	1	0.005	66	10	0.152

Maplewood Golf Course revetment study.– From January to May, 2000, we sampled a total of 367 fish at the Maplewood Golf Course site (Tables 11 and 12). Chinook salmon were present on each sample date (Table 12). Within the study site, they were usually concentrated in open, shallow, sandy areas where large salmonids and large cottids were uncommon. Seventy percent of the cottids sampled were torrent sculpin. Few large salmonids were collected. Of the 52 salmonids collected, only two were > 150 mm. Two juvenile Chinook salmon were observed in the stomach samples, one from a 97 mm torrent sculpin and the other from a 130 mm rainbow trout. Both occurrences of predation of Chinook salmon were on February 17, 2000.

Table 11.– Predation of juvenile Chinook salmon and other prey fish at the Maplewood Golf Course revetment site, rkm 7.1, Cedar River, January-May, 2000. N = the number of predator stomachs examined; number = the number of Chinook salmon found in the stomachs; min. = minimum; max. = maximum; pred. = predator. Cottid lengths are total length and salmonid length are fork length. Other prey fish included cottids and unidentified fish.

Family Species		Predator length (mm)			Predation of Chinook		Other Predation	
	N	min.	max.	mean	number	number/pred.	Sockeye	Other
Cottidae	315	52	150	90.2	1	0.003	15	12
Coastrange sculpin	10	65	105	88.5	0	0	0	0
Riffle sculpin	81	52	124	91.6	0	0	3	2
Shorthead sculpin	3	101	120	109.7	0	0	0	0
Torrent sculpin	221	52	150	89.5	1	0.004	12	10
Salmonidae	52	82	200	114.8	1	0.020	21	0
Coho salmon	18	90	124	103.3	0	0	1	0
Cutthroat trout	7	93	137	108.3	0	0	0	0
Rainbow trout	27	82	200	124.2	1	0.040	20	0

Table 12.– Predation of juvenile Chinook salmon on six sampling dates at the Maplewood Golf Course revetment site, rkm 7.1, Cedar River, 2000. Chinook abundance is the number of Chinook salmon observed (snorkel counts) at the site just prior to the collection of predators. N = the number of predator stomachs examined; number = the number of Chinook salmon found in the stomachs; pred. = predator.

		Predation by Cottids			Predation by Salmonids		
Date	Chinook abundance	N	number	number/pred.	N	number	number/pred.
January 31	21	60	0	0	7	0	0
February 17	47	57	1	0.018	8	1	0.125
February 28	93	43	0	0	3	0	0
March 16	37	34	0	0	8	0	0
April 13	96	65	0	0	17	0	0
May 18	100	56	0	0	9	0	0
Total		315	1	0.003	52	1	0.019

CONSUMPTION ESTIMATES

Population estimates indicated juvenile coho salmon were the most abundant salmonid in primary pools (Table 13); however, most coho salmon were observed in four pools that had large logjams. In the other primary pools, large rainbow trout (> 130 mm) were the dominant salmonid. In secondary pools, most salmonids were < 130 mm, consisting primarily of coho salmon and rainbow trout (Table 13).

Table 13.– Population estimates of predatory fishes in the Cedar River, February-April. Salmonid estimates were based on snorkel surveys in 1998, 1999 and 2000; torrent sculpin estimates were based on mark-recapture data in 1997. Only species that consumed juvenile Chinook salmon are listed; also only habitats where predation of Chinook salmon was detected is listed. Total habitat length is the length of each habitat for the entire Chinook salmon rearing area (rkm 0 - 30). CI = confidence interval; Pop. est. = population estimate.

Habitat type Size class	Number of units surveyed	Fish/m	Total habitat length (m)	Pop. est.	95% CI
Primary pools					
Rainbow trout					
< 130	19	0.33	2,721	894	570 - 1,230
> 130	19	0.61	2,721	1,181	658 - 1,670
Cutthroat trout					
< 130 mm	19	0.06	2,721	174	114 - 236
> 130 mm	19	0.32	2,721	610	340 - 862
Coho salmon (< 130 mm)	19	0.86	2,721	2,327	1,662 - 3,005
Torrent sculpin (> 50 mm)	--	3.98	2,721	10,830	--
Secondary pools					
Rainbow trout					
< 130 mm	34	0.24	3,352	797	440 - 1,154
> 130 mm	34	0.10	3,352	328	70 - 563
Cutthroat trout					
< 130 mm	34	0.09	3,352	292	161 - 422
> 130 mm	34	0.04	3,352	141	30 - 241
Coho salmon (< 130 mm)	34	0.26	3,352	855	472 - 1,239
Torrent sculpin (> 50 mm)	--	2.44	3,352	8,197	--

Consumption estimates were made for 1998 and 2000 (Table 14). In other years, we only sampled a small section of the total Chinook salmon rearing area and we were unable to make a consumption estimate. In 1998 and 2000, we surveyed throughout the rearing area. Total predation was considerably higher in primary pools than secondary pools. For the two years combined, 67% of the predation (bioenergtics model) occurred in primary pools. Predation of Chinook salmon by rainbow trout occurred primarily in primary pools (70%); whereas, predation by cutthroat trout occurred primarily in secondary pools (74%). The bioenergtics model and the direct consumption model gave similar results for the 2000 data. However, in 1998 the estimates were quite different. The total predation loss was estimated to be 10,000 for the bioenergtics model and 37,000 for the direct consumption model. In 1998, large numbers of sockeye salmon fry were consumed and Chinook salmon made up a small part of the diet and thus the bioenergtics estimate was low. We estimated growth for the full year and a potential bias in our estimate is an underestimation of growth during the period when sockeye salmon fry are quite abundant. The direct consumption model was based on the number of Chinook salmon ingested, regardless of their importance in the diet.

PREY SIZE ANALYSIS

Of the 41 juvenile Chinook salmon observed in predator stomachs (all study components combined), we were able to estimate the original length of 39 fish. Cutthroat trout consumed a wide-size range of Chinook salmon, from 33 to 88 mm FL; whereas the sizes consumed by rainbow trout and coho salmon were all within a narrow range, from 33 to 42 mm FL (Figure 4). Seventy-one percent of the Chinook salmon consumed by cutthroat trout were greater than 40 mm FL; whereas, only 10% of those consumed by rainbow trout were > 40 mm FL. Sizes of Chinook salmon consumed by cottids were also within a narrow-size range, 33 to 49 mm TL (only one Chinook salmon was > 41 mm TL.). Most cottids (9 of 11) that consumed Chinook salmon were between 85 and 110 mm TL. The other two cottids were 67 and 75 mm TL.

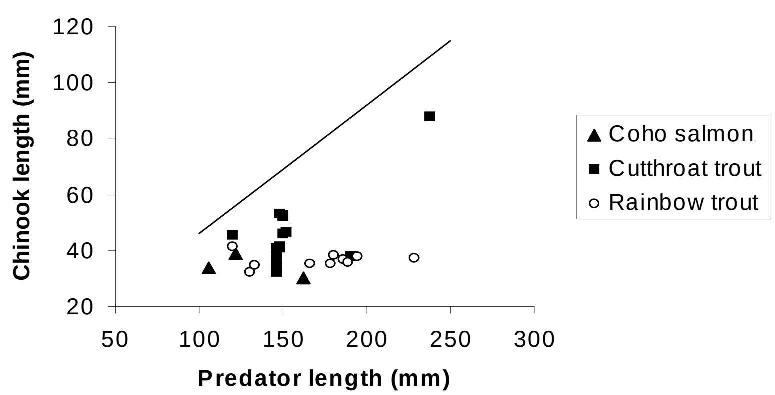

Figure 4.-- Sizes of Chinook salmon (n = 27) consumed by three species of predatory salmonids, Cedar River, 1995-2000. Data were combined from different data sources (see methods). The line represents the suggested maximum size of Chinook salmon that salmonid predators could consume (46% of predator length; Pearsons and Fritts 1999).

Table 14.– Total consumption estimates (number of Chinook salmon) of four species of predatory fishes in the Cedar River in 1998 and 2000. Consumption estimates were calculated two ways, a bioenergetics model and a direct meal-turnover method (Adams model). The lower and upper consumption estimates were based on the 95% confidence intervals of the population estimate. ND = no data.

	1998				2000			
Species	Bioenergetics model		Adams model		Bioenergetics model		Adams model	
Month	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.
Rainbow trout								
January	0	--	0	--	0	--	0	--
February	4,395	949 - 7,549	2,198	527 - 4,185	12,003	6,917 - 16,865	5,581	3,270 - 8,058
March	0	--	0	--	11,655	5,097 - 17,725	13,778	7,235 - 20,749
April	0	--	0	--	ND	--	ND	--
Total	4,395	949 - 7,549	2,198	527 - 4,185	23,658	12,014 - 34,589	19,359	10,505 - 28,807
Cutthroat trout								
January	0	--	0	--	0	--	0	--
February	0	--	0	--	0	--	0	--
March	2,562	772 - 4,184	18,197	7,130 - 28,303	0	--	0	--
April	407	227 - 575	2,101	1,161 - 2,969	ND	--	ND	--
Total	2,969	999 - 4,757	20,298	8,291 - 31,272	0	--	0	--
Coho salmon								
January	0	--	0	--	0	--	0	--
February	0		0	--	0	--	0	--
March	528	377 - 682	2,327	1,662 - 3005	0	--	0	--
April	0	--	0	--	ND	--	ND	--
Total	528	377 - 682	2,327	1,662 - 3005	0	--	0	--
Torrent sculpin								
January	0	--	0	--	563	--	2,664	--
February	0	--	0	--	0	--	0	--
March	2,106	--	12,285	--	0	--	0	--
April	0	--	0	--	ND	--	ND	--
Total	2,106	--	12,285	--	563	--	2,664	--

DISCUSSION

We estimated that approximately 24,000 Chinook salmon fry were consumed in 2000. At the fry trap there was an estimated 48,900 early migrants and 18,800 late migrants. Assuming that other predation (fish predation in April-June and by other predators such as birds) was minor, the percentage that was lost to fish predators would be 27%. Based on this estimate, predatory fishes appear to have an important effect on the number of juvenile Chinook salmon produced in the Cedar River.

Rainbow trout and cutthroat trout appeared to be the most important predators of Chinook salmon. Taken together they accounted for 74% of the estimated predation loss (bioenergtics model) in 1998 and 98% in 2000. Predation rates of rainbow trout and cutthroat trout were substantially higher than other predators. Because they obtain a large size and can forage throughout the water column and in a wide range of current velocities, they probably are more likely to prey on Chinook salmon than other predatory fishes in the Cedar River such as cottids and coho salmon. In Elokomin River, Washington, a system with similar predator species as the Cedar River, Patten (1971) also found that cutthroat trout and rainbow trout had the highest predation rate of newly released hatchery Chinook salmon. Similarly, Hawkins and Tipping (1999) documented high predations rates of wild juvenile Chinook salmon by steelhead and cutthroat trout in the Lewis River, Washington.

Although cutthroat trout and rainbow trout both had relatively high predation rates of Chinook salmon, total predation loss by rainbow trout was much higher than by cutthroat trout because of their larger population size. By examining the catch ratio of rainbow trout to cutthroat trout from our 1995-2000 data, two general trends emerge. The ratio of rainbow trout to cutthroat trout increases at upstream locations and the ratio decreases each month from February to June. We did not sample upstream locations in April, May and June, however samples collected in February and March showed that rainbow trout represented 86% of the trout in locations from rkm 7 to rkm 35 but only 72% of the trout below rm 7. Additionally, from Landsburg Dam to Cedar Falls (rkm 35 - 55) the vast majority of the trout are rainbow trout (D. Paige, Seattle Public Utilities, personnel communication). Within the lower 7 km, 84% of the trout collected were rainbow trout in March but by June only 18% of the trout were rainbow trout. During the time period (January - April) when Juvenile Chinook salmon are most vulnerable, rainbow trout are substantially more abundant than cutthroat trout.

The only extensive sampling conducted during the smolt outmigration period (May and June) was done in the lower 2 km of the river. During this period, juvenile Chinook salmon are much larger and are probably only vulnerable to large salmonids (i.e. > 175 mm FL) and large cottids (i.e. > 125 mm TL). Of the 177 large salmonids and 119 large cottids examined, only one Chinook salmon was found. In May and June, there are several other alternative prey types including catostomid eggs (May), larval catostomids (June), aquatic and terrestrial insects, and crayfish. Milick (1977) found that drift of aquatic insects increased through the spring months. The diet of large salmonids in May and June included fish eggs (43%), sockeye salmon fry (22%), and larval fish (15%) and the diet of large cottids was primarily comprised of lamprey (34%), crayfish (19%), fish eggs (17%), and sculpin (16%). Based on the observed low predation rates in the lower river, size of the smolts, and the abundance of alternative prey, we assume that predation rates of Chinook salmon by piscivorous fishes were low in other sections of the river as well.

The role sockeye salmon play on predation of Chinook salmon is unclear. The presence of sockeye salmon fry may act as a buffer species and reduce the predation rate of juvenile Chinook salmon by an individual predatory fish. Also, the large amount of added nutrients to the system may benefit the forage conditions of juvenile Chinook salmon, which enables them to grow faster and reduce their vulnerability to predators. Increased prey populations may also provide alternative prey for predatory fishes. Alternatively, large numbers of sockeye salmon may increase the overall population of predatory fish directly through consumption of sockeye salmon eggs and fry and indirectly by increased nutrients in the system. Thus, predation rates of Chinook salmon may be low but the total amount of predation may be as high as in other systems where sockeye salmon do not occur.

Predation of Chinook salmon by rainbow trout occurred primarily in large deep pools; whereas, predation by cutthroat trout occurred primarily in secondary pools. Rearing juvenile Chinook salmon typically inhabit shallow, low-velocity areas along the river's edge and their habitat may not overlap much with rainbow trout. Few Chinook salmon were observed in the large, deep pools inhabited by rainbow trout. Chinook salmon may become vulnerable to predation by rainbow trout when they migrate downstream. Predation was observed mostly in February and March, which is the same time period when large numbers of Chinook salmon migrate downstream to the lake. In general, cutthroat trout are more piscivorous than rainbow trout (Idyll 1942; Nilsson and Northcote 1981; Tabor and Chan 1997) but because rainbow trout typically inhabit higher velocity water than cutthroat trout (Bisson et al. 1988), rainbow trout may be the dominant predator in mainstem of the Cedar River which has high water velocities, even in primary pools. Rainbow trout may prey mostly on migrating Chinook salmon fry while cutthroat trout may prey on rearing Chinook salmon. In April, when downstream migration of juvenile Chinook salmon is typically low (Seiler et al. 2003), predation was observed mostly by cutthroat trout. In the south end of Lake Washington, a major rearing area for Chinook salmon, predation has been observed in cutthroat trout but not rainbow trout (see Chapter 2)

A major limitation of 1998 and 2000 consumption estimates was the small sample size of salmonids > 130 mm. For the two years combined, we only sampled 39 of these sized fish. Our sampling techniques (backpack electrofishing and dip netting) appear to work well for collecting cottids and small salmonids but may not be effective for sampling large salmonids. Additional sampling techniques, such as angling or raft electrofishing, needs to be employed to obtain a more accurate estimate of predation of Chinook salmon by large salmonids.

Another potential bias in our large salmonid consumption estimate is the population estimate which was based on snorkeling observations. Large salmonids tend to be far more wary of snorkelers than small salmonids (Grant and Noakes 1987) and thus we could have easily underestimated the number of large salmonids. Recent research by WDFW (D. Seiler, unpublished data) has indicated there is a sizeable population of large trout (> 200 mm FL) in the Cedar River during the summer. Their abundance during the winter is unknown. We expect that our population estimate of large salmonids is low and thus our estimates of predation of Chinook salmon are probably conservative.

Because juvenile coho salmon can be an important predator of sockeye salmon fry and other salmonid fry, they may also be a potential predator of juvenile Chinook salmon. Predation of wild juvenile Chinook salmon by coho salmon was observed in the Lewis River, albeit predation rates were generally low (Hawkins and Tipping 1999). Overall, we only observed three juvenile Chinook salmon in the 526 coho salmon examined. The lengths of the coho salmon that had consumed Chinook salmon were 106, 122, and 162 mm FL, which is generally much larger than the average size of coho salmon sampled (mean, 105 mm FL) or the mean size observed at the fry trap (Seiler et al. 2003). Based on a length frequency analysis, coho salmon greater than 130 mm FL are probably age 2 fish. Yearling coho salmon appear to be numerous but rarely consume Chinook salmon. Age 2 coho salmon are probably rare but have a relatively high predation rate and may have a similar predation rate as trout that are greater than 130 mm FL. Overall, coho salmon do not appear to be a major predator of Chinook salmon in the Cedar River.

No predation of juvenile Chinook salmon by cottids was observed in April, May, or June. The latest date a Chinook salmon was observed in a cottid stomach sample was March 18. By April, Chinook salmon may be large enough to avoid predation by most cottids. Hillman (1989) observed that predation of Chinook salmon and steelhead by shorthead sculpin ceased once the salmonids grew to aprroximately 50 to 55 mm. In the Cedar River, coastrange sculpin and riffle sculpin do not attain a large size (maximum size, approximately 120 mm TL for both species) and they have a relatively small gape (Patten 1971). Because torrent sculpin and prickly sculpin are often greater than 120 mm TL and have a relative large gape, they may be able to prey on Chinook salmon in April and May. However, predation may be minimal during this time because of habitat segregation. Large cottids are usually found around large substrates such as cobble and boulders (Tabor et al. 1998); whereas, Chinook salmon prefer small substrates such as sand and gravel (R. Peters, USFWS, unpublished data). Additionally, prickly sculpin, the largest cottid species, are primarily found only in the convergence pool in the lower 1 km of the river and Chinook salmon appear to be only common there in February. In June, Chinook salmon are usually larger than 90 mm FL and thus may only be vulnerable to the largest cottids. Torrent sculpin rarely exceed 140 mm TL. Prickly sculpin larger than 140 mm occur in the convergence pool but their diet in June consists primarily of large benthic prey such as crayfish, cottids, and lamprey.

Predation of juvenile Chinook salmon by cottids has been examined in three other systems in Washington and Oregon. Patten (1971) studied predation by cottids shortly after large numbers of Chinook salmon were released from a hatchery. All four cottid species in Elokomin River, Washington consumed newly-released Chinook salmon (range, 39-80 mm). Prickly sculpin appeared to be the most important predator. Their high predation rates were attributed to their large size in comparison to the other sculpin. Torrent sculpin was also an important predator. Reticulate sculpin had similar predation rates as torrent sculpin but their overall predation was lower due to their lower abundance. Coastrange sculpin rarely consumed Chinook salmon, which was attributed to their comparatively small mouth. In Herman Creek, Oregon (Patten 1971), where only prickly sculpin and reticulate sculpin were present, both species consumed newly-released Chinook salmon (range, 45-64 mm). However, prickly sculpin had substantially higher predation rates. In the Wenatchee River, Hillman (1989) studied the predation of juvenile spring Chinook salmon and juvenile steelhead by shorthead sculpin. The author found shorthead sculpin preyed heavily on small (< 55 mm) Chinook salmon and steelhead from May to August. Salmonids made up the vast majority of the diet during this period. Large numbers of juvenile salmonids were clustered in shallow areas of pools and glides at night and shorthead sculpin apparently moved approximately 30 m from their daytime riffle habitat to these shallow areas at night to take advantage of this prey source. In September, the lengths of all juvenile salmonids exceeded 55 mm and the predation no longer occurred.

Chapter 2. Predation of Chinook salmon by Littoral Fishes in South End of Lake Washington

INTRODUCTION

From January to April, large numbers of Chinook salmon fry migrate downstream out of the Cedar River and into Lake Washington (Seiler et al. 2003). For example, in 2003, an estimated 166,000 fry entered Lake Washington between January 15 and the middle of April (D. Seiler, personal communication). Once Chinook salmon enter Lake Washington, they inhabit shallow water less than a meter deep and are concentrated in the south end of the lake near the mouth of the Cedar River (Tabor and Piaskowski 2002; Tabor et al. 2004). Chinook salmon are present in the shallow nearshore area from January to mid May. After mid May, they move into deeper water and are no longer concentrated in the south end of the lake. In the latter part of May, hatchery Chinook salmon are released from the Washington Department of Fish and Wildlife's Issaquah Fish Hatchery on Issaquah Creek. Within a few weeks, these fish are found throughout Lake Washington.

The south end of Lake Washington, where Chinook salmon are concentrated, is the same general area that was sampled in 1995, 1996, and 1997 to study predation of sockeye salmon fry by nearshore predators (Tabor and Chan 1996b, Tabor and Chan 1997, Tabor et al. 1998). During laboratory analysis of the stomach samples, the presence of Chinook salmon was noted but several salmonids could not be identified because they were too digested and therefore we were unable to get an accurate estimate of predation of Chinook salmon. To obtain a better estimate, genetic analysis was conducted on the unidentified salmonids to determine the species.

In this chapter we review existing data from the south end of Lake Washington and present consumption estimates for various fishes on predation of Chinook salmon.

METHODS

In 1995 to 1997, predators were collected in the nearshore area of south Lake Washington from February to June (Figure 2). Fish were collected primarily via boat electrofishing. Beach seining was also used in 1995. Gill netting was used in 1996 and backpack electrofishing was used in 1997.

The littoral zone of the south end of the lake was sampled with a 6-m Smith-Root electrofishing boat. We used 60-Hz direct current to shock fish. Percent output was adjusted to deliver 4-5 amps of electricity to the water. We established 15 transects in the littoral zone of Lake Washington. Transect boundaries were chosen based on changes in habitat and easily recognizable landmarks. We were able to sample virtually the entire shoreline of the study area. However, due to large catches in late May and June, we limited our sampling to nine transects (64% of total length) which were representative of the other transects. We made one pass along each transect, except at the large shallow areas where we made two to four passes. For transects along the south and east shores, we passed parallel to shore where the water depth was approximately 1.5-4 m. Along the west shore, which has numerous boat docks, we shocked the perimeter of each accessible boat dock, where water depths sampled ranged from 1-7 m.

In addition to boat electrofishing, beach seining was also conducted in 1995. We used a 30-m-long beach seine with a maximum depth of 2 m in the wings and 2.4 m in the middle (bag). The wings were made of 20-mm stretch mesh and the bag was made of 6-mm stretch mesh. Beach seining was conducted at eight sites in the south end of Lake Washington. The seine was deployed from a 7-m work boat. All sampling occurred at night. Initially each site was sampled once and, time permitting, a second haul was conducted. Beach seining was conducted once every two to three weeks from February 2 to May 31, 1995.

In 1996, predatory fish were also collected by gill nets. Variable mesh, sinking, horizontal gill nets were set in the littoral zone, perpendicular to the shoreline. Each net was 42.7 m long, 1.8 m deep, and consisted of 6 panels of white polyfilament mesh. Stretched mesh size ranged from 3.8 to 10.2 cm in 1.3 cm increments. Nets were generally deployed just before dusk. Nets were checked every 2-3 hours, the catch removed, and then the nets were immediately redeployed in approximately the same location. Gill netting was terminated at dawn. A gill net was set at each of two sites, 1) Cedar River delta and 2) west shore (approximately 1,200 m from the Cedar River). Gill nets were deployed once every two to three weeks from March 14 to May 28, 1996.

In 1997, we also used backpack electrofishing equipment to collect additional cottids. Cottids are often difficult to sample with boat electrofishing equipment because they can be difficult to see, especially in turbid conditions, and the large dip nets are difficult to maneuver around cobble and boulders where cottids often occur. Sampling in shallower water and using small dip nets, we were able to more efficiently collect large numbers of cottids; however, we were only able to effectively sample in water < 1.2 m deep. We selected four sites to collect cottids, three sites along cobble/gravel shoreline and one along a sand/mud shoreline. Sampling was done every three to four weeks from February through April.

Fish processing and laboratory analysis of stomach samples were the same as described in Chapter 1. Genetic analysis was also done on unidentified salmonid prey greater than 32 mm FL (see Chapter 1). Similar to Chapter 1, consumption rates were calculated two separate ways; a bioenergetics method (Hanson et al. 1997) and a simple meal-turnover method adapted from Adams et al. (1982). We used a smallmouth bass bioenergetics model suggested by Petersen et al. (2000). The model was originally developed by Roell and Orth (1993) and later refined by Petersen et al. (2000). We used the largemouth bass model of Rice et al. (1983). For prickly sculpin, we used a bioenergetics model developed by Moss (2001). Growth of cutthroat trout was taken from Nowak (2000). Prickly sculpin age and growth was based on information from Rickard (1980). We used data collected in the LWSC (see Chapter 3) to approximate the age and growth of smallmouth bass and largemouth bass in the south end of Lake Washington.

Digestion equations used in the meal-turnover method for salmonids and cottids are described in Chapter 1. For smallmouth bass and largemouth bass we used the following equation from Rogers and Burley (1991),

$$E = S(1-e^{-0.012S^{-0.29}e^{0.15T}W^{0.23}})^{1.95},$$

E = grams evacuated in 24 h; S = meal weight (g); T = temperature (°C); W = predator weight (g).

Population estimates for salmonids were based on a single mark-recapture effort conducted on May 1-3, 1995 (Tabor and Chan 1996b). Estimates were adjusted to account for shoreline areas not sampled. Monthly estimates were also calculated based on differences in catch per unit effort between May and other months. For smallmouth bass, we used a multiple mark-recapture population estimate. Smallmouth bass were marked and recaptured from February to June, 1995. Because too few largemouth bass were collected to do a mark-recapture estimate, we estimated their population size on the ratio in catch per unit effort between largemouth bass and smallmouth bass times the population size of smallmouth bass. Cottid population estimates were based on backpack electrofishing catch rates from 1997 sampling (Tabor et al. 1998). Catch per shoreline length was determined for sand/gravel shorelines and cobble/gravel shorelines. Electrofishing effort consisted of one pass along the shoreline. To estimate the total number of cottids present along the shoreline, we used a catch efficiency estimate that was based on data from mark-recapture work in the Cedar River (Tabor et al. 1998). We estimated that 18% of the cottids were captured on the first pass. Mark-recapture work in the Cedar River was conducted along low velocity shoreline sites and thus these sites were somewhat similar to shoreline sites in Lake Washington. Shoreline sections of south Lake Washington was categorized by the dominant substrate as either sand/gravel, cobble/gravel, rip rap(boulders), or mixed. The mixed shoreline was large areas that had a mix of all substrate types. This category was used for shoreline along residential homes. We used the same number of cottid per shoreline for cobble/gravel as rip rap. For mixed shorelines, we used an intermediate value between sand/gravel and cobble/gravel. The total length of each shoreline type within the study area was estimated. A population estimate was then determined for each shoreline type and added together to calculate a total population size.

RESULTS

In the three years combined, we examined the stomach contents of 1,875 fish from the nearshore area of the south end of Lake Washington (Table 15). A total of only 15 Chinook salmon were found. We also found an additional 29 salmonids that were large enough to be Chinook salmon. Of those, 16 were other salmonids (five sockeye salmon presmolts, three coho presmolts, and eight rainbow trout) and 13 were unidentified salmonids. Therefore, we would expect that approximately half of the unidentified salmonids would have been Chinook salmon. The rainbow trout that were consumed were probably newly-released hatchery fish because they appeared in the stomach samples shortly after they were released, were similar in size to those released, and electrofishing observations indicated newly released rainbow trout were very abundant in the nearshore area.

Predation of Chinook salmon was observed in four species: cutthroat trout, prickly sculpin, smallmouth bass, and largemouth bass (Table 15). Eight of the fifteen Chinook salmon were found in cutthroat trout. Predation by cutthroat trout was only observed in February, March and the first part of April (Table 16). Of the eight cutthroat trout that consumed Chinook salmon, seven were between 140 and 190 mm FL. The other cutthroat trout was 298 mm FL. Chinook salmon consumed by cutthroat trout ranged in size from 35 to 47 mm FL (mean, 41.5 mm FL). Chinook salmon made up 9% of the overall diet of cutthroat trout diet in February and 6% in March and 0.4% in April (Table 17). Throughout the study period, cutthroat trout consumed a wide variety of prey types, such as oligochaetes, fish (longfin smelt, sockeye salmon fry, sculpin, and larval fish), fish eggs, aquatic insects, terrestrial insects, zooplankton, and crayfish.

Table 15.– Predation of juvenile Chinook salmon and other prey fish (number consumed) in the south end of Lake Washington, February-June, 1995-1997. N = the number of predator stomachs examined; number = the number of Chinook salmon found in the stomachs; min. = minimum; max. = maximum; pred. = predator. Cottid lengths are total length and salmonid length are fork length. Other prey fish included primarily other salmonids, cottids, and unidentified fish.

Family Species		Predator length (mm)			Predation of Chinook		Other Predation	
	N	min.	max.	mean	number	number/pred.	Sockeye	Other
Salmonidae								
Coho salmon	190	90	305	129.8	0	0	25	7
Cutthroat trout	391	90	485	184.5	8	0.020	121	84
Rainbow trout[a]	283	97	482	184.0	0	0	0	21
Mountain whitefish	34	142	406	294.5	0	0	0	1
Cyprinidae								
Northern pikeminnow	77	115	563	361.4	0	0	0	34
Ictaluridae								
Brown bullhead	27	153	316	245.5	0	0	0	1
Cottidae								
Coastrange sculpin	21	56	86	69.8	0	0	0	0
Prickly sculpin	377	52	196	109.8	1	0.003	6	40
Centrarchidae								
Smallmouth bass	258	68	410	212.1	5	0.019	4	196
Largemouth bass	35	63	454	197.1	1	0.029	1	11
Percidae								
Yellow perch	182	108	290	191.3	0	0	1	131

[a] includes 110 rainbow trout that appeared to be newly-released hatchery fish

Only one Chinook salmon was found in 377 stomach samples of prickly sculpin. The prickly sculpin that consumed a Chinook salmon (38 mm FL) was 93 mm TL and was caught in early February. Overall, Chinook salmon made up 11% of their diet in February (Table 18). The main prey item of prickly sculpin in February and March was *Neomysis mercedis*. Prickly sculpin larger than 125 mm TL often preyed on fish but primarily consumed sculpin, yellow perch, and threespine stickleback.

Table 16.– Predation of juvenile Chinook salmon by four species of predatory fishes in the south end of Lake Washington, February-June, 1995-1997.   N = the number of predator stomachs examined; # = the number of Chinook salmon found in the stomachs; pred. = predator.

Month	Cutthroat trout			Prickly sculpin			Smallmouth bass			Largemouth bass		
	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.	N	#	# / pred.
February	39	3	0.077	75	1	0.013	20	0	0	13	0	0
March	84	4	0.048	77	0	0	14	0	0	10	0	0
April	101	1	0.010	98	0	0	13	0	0	4	0	0
May	137	0	0	90	0	0	147	3	0.020	6	0	0
June	30	0	0	37	0	0	64	2	0.031	2	1	0.500
Total	391	8	0.020	377	1	0.003	258	5	0.019	35	1	0.029

Predation of Chinook salmon by smallmouth bass was only observed in May and June. Most of those collected in February through April had empty stomachs (37 of 47). In May, Chinook salmon consumed by smallmouth bass averaged 57 mm FL (range, 50-69 mm FL). The only Chinook salmon consumed in June that was measurable was 95 mm FL. Smallmouth bass that consumed Chinook salmon ranged in size from 177 to 309 mm FL. Chinook salmon made up 4% of the overall diet of smallmouth bass. Besides Chinook salmon, smallmouth bass also consumed other salmonids (9% of the overall diet), including rainbow trout (apparently newly released hatchery fish) and coho salmon smolts. The diet of smallmouth bass consisted primarily of sculpin and crayfish (Table 19).

Throughout the sampling period, small numbers of largemouth bass were collected. Similar to smallmouth bass, most largemouth bass collected in February through April had empty stomachs (14 of 27). Predation of Chinook salmon by largemouth bass was only observed in June in one fish, a 335 mm FL largemouth bass had consumed a 95 mm FL Chinook salmon.

The Cedar River delta was sampled extensively with electrofishing gear and gill nets. We found no evidence of an aggregation of piscivorous fishes to prey on outmigrating Chinook salmon or sockeye salmon. Of the fish that were collected, none consumed Chinook salmon and few consumed sockeye salmon fry. Northern pikeminnow appeared to aggregate near the delta but they preyed primarily on adult longfin smelt that were either moving in to spawn or were spawned out fish from the Cedar River. No Chinook salmon or sockeye salmon fry were observed in the digestive tracts of northern pikeminnow.

We estimated a total of 1,400 Chinook salmon fry were consumed by littoral predators from February to mid May (Table 20). Most of the predation loss was attributed to prickly sculpin. Although they had a low predation rate, their total consumption was higher than other species because their population size was substantially higher. Our late May and June consumption estimate (smallmouth bass and largemouth bass) was only 110 fish (bioenergetics model) to 199 fish (Adams model).

Table 17.– Diet (%) of five size categories of cutthroat trout in the south end of Lake Washington, 1995-1997. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs.

Month Length group	N	Chinook	Sockeye	Other fish	Aquatic insects	Oligochaetes	Other invertebrates	Other
February								
100-149	10 (0)	12.1	83.5	0.0	2.2	0.0	2.1	0.0
150-199	15 (2)	7.1	36.2	31.8	12.1	4.3	2.8	5.7
200-249	7 (0)	0.0	16.0	16.1	12.7	7.6	22.7	24.9
250-299	3 (1)	28.7	4.6	42.6[a]	22.9	0.0	1.1	0
March								
100-149	10 (3)	15.7	13.4	1.0	5.1	51.2	9.3	4.2
150-199	35 (7)	7.5	10.3	3.5	11.5	59.9	5.9	1.5
200-249	17 (3)	0.0	0.2	80.9[a]	16.4	0.0	0.9	1.6
250-299	6 (1)	0.0	0.0	97.4[a]	2.0	0.0	0.2	0.4
April								
100-149	20 (4)	0.0	0.0	1.2	25.8	54.4	17.1	1.5
150-199	41 (6)	0.8	6.8	4.8	27.1	51.7	6.9	1.8
200-249	15 (3)	0.0	0.7	35.0[a]	35.1	16.9	11.2	1.1
250-299	3 (3)	0.0	0.0	86.2[a]	6.1	0.0	7.7	0.0
> 300	5 (1)	0.0	0.0	98.6[a]	1.1	0.0	0.4	0.0
May								
100-149	28 (1)	0.0	0.0	14.3	29.4	12.4	42.3	1.5
150-199	80 (6)	0.0	0.0	4.3	22.7	0.5	35.7	36.9[b]
200-249	12 (2)	0.0	0.0	2.7	30.5	16.3	8.4	42.1[b]
> 300	3 (3)	0.0	96.7	1.1	0.7	0.0	1.4	0.0
June								
100-149	5 (0)	0.0	0.0	36.6	41.8	0.0	16.8	4.9
150-199	22 (0)	0.0	3.0	81.9	4.2	4.7	1.8	4.4
200-249	2 (1)	0.0	0.0	98.8	1.2	0.0	0.0	0.0

[a] primarily longfin smelt
[b] primarily fish eggs

Table 18.– Diet (%) of five size categories of prickly sculpin in the south end of Lake Washington, 1995-1997. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs.

Month Length group	N	Chinook	Sockeye	Other fish[a]	Fish eggs	Crustaceans[b]	Other invertebrates[c]	Other
February								
50-74	7 (1)	0.0	0.0	0.0	0.0	77.4	20.4	2.2
75-99	22 (3)	33.2	0.0	0.6	0.0	60.1	5.9	0.3
100-124	24 (3)	0.0	0.0	11.8	0.0	51.7	35.2	1.3
125-149	9 (2)	0.0	0.4	8.4	0.0	65.9	17.6	7.7
> 150	3 (1)	0.0	0.0	86.5	0.0	2.7	10.6	0.2
March								
50-74	20 (4)	0.0	0.0	9.1	0.0	16.1	74.1	0.7
75-99	25 (0)	0.0	0.0	14.3	0.4	44.0	35.6	5.8
100-124	11 (2)	0.0	0.7	0.0	57.1	31.6	10.0	0.5
125-149	2 (3)	0.0	0.0	65.8	0.0	5.9	26.8	1.5
> 150	7 (3)	0.0	1.0	11.4	83.9	2.3	1.1	0.2
April								
50-74	18 (2)	0.0	0.0	5.6	0.0	19.9	67.0	7.6
75-99	26 (5)	0.0	0.0	10.6	26.4	10.7	50.8	1.5
100-124	20 (8)	0.0	0.0	0.0	10.5	18.0	70.4	1.1
125-149	7 (3)	0.0	3.1	1.1	85.9	9.0	0.7	0.3
> 150	8 (1)	0.0	0.0	52.5	8.3	18.4	18.1	2.8
May								
50-74	4 (0)	0.0	0.0	0.0	0.0	0.0	71.7	28.3
75-99	9 (0)	0.0	0.9	0.0	61.0	6.1	17.3	14.7
100-124	29 (2)	0.0	0.0	0.1	78.2	7.0	8.0	6.7
125-149	20 (3)	0.0	0.2	14.9	62.8	15.9	3.8	2.4
> 150	12 (2)	0.0	0.0	0.5	78.4	11.5	0.1	9.5
June								
75-99	4 (0)	0.0	0.0	0.0	71.1	3.8	17.9	7.1
100-124	8 (0)	0.0	0.0	9.9	14.9	0.0	74.2	0.9
125-149	17 (2)	0.0	0.0	7.5	11.5	2.9	68.1	9.9
> 150	5 (1)	0.0	0.0	83.3	1.2	7.8	4.6	3.2

[a] primarily sculpin, yellow perch, and threespine stickleback
[c] primarily *Neomysis mercedis*, but also some crayfish, amphipods, and isopods
[c] primarily oligochates, dipteran larvae, hirudinea, and gastropods

Table 19.– Diet (%) of smallmouth bass and largemouth bass in the south end of Lake Washington, 1995-1997. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs. All sizes of largemouth bass were combined due to small sample sizes.

Species Length group	N	Chinook	Sockeye	Other Salmonids[a]	Other fish[b]	Crayfish	Other invertebrates[c]	Other
Smallmouth bass								
50-99	2 (13)	0.0	0.0	0.0	15.6	44.5	33.1	6.8
100-149	11 (19)	0.0	0.0	0.0	68.9	1.6	24.5	5.0
150-199	77 (29)	6.9	0.0	1.1	56.6	31.6	3.3	0.5
200-249	23 (2)	0.0	0.0	20.1	53.0	26.7	0.1	0.1
250-299	32 (3)	0.0	0.0	12.1	47.3	38.8	0.6	1.2
300-349	27 (7)	5.9	0.0	0.3	79.1	13.8	0.5	0.4
> 350	9 (3)	0.0	0.0	79.1	11.0	9.1	0.5	0.3
Largemouth bass								
Combined	20 (14)	11.9	7.7	0.0	51.6	0.0	26.5	2.3

[a] includes rainbow trout and coho salmon
[c] primarily sculpin but also some peamouth, yellow perch, brown bullhead, largescale sucker, lamprey, and longfin smelt
[c] primarily *Neomysis mercedis* and amphipods

Table 20.– Population sizes and total consumption estimates (number of Chinook salmon) of four species of predatory fishes in the south end of Lake Washington, 1995-1997. Consumption estimates were calculated two ways, a bioenergetics model and a direct meal-turnover method (Adams model). The lower and upper consumption estimates were based on the 95% confidence intervals of the population estimate.

				Consumption of Chinook salmon					
	Population estimate			Bioenergetics model			Adams model		
Species Month	N	lower CI	upper CI	Number	lower CI	upper CI	Number	lower CI	upper CI
Cutthroat trout									
February	43	23	88	230	123	470	93	53	203
March	81	43	166	213	114	431	120	62	237
April	193	104	395	28	15	58	57	31	117
May	220	118	450	0	--	--	0	--	--
June	173	93	354	0	--	--	0	--	--
Prickly sculpin (> 85 mm)									
February	2,254	--	--	901	--	--	1,002	--	--
March	3,644	--	--	0	--	--	0	--	--
April	4,859	--	--	0	--	--	0	--	--
May	5,249	--	--	0	--	--	0	--	--
June	5,349	--	--	0	--	--	0	--	--
Smallmouth bass (> 150 mm)									
February	190	114	445	0	--	--	0	--	--
March	190	114	445	0	--	--	0	--	--
April	190	114	445	0	--	--	0	--	--
May	190	114	445	37	22	86	120	70	272
June	190	114	445	42	25	97	89	53	209
Largemouth bass (> 150 mm)									
February	12	7	12	0	--	--	0	--	--
March	12	7	12	0	--	--	0	--	--
April	12	7	12	0	--	--	0	--	--
May	12	7	12	0	--	--	0	--	--
June	12	7	12	68	41	160	110	64	249

DISCUSSION

Our predation estimates were only for the south end of the lake and we would expect some additional predation in further north locations. From January to May, Chinook salmon are concentrated in the littoral zone in the south end and the area we sampled is probably where a large proportion of the population would be present. Based on snorkel data in 2000-2003, few Chinook salmon are north of Pritchard Beach on the west shoreline and the mouth of May Creek on the east shoreline. We sampled predators in approximately 50% of that shoreline. Adjusting our estimate of 1,400 (February to May) by the percentage of shoreline sampled, we would estimate a loss of 2,800 juvenile Chinook salmon. However, the density of Chinook salmon would be expected to be lower in the area we did not sample because it is further away from the Cedar River. Therefore, an intermediate estimate such as 2,100 might be a more reasonable estimate. Additionally, some unidentified salmonids were probably Chinook salmon. We would expect that roughly 50% were Chinook salmon which would result in roughly a 25% change in their diet. Our final estimate would then be approximately 2,600 Chinook salmon. In conclusion, we feel that less than 3,000 Chinook salmon are consumed by littoral predators in the south end of Lake Washington between February and mid May. Because Chinook salmon become well distributed around the entire lake after mid May, our predation estimates in June might be typical of other shoreline areas of the lake

The number of Chinook salmon in south Lake Washington in 1995-1997 is unknown. No fry trap estimate of Chinook salmon migrating out of the Cedar River was made in the three study years. However, using 1999 to 2003 information from the fry trap (D. Seiler, personal communication), we estimated that each year (1995-1997) an average of 35,000 fry migrated to the lake between the February and April. We used WDFW spawner escapement estimates (S. Foley, unpublished data) and assumed that 40% of the spawners were female and the fecundity was 4,500 eggs/female. For 1995 and 1997, which had peak incubation flows less than 3,000 cfs, we used a 6% egg to fry (percent entering lake) survival rate. For 1996, we used a 2% egg to fry survival rate because the peak incubation flow was over 7,000 cfs. Additionally, peak February streamflow was over 1,900 cfs for each year, which should have caused large numbers of Chinook salmon fry to migrate to the lake.

Large numbers of Chinook salmon rear in the south end Lake Washington and based on observed levels of predation as well as their high growth rates (K. Fresh, NOAA Fisheries, unpublished data), the littoral zone of the lake appears to be a suitable rearing environment. Predation of Chinook salmon by littoral fishes in the south end of Lake Washington appeared to be less than 10%, based on a predation loss of approximately 2,600 fish out of the 35,000 fry entering the lake. The overall predation loss of early-migrating Cedar River Chinook salmon fry is unknown because some additional predation would be expected from other predators such as birds. Historically, most early-migrating Cedar River Chinook salmon fry probably reared in the Duwamish estuary. How Lake Washington compares to an estuary as a nursery area is unknown. The estuarine environment appears to be an important nursery area for Chinook salmon fry; however, the survival of Chinook salmon fry in estuaries is not well known (Healey 1991). Current information on Lake Washington Chinook salmon suggests that predation is not abnormally high and growth rates are high and thus, the lake may function as well as an estuary for producing Chinook salmon.

In February and March, juvenile Chinook salmon are small (< 45 mm FL) and are especially vulnerable to predatory fishes. Although we observed some predation during this period, predation rates and total consumption were generally low. Water temperatures were low which probably reduced predator abundance as well as feeding rates. Catch rates of all predatory species were substantially lower in February and March than April, May, or June. Chinook salmon may also be spatially segregated from their predators. Chinook salmon generally inhabit areas with small substrates (sand and gravel) and gentle slopes (Tabor and Piaskowski 2002); whereas, large prickly sculpin are substantially more abundant in areas with larger substrates (cobble and boulders; Tabor et al.1998) and cutthroat trout probably inhabit deeper water and possibly areas with larger substrates. In addition, Neomysis appear to be extremely abundant in the nearshore area (based on snorkel surveys) and make up a high percentage of the diet of prickly sculpin. Sockeye salmon are also common in the nearshore area and because of their small size they may be easier to capture than Chinook salmon.

After March, predation levels appeared to be substantially reduced. Between April 1 and May 14, no predation of Chinook salmon was detected. During this time, Chinook salmon have grown and may be able to effectively avoid littoral predators such as prickly sculpin and cutthroat trout. Most cutthroat trout in the littoral zone are less than 200 mm FL (Nowak et al. in press). In addition, other prey types such as oligochaetes and aquatic insects may be abundant and easier to capture than Chinook salmon. Larger cutthroat trout may be more effective predators of Chinook salmon but are not common in the littoral zone. The diet of large cutthroat trout was dominated by longfin smelt. In April, water temperatures are still around 10^{o}C and bass are probably not actively feeding yet. In mid May through June, bass are common in the littoral zone and are actively feeding. We did observe some predation of Chinook salmon by bass but the amount of predation was generally low and Chinook salmon made up a small percent of their diet. Chinook salmon may not be readily available to bass because Chinook salmon have moved into deeper water (Fresh 2000; Tabor and Piaskowski 2002) to feed on *Daphnia* spp. (Koehler 2002). Additionally, bass may be better adapted at feeding on benthic prey such as sculpin and crayfish than fast-swimming prey such as Chinook salmon.

This study provides some basic information on predation of Chinook salmon by littoral fishes; however, further data are needed to get a complete picture of the effect that predators have on Chinook salmon in Lake Washington. Sampling in years when Chinook salmon are abundant such as 2003 (166,000 fry entered the lake from the Cedar River) would provide a more accurate list of fish species that consume Chinook salmon. Our prickly sculpin consumption estimate was based on finding one Chinook salmon in their stomachs and the population size was estimated from catch rates. Large numbers of prickly sculpin would need to be sampled to get an accurate estimate of their predation. Also, a more accurate population estimate would need to be obtained. Sampling predatory fishes within a larger area of Lake Washington would also provide a more accurate predation estimate. In addition to sampling piscivorous fishes, some sampling of other types of predators such as birds would need to be conducted.

Chapter 3. Predation of Salmonids by Littoral Fishes in the Lake Washington Ship Canal

INTRODUCTION

An important aspect of Chinook salmon life history is outmigration to the ocean as smolts. During this phase, smolts are vulnerable to predators, primarily predatory fishes and birds. In other systems such as the Columbia River, predators can consume a significant proportion of the Chinook salmon smolts (Rieman et al. 1991). Smolts appear to be particularly vulnerable to predators near impoundments (Vigg et al. 1991). In the Lake Washington basin, smolts must migrate through Lake Union and the Lake Washington Ship Canal (collectively referred to as LWSC) and pass through Ballard Locks before they reach saltwater. Within the LWSC, smolts are vulnerable to several species of predatory fishes including smallmouth bass and northern pikeminnow. Recent work done by the Muckleshoot Indian Tribe (unpublished data), U.S. Fish and Wildlife Service (USFWS), and University of Washington (Fayram 1996) has indicated that smallmouth bass are probably the primary fish predator of salmonid smolts in the LWSC because smolts make up a large percentage of their diet during the smolt outmigration period and smallmouth bass are relatively abundant. Although some information has been collected on the diets of smallmouth bass in the LWSC, sampling has been limited to a few dates and some areas of the LWSC have not been sampled. Also, most ingested smolts have not been identified to species. To determine the overall consumption of smolts by smallmouth bass in the LWSC, information on population sizes and growth rates of smallmouth bass was also needed.

The objective of this aspect of the study was to evaluate predation of juvenile salmonids by smallmouth bass and other littoral predators within the LWSC. This study was a one-year study to build on recent predator studies in the LWSC performed by the Muckleshoot Tribe and other resource agencies. Important new components of the study included:1) obtaining a population estimate for smallmouth bass in the LWSC; 2) sample during the entire outmigration period of salmonid smolts; 3) sample areas not previously sampled by the Muckleshoot Tribe (i.e., downstream of the Fremont Bridge); and 4) identification of ingested salmonids through genetic analysis. Study components also included age and growth and consumption rates.

METHODS

FISH COLLECTIONS

The study area included shoreline areas of the LWSC from Montlake Bridge to the Ballard Locks (Figure 3). The basic sampling scheme was a stratified sampling design. The study area was divided into four main zones: 1) Portage Bay (Montlake Bridge to I-5 Bridge); 2) north Lake Union (I-5 Bridge to Aurora Avenue Bridge; did not include south end of Lake Union); 3) Fremont Cut (Aurora Avenue Bridge to Foss Shipyard); 4) Salmon Bay (Foss Shipyard to Ballard Locks). Within each area, the shoreline was divided into several transects of approximately

500 m in length. For each sample date, two randomly selected transects were selected from each zone. Other transects were done as time permitted. In April and May, sampling was done once every other week. In June and July, sampling was done once every week. Sampling started the last week of April and extended through the end of July. A total of 13 sampling dates were done. Additionally, supplemental sampling was done on two dates in south Lake Union.

The littoral zone was sampled with a 6-m Smith-Root electrofishing boat. Stunned fish were collected with dip nets and kept in a live well. Fish were processed and returned to the general area where they were caught. Sampling was done at night. Some preliminary day sampling was conducted but was discontinued because of its ineffectiveness.

FISH PROCESSING AND DIET ANALYSIS

After capture, fish were anesthetized with MS-222, identified to species, and fork length (FL) was measured to the nearest millimeter. Fish < 500 g were weighed to the nearest gram. Larger fish were weighed to the nearest 10 g. Stomach contents of most fish were removed using a gastric flushing apparatus. Northern pikeminnow do not have a true stomach and thus gastric lavage is ineffective. All northern pikeminnow were sacrificed and the contents of the entire digestive tract were collected. Stomach samples were taken from all smallmouth bass and largemouth bass > 135 mm FL . Samples of bass 100-135 mm FL were done if time permitted. Stomach contents of cutthroat trout, rainbow trout, coho salmon, brown bullhead, prickly sculpin, and yellow perch were taken as time permitted. For these species, except prickly sculpin, we sampled fish > 200 mm FL. Prickly sculpin > 150 mm total length (TL) were sampled for diet analysis. Smaller fish and other incidental fish species were not removed from the water, however, we estimated the number observed along each transect.

To estimate population sizes, smallmouth bass and largemouth bass > 150 mm FL were tagged just behind the dorsal fin with individually-numbered Floy tags. A small hole was also punched in the opercle as a backup in case the Floy tag was lost. A few scales were also removed for scale analysis. After fish were allowed to recovered, they were released in the middle of the same transect where they were captured.

Laboratory analysis of stomach samples was the same as described in Chapter 1. All salmonid prey that could not be readily identified to species were sent to the Conservation Biology Molecular Genetics Laboratory at the Northwest Fisheries Science Center (NOAA Fisheries) and molecular genetic (DNA) analysis was conducted. Methodologies were similar to those used by Purcell et al. (2004) except, when available, muscle tissue was analyzed instead of bones.

CATCH ANALYSIS

Catch rates were calculated two ways: 1) number caught per transect length, and 2) number caught per length of shoreline that we were able to effectively sample. Because of the large number of large man-made structures (piers, docks, houseboats, large vessels, etc.) in the

LWSC, we were only able to sample a small portion of the shoreline of many transects. Since most of fish were captured close to shore, we may have missed most fish that were underneath the large structures. Using a range finder, we determined the approximate shoreline distance we were able to and not able to sample. The number caught per shoreline sampled assumes that fish were evenly distributed along the shore. Catch per time fishing was not used because we often spent a lot of time sampling around structures in deep water where few fish were collected. Monthly catch rates and catch rates by zone were analyzed with a two-way analysis of variance (ANOVA). Catch rates were log transformed because the data were positively skewed (Zar 1984). April sampling consisted of only one date in late April and thus was combined with May sampling. We compared fish lengths between zones with one-way ANOVA tests and a post-hoc Tukey's Honestly Significant Difference (HSD) tests. Lengths were log transformed because the data were positively skewed (Zar 1984).

POPULATION ESTIMATES

To estimate the population sizes, a modified Schnabel multiple censuses technique (Ricker 1975) was used:

$$N = \frac{\Sigma(C_t M_t)}{R + 1}$$

where N = population size; C_t = total sample taken on day *t*; M_t = total marked fish at large at the start of the *t*th day (the number previously marked less any accidentally killed at previous recaptures); and R = total number of recaptures during the experiment. Population estimates were adjusted to incorporate large shoreline areas (such as house boats areas) we were unable to sample. Estimates were also adjusted to account for smallmouth bass between 135 and 150 mm FL. Population estimates of Salmon Bay and south Lake Union were determined by comparing catch per unit area data between areas with a mark-capture estimate and those with an estimate. Results of the population estimate were combined with consumption rate estimates to determine total consumption.

CONSUMPTION ESTIMATES

Similar to Chapter 1, consumption rates were calculated two separate ways: a bioenergetics method (Hanson et al. 1997) and a simple meal-turnover method adapted from Adams et al. (1982). We used a smallmouth bass bioenergetics model suggested by Petersen et al. (2000). The model was originally developed by Roell and Orth (1993) and later refined by Petersen et al. (2000) for adult fish. We used the largemouth bass model of Rice et al. (1983). For northern pikeminnow, we used a bioenergetics model developed by Petersen and Ward (1999). We analyzed the scales of smallmouth bass and largemouth bass to determine their age and growth. The data were fitted with a Von Bertalanffy growth equation (Dickie 1971) to estimate the fish size at age. Age and growth of northern pikeminnow was based on information from Olney (1975) and Brocksmith (1999). Water temperatures used in the models were from surface measurements we took on fish sampling dates or were from measurements taken by King County at 1-m depth at a Portage Bay reference site.

Digestion equations used in the meal-turnover method for smallmouth bass and largemouth bass are described in Chapter 2. For northern pikeminnow, we used the following equation from Beyer et al. (1988);

$$E = 0.01S^{0.43}T^{1.49}W^{0.25} ,$$

E = grams evacuated (12 h); S = meal weight (g); T = temperature (°C); W = predator weight (g). Based on digestive equations (Beyer et al. 1988), northern pikeminnow can completely digest an average-sized smolt in less than 24 hours. Therefore, we only included fish consumed within the past 12 h in our consumption calculation and then multiplied the number consumed by two to obtain the number consumed per day.

RESULTS

CATCH

Between April 21 and June 15, eight 500-m transects were sampled in Salmon Bay. Throughout this period, catch rates of smallmouth bass were substantially lower than other areas. Smallmouth bass were only caught in one of the eight transects (12.5%); whereas, smallmouth bass were caught in 76.7% of the transects (N = 30) in the other zones (2, 3, and 4). The mean number of smallmouth bass per 100 m of shoreline shocked was 0.046 in Salmon Bay and 0.387 in the other zones during the same time period. Largemouth bass were caught in 37.5 % of the transects in Salmon Bay and 70% of the transects in the other zones. The mean number of largemouth bass caught per transect was 0.175 in Salmon Bay and 0.471 in the other zones. However, the number of largemouth bass per 100 m of shoreline shocked was similar between Salmon Bay and the other zones; 0.217 in Salmon Bay and 0.231 in the other zones. The reason for the discrepancy between the two types of catch calculations is that Salmon Bay has many large structures and little shoreline that can be adequately sampled, whereas the other zones have a larger percentage of the total shoreline that can be sampled. The total catch for the eight transects in Salmon Bay was only one smallmouth bass, nine largemouth bass, and one northern pikeminnow. Because of the low catch rates and difficulty in sampling around all the large structures in Salmon Bay, we decided to discontinue sampling in Salmon Bay and concentrate our efforts in other areas which included sampling of south Lake Union.

Catch of bass was highly variable between transects. For example, catch of smallmouth bass in May in north Lake Union ranged from 0 to 15 fish per 100 m of shoreline. Overall, catch rates (catch per 100 m of shoreline) of smallmouth bass were significantly lower in April-May than June or July (Figure 5; F = 3.4, df = 2, 61, P = 0.039). Zone had a marginal effect on catch rates (F = 3.0, df = 2, 61, P = 0.057) and the interaction of month and zone was not significant (F = 0.7, df = 4, 61, P = 0.61). Catch rates in Fremont Cut were generally lower than the other two zones (Figure 5). The effects of month and zone had no significant effect on the catch rate of largemouth bass (month, F = 1.0, df = 2, 61, P = 0.37; zone, F = 0.33, df = 2, 61, P = 0.72). The interaction of month and zone had a marginal effect on catch rates (F = 2.4, df = 4, 61, P = 0.058). Comparing catch rates as catch per transect gave similar results as catch per 100 m of shoreline. In Portage Bay and north Lake Union, over two-thirds of the bass collected were smallmouth bass (Figure 6). In Fremont Cut, 56% of the bass were smallmouth bass and 44% were largemouth bass. In Salmon Bay and south Lake Union, more largemouth bass were collected than smallmouth bass (Figure 6).

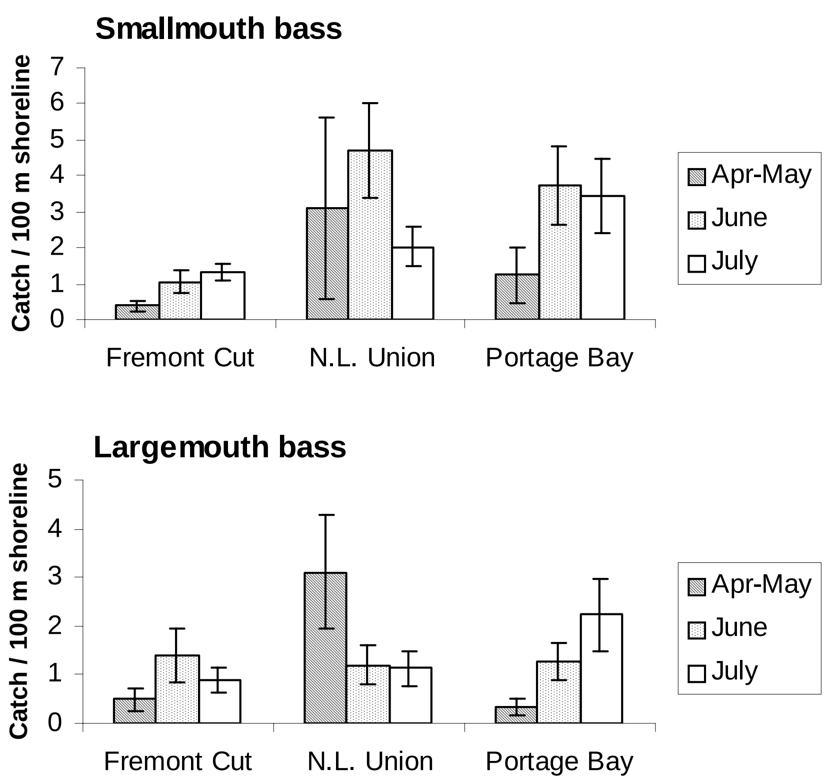

Figure 5.– Catch rates (±1 SE, catch/100 m of shoreline) of two species of bass in three zones of the LWSC, April-July, 1999. N.L. Union = north Lake Union.

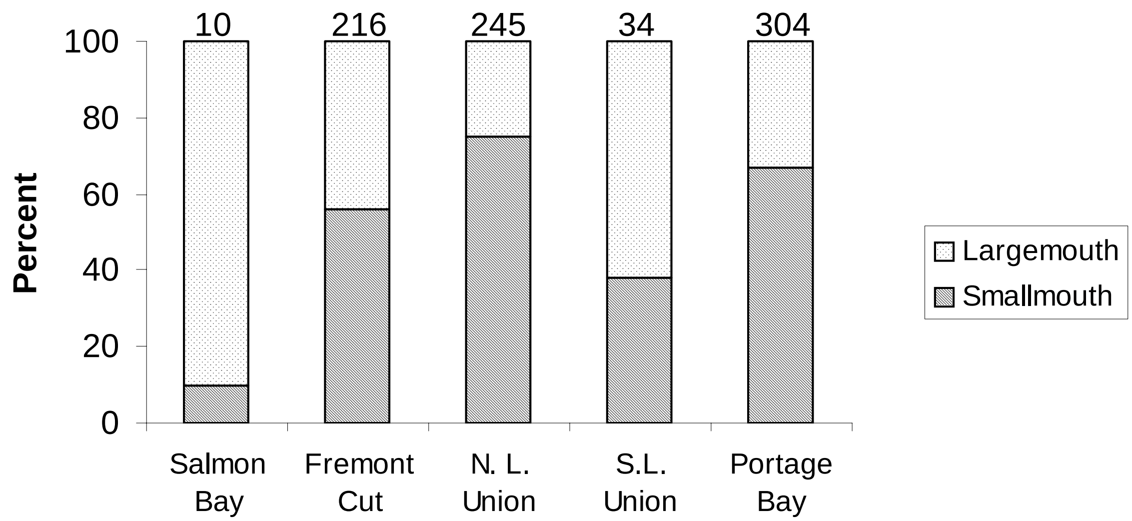

Figure 6.– Proportion of smallmouth bass and largemouth bass that were collected in five areas of LWSC, April-July, 1999. Numbers above bars indicate the sample size. N.L. Union = north Lake Union; S.L. Union = south Lake Union.

A total of 52 northern pikeminnow were collected. They were primarily caught in three areas, UW shoreline in Portage Bay, Gas Works Park in north lake Union, and Fremont Cut. Taken together, these three sites accounted for 79% of the northern pikeminnow total catch. The average catch rate for these three sites was 0.26 fish per 100 m shoreline (0.21 fish/transect), whereas it was only 0.11 fish per 100 m shoreline (0.05 fish/transect) for all the other locations. Some of the northern pikeminnow collected along the UW shoreline were collected within a few meters of the outflow of the university hatchery.

Fish length was significantly shorter in the Fremont Cut than north Lake Union or Portage Bay for both smallmouth bass (Figure 7; ANOVA, $F = 18.5$, df = 2, 466, $P < 0.001$) and largemouth bass (Figure 7; ANOVA, $F = 8.6$, df = 2, 246, $P < 0.001$). There was no significant difference between Portage Bay and north Lake Union. Because south Lake Union and Salmon Bay were not sampled throughout the entire study period and few fish were collected, they were not included in the analysis. We only collected 15 largemouth bass > 300 mm FL which made up only 5% of the largemouth bass > 135 mm FL (Figure 8). In contrast, we collected 83 smallmouth bass > 300 mm FL which made up 17% of the smallmouth bass > 135 mm FL.

The fork length of northern pikeminnow was not significantly different between the three zones (Figure 9; ANOVA, $F = 2.8$, df = 2, 48, $P = 0.07$). Northern pikeminnow ranged in size from 253 to 556 mm FL (Figure 10).

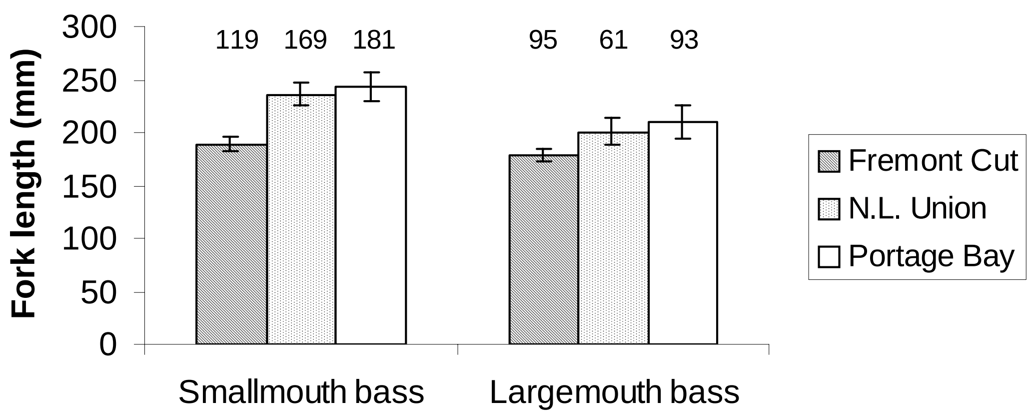

Figure 7.– Mean fork length (±1 SE) of bass collected in three areas of LWSC, April-July, 1999. Numbers above bars indicate the sample size. N.L. Union = north Lake Union.

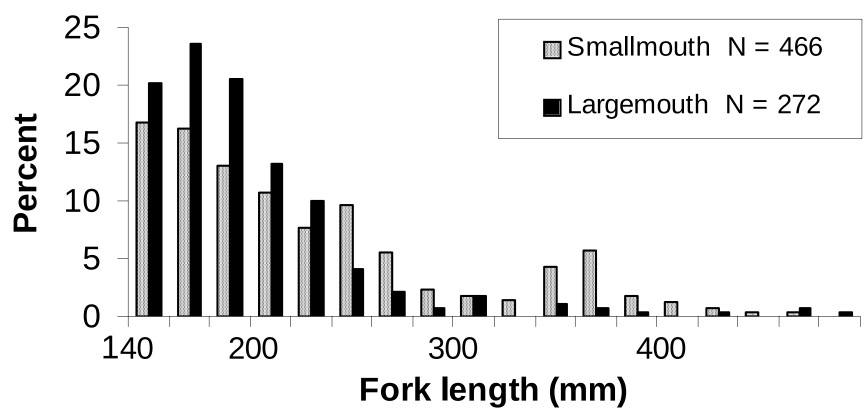

Figure 8.– Length frequency (20 mm increments) of bass > 140 mm FL collected in LWSC, April-July, 1999. All fish were collected with electrofishing equipment.

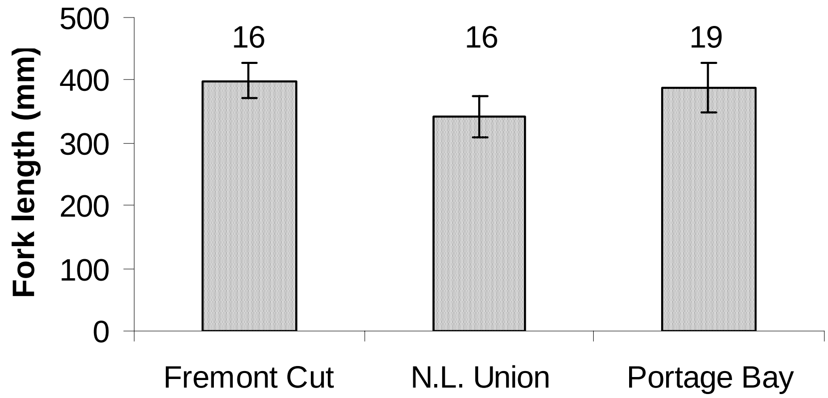

Figure 9.– Mean fork length (±1 SE) of northern pikeminnow collected in three areas of LWSC, April-July, 1999. Numbers above bars indicate the sample size. N.L. Union = north Lake Union.

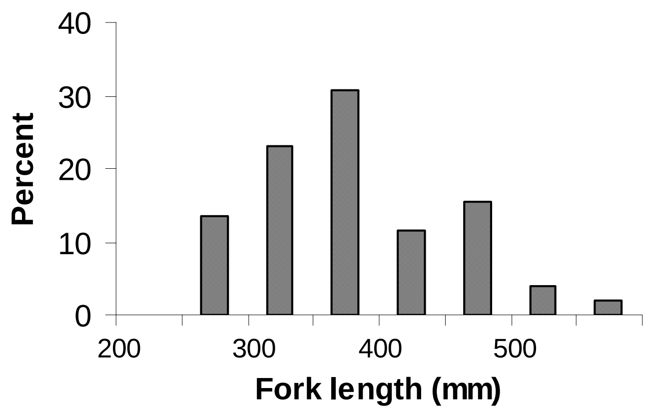

Figure 10.– Length frequency (50 mm increments) of northern pikeminnow (N = 52) collected in LWSC, April-July, 1999. All fish were collected with electrofishing equipment.

POPULATION ESTIMATES

Movement of smallmouth bass and largemouth bass appeared to be minimal. Eight-six percent of all recaptured smallmouth bass were caught either in the same transect (60%) or an adjoining transect (26%). Likewise, 88% of recaptured largemouth bass were captured in the same transect (41%) or an adjoining transect (47%). Therefore, we believe emigration of bass (marked and unmarked fish) to areas outside of our study area was minimal. The level of immigration of bass into our study area is unknown but we assume that it was minimal. Population estimates were calculated two ways; 1) by each zone and 2) combined. By calculating an estimate for each zone, we estimated the total number (zones 2, 3, and 4) of smallmouth bass was 1,655 (95% CI, 892 and 3,691) and 902 (95% CI, 339 and 5,297) largemouth bass (Table 21). The combined estimate for smallmouth bass was 1,309 (95% CI, 892 and 1,793) and 891 (95% CI, 590 and 1,420) for largemouth bass. The combined estimate provided tighter confidence intervals; however, the transects were sampled in a stratified random manner and thus, calculating an estimate for each zone may be more appropriate. Population estimates for each zone were also adjusted to take into account large shoreline areas we were unable to sample (i.e., houseboat communities) and were also adjusted for bass 135 and 150 mm FL which were not marked. Population estimates for Salmon Bay and south Lake Union were based on the mark-recapture population estimates in other zones and then adjusted based on differences in CPUE between zones and differences in shoreline length. Overall, we estimated the potential number of bass that could consume salmonid smolts in the LWSC was 3,388 smallmouth bass and 2,500 largemouth bass (Table 21).

Table 21.– Population estimates of smallmouth bass and largemouth bass in five areas of the LWSC, April-July, 1999. Mark-recapture estimates are based on a modified Schnabel multiple census technique. Adjusted estimates take into account large shoreline areas we were unable to sample and were also adjusted for bass 135 and 150 mm FL which were not included in the unadjusted estimate. CPUE (catch per unit effort) estimates were based on the mark-recapture population estimates in other zones and then adjusted based on differences in CPUE between zones. M = the total number of marked fish, R = the number of recaptures, N = population estimate, lower and upper CI = 95% confidence intervals. The total estimate is the adjusted mark-recapture estimates plus the CPUE-based estimates.

Type of estimate	Smallmouth bass					Largemouth bass				
Zone	M	R	N	lower CI	upper CI	M	R	N	lower CI	upper CI
Mark-recapture										
Unadjusted										
Fremont Cut	93	12	321	183	671	67	10	194	92	281
North Lake Union	117	22	346	229	551	43	2	425	118	4,245
Portage Bay	121	7	988	480	2,469	59	6	283	129	771
Adjusted										
Fremont Cut	--	--	370	212	717	--	--	214	102	309
North Lake Union	--	--	556	368	886	--	--	642	178	6,422
Portage Bay	--	--	1,941	944	4,853	--	--	461	211	1,258
Subtotal	--	--	2,867	1,524	6,456	--	--	1,317	491	7,989
CPUE										
South Lake Union	--	--	426	--	--	--	--	507	--	--
Salmon Bay	--	--	95	--	--	--	--	676	--	--
Total			3,388					2,500		

DIET ANALYSIS

Smallmouth bass.– Half of the overall diet of smallmouth bass was made up of salmonid smolts. Seventy-five percent of all ingested salmonids from all fish samples were found in smallmouth bass stomach samples. Of 508 stomachs examined, 158 smolts were found. Smallmouth bass as small as 139 mm FL were observed to have consumed salmonid smolts. For all size categories of smallmouth bass, salmonids made up a substantial percent of the diet (Table 22). Fish 200-249 mm FL had the highest percentage (62%) of the diet that was made up of salmonids. Smallmouth bass consumed large numbers of smolts in all areas where bass were collected. Even in south Lake Union, 50% of the diet of smallmouth diet was made up of salmonid smolts.

Most of the remainder of the diet of smallmouth bass consisted of either crayfish (19% by weight), cottids (16%), or yellow perch (9%). Smallmouth bass of all sizes consumed cottids but they were rare in fish > 350 mm FL. Besides salmonids, cottids, and yellow perch, few other prey fish were observed in smallmouth bass stomachs (Table 23). We did, however, observe two northern pikeminnow in their stomachs.

Table 22.– Diet (%) of six size categories of smallmouth bass in the LWSC, April 21-July 29, 1999. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs. Invert. = invertebrates.

Fork length (mm) Month	N	Salmonids	Other fish	Tadpole	Crayfish	Other Crustaceans	Aquatic insects	Other invert.	Other
100-149									
April-May	0 (0)	--	--	--	--	--	--	--	--
June	25 (4)	37.91	44.45	0.00	6.02	1.00	7.11	2.03	1.48
July	41 (12)	0.00	56.21	0.00	39.63	0.36	3.12	0.23	0.45
150-199									
April-May	11 (3)	0.00	34.77	0.00	57.96	1.74	0.32	2.83	2.38
June	54 (7)	52.62	30.64	0.00	14.03	0.21	1.93	0.13	0.43
July	71 (29)	40.40	38.03	0.00	18.17	0.13	0.62	2.36	0.30
200-249									
April-May	9 (5)	43.04	26.31	0.00	29.99	0.34	0.05	0.00	0.27
June	41 (11)	78.11	14.80	0.00	6.78	0.01	0.11	0.00	0.19
July	27 (16)	44.47	10.81	0.00	42.62	0.53	0.35	0.21	1.01
250-299									
April-May	7 (0)	27.22	49.18	22.54	0.00	0.23	0.00	0.05	0.79
June	25 (9)	70.64	3.57	0.00	25.26	0.00	0.04	0.00	0.48
July	14 (4)	61.64	34.73	0.00	3.29	0.00	0.13	0.00	0.21
300-349									
April-May	2 (1)	84.41	15.02	0.00	0.00	0.00	0.00	0.00	0.57
June	9 (8)	76.92	10.81	0.00	12.24	0.00	0.02	0.00	0.01
July	4 (1)	29.94	31.31	0.00	38.64	0.00	0.12	0.00	0.00
> 350									
April-May	6 (6)	16.42	81.38	0.00	1.56	0.00	0.00	0.02	0.63
June	29 (8)	54.50	2.97	0.00	42.40	0.00	0.01	0.09	0.03
July	5 (4)	61.90	37.94	0.00	0.00	0.00	0.01	0.00	0.15

Table 23.– Number of prey fish consumed by three predatory fishes in the LWSC, 1999. The total number of predator stomachs examined is given in parentheses.

Family species	Smallmouth bass			Largemouth bass			Northern pikeminnow		
	Ap-My (50)	June (230)	July (228)	Ap-My (42)	June (64)	July (127	Ap-My (2)	June (25)	July (25)
Salmonidae									
Chinook salmon	0	55	16	0	5	1	0	2	7
Coho salmon	0	42	10	0	15	2	0	6	0
Sockeye salmon	5	7	10	0	1	5	1	0	0
Unidentified salmonid	0	13	1	0	1	1	0	1	3
Cyprinidae									
Peamouth	0	0	0	0	1	0	0	0	0
Northern pikeminnow	0	1	1	0	0	0	0	0	0
Cobitidae									
Oriental weatherfish	0	0	0	2	0	0	0	0	0
Ictaluridae									
Brown bullhead	0	1	0	0	0	0	0	0	0
Gasterosteidae									
Threespine stickleback	0	1	3	1	6	28	0	0	0
Centrarchidae									
Lepomis spp.	0	0	1	2	0	3	0	0	0
Micropterus spp.	0	0	0	0	1	6	0	0	0
Percidae									
Yellow perch	5	2	2	0	2	1	0	0	0
Cottidae									
Cottus spp.	10	38	51	21	27	31	0	1	0
Unidentified non-salmonid	1	8	31	1	5	14	0	0	0
Other unidentified fish	0	0	3	0	0	1	1	0	0

Largemouth bass.– Largemouth bass appeared to consume substantially less salmonids than smallmouth bass (Tables 23 and 24). Predation of salmonids by largemouth bass was only observed in fish 159 to 264 mm FL. Of 280 stomachs examined, only 32 smolts were found. Predation of smolts by largemouth bass occurred primarily in Portage Bay, where 23 smolts were found in 94 stomach samples. Salmonids represented 36% of the largemouth bass diet in Portage Bay. In Lake Union and the Fremont Cut only nine smolts were found in 177 largemouth bass stomachs. There, only 5% of the diet consisted of salmonids. In addition to salmonids, largemouth bass also consumed large numbers of other prey fish species (Table 23) and consumed a much wider variety of fishes than smallmouth bass. Over 75% of the diet of largemouth bass consisted of fish. Other prey fish consumed included 68 cottids (40% of the diet by weight), 32 salmonids (16%), 35 threespine stickleback (2%), five sunfish (*Lepomis* spp.;7%), three yellow perch (6%), two oriental weatherfish (3%), seven bass (1%), and one peamouth (1%). In addition to several species of fish, largemouth bass also consumed other vertebrates which included one duckling and seven large tadpoles. The duckling was consumed by a 438 mm FL fish. Tadpoles represented 5% of the overall diet and 8% of the diet of largemouth > 250 mm FL. The diet of largemouth bass 100-149 mm FL consisted of 43% aquatic insects (mostly larval trichopterans and chironomids), 38% other fish (small sculpin and threespine stickleback) and 16% small crustaceans (isopods and amphipods).

Table 24.– Diet (%) of six size categories of largemouth bass in the LWSC, April 21-July 29, 1999. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs. Invert. = invertebrates.

Fork length (mm) Month	N	Salmonids	Other fish	Tadpole	Crayfish	Other Crustaceans	Aquatic insects	Other invert.	Other
100-149									
April-May	0 (0)	--	--	--	--	--	--	--	--
June	10 (4)	0.00	20.34	0.00	0.58	17.26	60.52	1.13	0.17
July	9 (7)	0.00	73.98	0.00	0.00	14.86	9.15	0.75	1.25
150-199									
April-May	17 (3)	0.00	22.95	0.00	70.87	4.51	0.82	0.07	0.78
June	46 (16)	47.48	33.30	5.01	10.33	1.50	1.53	0.11	0.75
July	46 (26)	5.27	67.23	0.00	23.42	0.30	1.70	1.78	0.31
200-249									
April-May	9 (4)	0.00	76.58	16.41	6.61	0.23	0.00	0.11	0.00
June	23 (2)	22.12	70.01	0.00	7.10	0.05	0.06	0.02	0.63
July	24 (8)	33.14	47.97	0.00	11.92	0.12	6.62	0.02	0.22
250-299									
April-May	5 (0)	0.00	92.92	0.00	6.31	0.36	0.00	0.00	0.40
June	3 (1)	20.35	39.83	39.82	0.00	0.00	0.00	0.00	0.00
July	3 (0)	0.00	20.18	77.43	0.00	0.00	0.17	0.00	2.22
300-349									
April-May	2 (0)	0.00	99.97	0.00	0.00	0.00	0.00	0.00	0.03
June	1 (1)	0.00	0.00	94.39	5.61	0.00	0.00	0.00	0.00
July	2 (1)	0.00	78.25	0.00	20.58	0.00	0.00	0.00	1.17
> 350									
April-May	1 (1)	0.00	88.29	0.00	0.00	0.00	0.00	0.00	11.71
June	2 (2)	0.00	71.93	0.00	26.54	0.00	0.00	0.02	1.50
July	1 (0)	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00

Northern pikeminnow.– We examined the digestive tracts of 52 northern pikeminnow. Juvenile salmonids were important in the diet of all sizes of northern pikeminnow (Table 25) and were consumed throughout the sample period. Although sample sizes were low, predation of salmonids appeared to be concentrated in Portage Bay in June but in July predation of salmonids was only detected in the Fremont Cut. The diet of northern pikeminnow consisted primarily of two prey items (Table 25): crayfish (49%) and juvenile salmonids (45%). The only other important prey item was fish remains (6%) from what appeared to be discarded fish heads. These were observed in just one fish caught in the west part of Fremont Cut. Examination of diagnostic bones indicated they were from an unknown fish species not normally found in the LWSC. Additionally, no vertebrae were found and only head bones present. Thus, we assumed the fish remains were probably discarded fish heads from some type of fish processing operation. Few other prey fish were present in the digestive tracts of northern pikeminnow. Only one sculpin and one unidentified fish was found. One northern pikeminnow caught along the UW shoreline had consumed marine mussels which probably came from an ocean-going vessel and possibly, the mussels were available as a result of the vessel being cleaned.

Table 25.– Diet (%) of three size categories of northern pikeminnow in the LWSC, April 21-July 29, 1999. N = sample size; the first number is the number of fish that had prey items in their stomach and the second number in parentheses is the number that had empty stomachs.

Fork length (mm) Month	N	Salmonids	Other fish	Crayfish	Other Crustaceans	Aquatic insects	Other invertebrates	Other
250-349								
April-May	0 (0)	--	--	--	--	--	--	--
June	8 (3)	91.50	0.70	7.59	0.00	0.00	0.00	0.21
July	4 (4)	0.00	0.00	94.80	0.00	0.00	0.55	4.65
350-449								
April-May	0 (0)	--	--	--	--	--	--	--
June	7 (2)	12.86	0.00	84.75	0.00	0.00	0.03	2.37
July	9 (4)	45.54	0.00	54.24	0.10	0.07	0.05	0.00
> 450								
April-May	1 (1)	82.32	0.73	0.00	0.00	0.00	16.90	0.04
June	2 (3)	100.00	0.00	0.00	0.00	0.00	0.00	0.00
July	3 (1)	60.01	16.82	23.18	0.00	0.00	0.00	0.00

Other fish.– We sampled 38 cutthroat trout > 200 mm FL for diet analysis. An additional 12 cutthroat trout 150-200 mm FL were also sampled and included in the diet analysis. Thirty-six percent of the stomachs were empty and no salmonids were present in any sample. Most prey fish (cottids and unidentified fish) were observed in cutthroat trout > 250 mm FL. Cottids represented 43% of the overall diet of cutthroat trout. However, this was largely due to two large cutthroat trout (283 and 296 mm FL) which had ingested a total of four relatively large cottids. Only 9% of the cutthroat trout that contained food had consumed cottids. In contrast, chironomid larvae and pupae made up 22% of the diet by weight but were present in 88% of the stomachs that contained food. Of the chironomids consumed, most were pupae. Other important prey items included oligochaetes (10%), crayfish (6%), terrestrial insects (4%), and odonate nymphs (4%).

Only three rainbow trout/steelhead > 200 mm FL (range 222-267 mm FL) were collected. One had an empty stomach. Only one of the other two fish had an appreciable amount of food in its stomach. Prey included mostly chironomid pupae and the megalopteran *Sialas sp*.

Six coho salmon (range, 192-255 mm FL) were sampled for diet analysis. Five of the six coho salmon sampled had empty stomachs. The only fish with food had consumed *Daphnia* spp. and a few chironomid pupae.

Of the 22 brown bullhead examined for diet analysis, all but two were > 200 mm FL. Most of the diet of brown bullhead consisted of aquatic invertebrates such as mollusks (17%), chironomid larvae and pupae (16%), isopods (11%), and crayfish (10%). The stomachs also contained large amounts of detritus (23%) and plant material (16%). The only prey fish present in brown bullhead stomachs were two small unidentified fish which made up < 1% of the diet.

Although large numbers of prickly sculpin were observed, we only collected two sculpin that were > 150 mm TL. One had an empty stomach and the other stomach contained only crayfish.

A total of seven yellow perch were examined for stomach contents. All were > 200 mm FL (range, 204-253 mm FL). Over 99% of the diet was made up of three prey items; crayfish (83%), sculpin (14%), and threespine stickleback (2%).

Salmonid species identification.– A total of 210 salmonids were observed in the samples. We were able to directly identify 41 salmonids (20%) since they were little digested. An additional 148 (70%) were identified through genetic analysis. In May, all ingested salmonids (N = 6) were sockeye salmon (Figure 11, Table 26). In June, 47% of the ingested salmonids were Chinook salmon (N = 62), 47% were coho salmon and only 8% were sockeye salmon (N = 8). Fifty-three percent of the salmonids consumed by smallmouth bass in June were Chinook salmon, while only 24% and 25% of the salmonids consumed by largemouth bass and northern pikeminnow, respectively were Chinook salmon (Figure 11). Chinook salmon were found in 20% of the smallmouth bass in June; whereas, they were only present in 6% and 8% of the largemouth bass and northern pikeminnow, respectively (Table 27). In July, 47% of the ingested salmonids were Chinook salmon (N =24), 24% were coho salmon (N = 12) and 29% were sockeye salmon (N = 15). Chinook salmon made up 44% of the salmonids consumed by smallmouth bass in July and only 13% of salmonids consumed by largemouth bass. All of the identifiable salmonids consumed in July by northern pikeminnow were Chinook salmon.

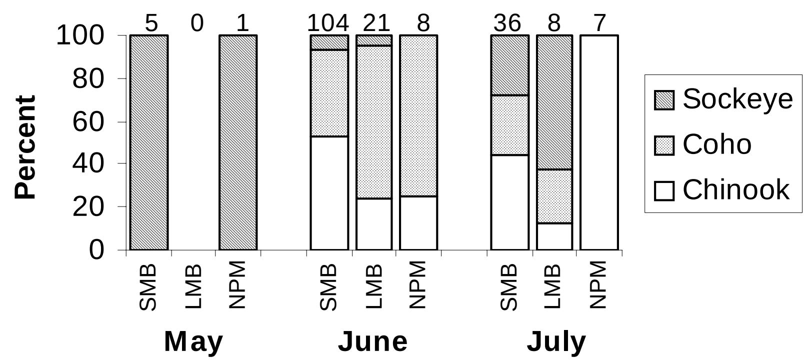

Figure 11.– Proportion of three salmonids consumed by predators in the LWSC, May-July, 1999. The number of identifiable salmonids observed for each predator species is shown above each bar. SMB = smallmouth bass; LMB = largemouth bass; and NPM = northern pikeminnow.

Table 26.– Number of salmonids consumed by three predatory fishes in the LWSC, 1999. N = the number of predator stomachs examined; Ch = Chinook salmon, Co = coho salmon, So = sockeye salmon, Un = unidentified salmonid.

	Smallmouth bass					Largemouth bass					Northern pikeminnow				
Date	N	Ch	Co	So	Un	N	Ch	Co	So	Un	N	Ch	Co	So	Un
April 21	11	0	0	0	0	7	0	0	0	0	0	-	-	-	-
May 5	18	0	0	0	0	22	0	0	0	0	2	0	0	1	0
May 18	21	0	0	5	0	13	0	0	0	0	0	-	-	-	-
June 3	54	20	3	1	4	12	3	5	0	1	11	1	4	0	1
June 9	28	7	7	0	3	13	2	1	0	0	1	0	0	0	0
June 15	36	8	14	0	2	16	0	2	0	0	0	-	-	-	-
June 22	65	16	14	3	4	23	0	4	0	0	10	1	1	0	0
June 30	47	4	4	3	0	47	0	3	1	0	3	0	1	0	0
July 6	36	3	7	3	1	53	1	1	3	0	6	2	0	0	2
July 13	57	5	3	4	0	22	0	1	1	0	5	0	0	0	1
July 22	69	6	0	3	0	30	0	0	0	0	7	2	0	0	0
July 29	66	2	0	0	0	22	0	0	1	1	7	3	0	0	0
Total	508	71	52	22	14	280	6	17	6	2	52	8	6	1	5

Table 27.– Frequency of occurrence (%) of salmonids consumed by three predatory fishes in the LWSC, 1999. The total number of predator stomachs examined is given in parentheses.

	Smallmouth bass			Largemouth bass			Northern pikeminnow		
Species	Ap-My (50)	June (230)	July (228)	Ap-My (42)	June (64)	July (127)	Ap-My (2)	June (25)	July (25)
Chinook salmon	0.0	20.0	13.5	0.0	6.3	0.8	0.0	8.0	16.0
Coho salmon	0.0	13.9	3.9	0.0	18.8	1.6	0.0	16.0	0.0
Sockeye salmon	10.0	3.0	3.9	0.0	1.6	3.9	50.0	0.0	0.0
Unidentified salmonid	0.0	4.8	0.4	0.0	1.6	0.8	0.0	4.0	12.0
All salmonids	10.0	38.3	14.0	0.0	26.6	6.3	50.0	28.0	24.0

Salmonid size.– We were able to estimate the original length of 116 of the 210 ingested salmonids. The size of ingested salmonids was generally similar between predator species for each month; however, northern pikeminnow consumed significantly larger salmonids in July than smallmouth bass or largemouth bass (ANOVA, $F = 17.0$, df = 2, 29, $P < 0.001$). The differences were due to the capture of four northern pikeminnow over 400 mm FL in late July which had all consumed salmonids greater than 130 mm FL. The monthly change in size varied between salmonid species. Chinook salmon tended to increase in size from June to July, coho salmon size remained the same, and sockeye salmon size was highest in May (Figure 12). Chinook salmon consumed in July were significantly larger than those consumed in June (Figure 12; t-test =-3.2, $P = 0.004$). The mean size of ingested coho salmon was 86.6 mm FL and there was no difference in size between June and July (Figure 12; t-test =0.14, $P = 0.89$). Sixty-seven percent of the ingested coho salmon were less than 90 mm FL. Sockeye salmon consumed in May were significantly larger than those consumed in June and July (ANOVA, $F = 16.15$, df = 2, 14, $P < 0.001$).

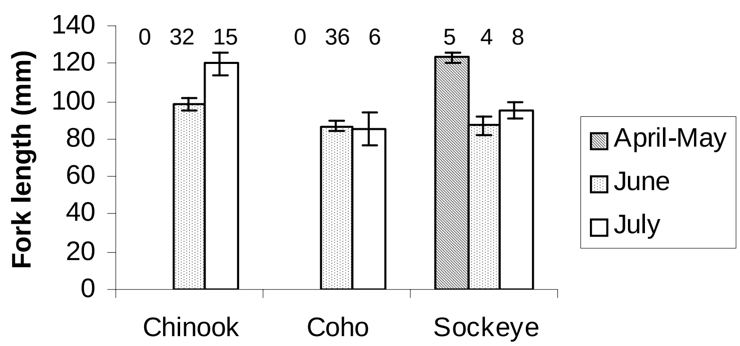

Figure 12.-- Mean fork length (±1 SE) of salmonids consumed by predatory fishes in the LWSC, April-July, 1999. Predatory fishes include smallmouth bass, largemouth bass, and northern pikeminnow. Data for each species were combined. Numbers above each bar indicate the sample size (number of ingested salmonids we were able to measure).

CONSUMPTION ESTIMATES

The bioenergetics model predicted smallmouth bass consumed 27,300 salmonids and largemouth bass consumed 8,700 (Table 28). The direct meal-turnover model predicted smallmouth bass consumed 41,100 salmonids and largemouth bass consumed 4,600. The highest total consumption of salmonids occurred in age 2 fish because of their large population size and high growth rates. Incorporating the results of both models, there was little apparent difference in the number of each salmonid species consumed by smallmouth bass. Largemouth bass appeared to consume mostly sockeye salmon and coho salmon and few Chinook salmon. Consumption of Chinook salmon and coho salmon by smallmouth bass and largemouth bass was substantially higher in June than July. Consumption of sockeye salmon was highest in July.

Consumption of salmonids by smallmouth bass was substantially higher in Portage Bay than the other zones (Table 29). Largemouth bass consumption of salmonids was similar between Portage Bay and north Lake Union. Most of the predation of coho salmon by smallmouth bass and largemouth bass occurred in Portage Bay. Smallmouth bass consumed substantially more salmonids than largemouth bass in each zone except south Lake Union.

We modeled northern pikeminnow consumption under three population scenarios (Table 30). In the two highest population estimates, the consumption rates were as high or higher than smallmouth bass. Unlike smallmouth bass, predation of Chinook salmon by northern pikeminnow was highest in July. The main salmonid consumed by northern pikeminnow was Chinook salmon (47% by number), followed by coho salmon (32%) and sockeye salmon (21%).

Table 28.– Total consumption estimates (number of smolts) of bass by month in the LWSC, 1999. Consumption estimates were calculated two ways, a bioenergetics model and a direct meal-turnover method (Adams model). Est. = estimate of consumption; 95% C.I. = lower and upper 95% confidence intervals which were based on the confidence intervals of the population estimate. Consumption estimates do not include Salmon Bay which was not sampled in late June and July.

	Smallmouth bass				Largemouth bass			
	Bioenergetics model		Adams model		Bioenergetics model		Adams model	
Species Month	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.
Chinook salmon								
May	0	-	0	-	0	-	0	--
June	6,269	3,425 - 13,717	10,231	5,482 - 22,983	471	218 - 1,108	450	209 - 980
July	2,509	1,349 - 5,539	4,090	2,126 - 9,529	121	56 - 329	266	121 - 724
Total	8,778	4,773 - 19,256	14,321	7,609 - 32,511	592	274 - 1,437	716	330 - 1,704
Coho salmon								
May	0	-	0	-	0	-	0	--
June	5,002	2,542 - 11,945	12,111	6,079 - 29,267	1,685	721 - 6,589	1,986	913 - 5,172
July	1,877	960 - 4,398	2,419	1,222 - 5,815	195	89 - 533	266	121 - 724
Total	6,880	3,502 - 16,343	14,531	7,301 - 35,082	1,880	810 - 7,122	2,252	1,034 - 5,896
Sockeye salmon								
May	472	312 - 760	894	519 - 1,212	0	-	0	--
June	3,549	1,726 - 8,873	3,708	1,800 - 9,272	93	43 - 253	256	117 - 699
July	4,558	2,344 - 10,721	5,119	2,724 - 11,586	6,102	1,959 - 50,282	1,335	466 - 8,028
Total	8,579	4,382 - 20,354	9,722	5,043 - 22,070	6,195	2,002 - 50,536	1,591	583 - 8,727
Unidentified								
May	0	-	0	-	0	-	0	--
June	1,157	661 - 2,364	1,618	624 - 3,506	0	-	0	--
July	1,869	909 - 4,673	925	449 - 2,313	0	-	0	--
Total	3,026	1,570 - 7,037	2,543	1,073 - 5,819	0	-	0	--
Totals								
May	472	312 - 760	894	519 - 1,212	0	-	0	--
June	15,977	8,356 - 36,899	27,669	13,985 - 65,028	2,248	981 - 7,950	2,692	1,240 - 6,850
July	10,813	5,561 - 25,332	12,553	6,523 - 29,243	6,419	2,104 - 51,144	1866	707 - 9,477
Grand Total	27,262	14,229 - 62,991	41,117	21,026 - 95,483	8,667	3,085 - 59,094	4,558	1,948 - 16,327

Table 29.– Total consumption estimates (number of smolts) of bass in four zones of the LWSC, 1999. Consumption estimates were calculated two ways, a bioenergetics model and a direct meal-turnover method (Adams model). Est. = estimate of consumption; 95% C.I. = lower and upper 95% confidence intervals which were based on the confidence intervals of the population estimate. Consumption estimates do not include Salmon Bay which was not sampled in late June and July.

Zone	Smallmouth bass				Largemouth bass			
	Bioenergetics model		Adams model		Bioenergetics model		Adams model	
Species	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.	Est.	95% C.I.
Fremont Cut								
Chinook salmon	1,112	637 - 2,154	2,027	1,156 - 4,237	138	66 - 199	194	92 - 281
Coho salmon	542	311 - 1,051	569	324 - 1,189	77	37 - 111	194	92 - 281
Sockeye salmon	262	150 - 509	142	81 - 297	0	-	0	-
Unidentified	222	127 - 431	0	-	0	-	0	-
Total	2,139	1,225 - 4,144	2,738	1,561 - 5,723	216	103 - 312	388	184 - 562
North Lake Union								
Chinook salmon	2,325	1,539 - 3,746	2,723	1,807 - 4,342	0	-	0	-
Coho salmon	622	412 - 1,002	1,122	744 - 1,789	287	80 - 2874	0	-
Sockeye salmon	1,066	705 - 1,718	2,171	1,366 - 3,247	3,203	888 - 32,035	803	223 - 6,580
Unidentified	384	254 - 619	160	106 - 256	0	-	0	-
Total	4,397	2,910 - 7,085	6,175	4,023 - 9,634	3,490	968 - 34,909	803	223 - 6,580
South Lake Union								
Chinook salmon	0	-	0	-	0	-	0	-
Coho salmon	0	-	0	-	0	-	0	-
Sockeye salmon	0	-	0	-	1,421	394 - 14,211	0	-
Unidentified	250	133 - 562	972	282 -2,037	0	-	0	-
Total	250	133 - 562	972	282 -2,037	1,421	394 - 14,211	0	-
Portage Bay								
Chinook salmon	5,342	2,598 - 13,356	9,571	4,647 - 23,932	333	152 - 909	522	239 - 1,423
Coho salmon	5,716	2,779 - 14,290	12,840	6,233 - 32,105	1,516	694 - 4,136	2,059	943 - 5,615
Sockeye salmon	7,251	3,526 - 18,128	7,409	3,596 - 18,525	1,572	720 - 4,290	788	360 - 2,147
Unidentified	2,169	1,055 - 5,424	1,411	685 - 3,527	120	55 - 327	0	-
Total	20,477	9,958 - 51,199	31,231	15,161 - 78,089	3,541	1,621 - 9,662	3,367	1,541 - 9,185

Table 30.– Predation estimates (number of smolts consumed under three population size scenarios) of northern pikeminnow in the LWSC, 1999. Consumption rates were calculated with two approaches: 1) bioenergetics model and 2) a direct meal-turnover methodology (Adams model). Predation estimates were calculated with three scenarios of the population size of northern pikeminnow: 1) 350 fish (equal catchability as smallmouth bass), 2) 1,000 fish (roughly one third the catchability as smallmouth bass), 3) 4,200 fish (similar density (#/surface area) as Lake Washington).

	Predation estimates					
	Scenario # 1		Scenario # 2		Scenario # 3	
Prey Species Month	Bioenergetics	Adams	Bioenergetics	Adams	Bioenergetics	Adams
Chinook salmon						
May	0	0	0	0	0	0
June	1,785	840	5,099	2,400	21,415	10,080
July	2,055	4,340	5,871	12,400	24,656	52,080
Coho salmon						
May	0	0	0	0	0	0
June	2,650	3,360	7,571	9,600	31,799	40,320
July	0	0	0	0	0	0
Sockeye salmon						
May	1,743	0	4,980	0	20,917	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
Unidentified salmon						
May	0	0	0	0	0	0
June	1,429	840	4,083	2,400	17,148	10,080
July	320	1,736	914	4,960	3,837	20,832
Totals						
May	1,743	0	4,980	0	20,917	0
June	5,853	5,040	16,753	14,400	70,362	60,480
July	2,375	6,076	6,785	17,360	28,493	72,912
Total	9,981	11,116	28,518	31,760	119,772	133,392

DISCUSSION

PREDATION

In May, large numbers of sockeye salmon migrated through the LWSC and they were the only salmonid species consumed by piscivorous fishes; however, the overall predation of sockeye salmon appeared to be low. Predation may be minimized due to low water temperatures. Smallmouth bass are not believed to feed much when water temperatures are below 10ºC and feed most actively at 20ºC (Wydoski and Whitney 2003). Water temperatures at one meter depth in Portage Bay ranged from 10 to 14.5ºC in May (King County, unpublished data). In contrast, water temperatures ranged from 14.5 to 18.5ºC in June and 17.5 to 21ºC in July. Bennett et al. (1991) concluded that water temperatures play a key role in affecting predation of salmonid smolts by smallmouth bass because a large part of smolt migration occurs when water temperatures are below 10ºC and smallmouth bass are not actively feeding. Besides water temperatures, low predation may be caused by large prey size and low predator abundance. Yearling sockeye salmon are often greater than 130 mm FL and thus may be too large for most bass to consume. In May, catch rates of smallmouth bass were lower than in June or July.

Sockeye salmon consumed in July and June were considerably smaller than those consumed in May. The large differences in size between the two groups suggest there were two age classes. Sockeye salmon consumed in May appear to be yearling fish; whereas, the later sockeye salmon were most likely age 0 fish. DeVries (2002) also found that there were two distinct size classes of sockeye salmon that passed through the LWSC, where the earlier outmigrants were substantially larger than the later outmigrants. Additionally, DeVries (unpublished data) noted that some of the small sockeye salmon (PIT tagged in the LWSC) residualized and passed through the Locks the following year. The behavior and habitat use of the age 0 sockeye salmon in the LWSC is not known. Age 0 sockeye salmon may be vulnerable to predators because of their small size. They may also become more vulnerable to predators in July as water quality conditions worsen. High water temperatures and low oxygen levels in the deep areas of Lake Union may squeeze sockeye salmon into a narrow depth range and thus they may become stressed. In general, fish in substandard condition are more vulnerable to predation (Mesa et al. 1994).

The sizes of ingested coho salmon suggests many were probably newly released fish from the UW Hatchery. The hatchery releases age 0 coho salmon that are smaller than yearling coho salmon that are either naturally produced or from the Issaquah Hatchery. The mean length of coho salmon released at the UW Hatchery in 1999 was 89.3 mm FL (Table 31) which is similar to the size observed in the predator samples (mean, 86.6 mm FL). The mean length of coho salmon smolts collected at the mouth of the Cedar River and Bear Creek was over 105 mm FL (Seiler et al. 2003). These fish were mostly collected in May and by the time they reach the LWSC in June and July they would be considerably larger. Coho salmon collected in 2001 in Lake Union averaged over 130 mm FL (DeVries 2002). Because 36% of the ingested coho salmon were less than 80 mm FL, it seems likely that many of these fish were from the UW Hatchery.

Table 31.– Hatchery release data for UW Hatchery and WDFW Issaquah Hatchery, 1999. Mean fork lengths and weights of the UW Hatchery fish were measured directly; whereas they were estimated from fish/kg information for the Issaquah Hatchery fish.

Hatchery species	Date	Number	Mean fork length (mm)	Mean weight (g)
University of Washington				
Chinook salmon	May 24	178,592	107.1	20.7
Coho salmon	May 24	99,818	89.3	9.9
Coho salmon	June 12	10,091	--	--
Issaquah Hatchery				
Chinook salmon	May 4	716,300	79.1	6.0
Chinook salmon	May 13	1,455,800	80.4	6.2
Coho salmon	April 16	409,000	135.5	25.8

Coho salmon released from the UW Hatchery may be especially vulnerable to predators for three main reasons; 1) they are relatively small, 2) newly-released fish are often extremely vulnerable to predators, and 3) many age 0 coho salmon may not be ready to outmigrate and thus may be available to predators for a long period of time. Smaller salmonids will be vulnerable to a larger range of predator sizes. Also, smaller salmonids are more vulnerable to predators because they have slower burst speeds (Webb 1976). Size-selective predation (selection for small salmonids) has been documented in northern pikeminnow (Poe et al. 1991). High predation rates of salmonids shortly after stocking have been observed in other locations. Shrader and Moody (1997) found much of predation of yearling rainbow trout (20 g fish) by largemouth bass in Prairie Crane Reservoir was near the stocking site and occurred shortly after the trout were stocked. Similarly, predation of Atlantic salmon (Warner 1972; Henderson and Letcher 2003) and rainbow trout (Wurtsbaugh and Tabor 1989) was intense shortly after the fish were stocked. Northern pikeminnow appear to be especially responsive to stocking of salmonids and will consume large numbers of newly-stocked fish (Thompson 1959; Collis et al. 1995; Shively et al. 1996; Fresh et al. 2003).

Although we were able to estimate the number of Chinook salmon consumed in the LWSC, we were unable to estimate the number of wild and hatchery Chinook salmon that were consumed. Because hatchery fish are substantially more numerous than wild fish, it would seem reasonable that far more hatchery fish are consumed than wild fish. Also, the UW Hatchery Chinook salmon are released directly into LWSC and there could be a strong post-stocking predation effect which would result in a disproportionate number of hatchery fish consumed. Alternatively, predators such as northern pikeminnow often consume smolts that are on average smaller than those available (Poe et al. 1991) and if wild fish are significantly smaller than hatchery fish, wild fish may be consumed disproportionally to hatchery fish. However, currently there is no evidence that wild Chinook salmon in LWSC are smaller than hatchery fish. At release, the approximate mean size of Issaquah Hatchery fish (80 mm) were actually smaller than

Chinook salmon collected at the mouth of Cedar River (84 mm FL, Seiler et al. 2003) or Bear Creek (86 mm FL, Seiler et al. 2003). Few comparisons have been made of sizes of wild and hatchery Chinook salmon in the LWSC; however, one comparison from June, 2001 data, indicated there was no difference in size (mean size of both groups, 99 mm FL, P. DeVries, R2 Resource Consultants, Inc., personal communication). Besides differences in size, wild fish may be disproportionally consumed if wild fish migrate later than hatchery fish. Many Cedar River Chinook salmon appear to migrate later than Issaquah Hatchery Chinook salmon (DeVries 2002). Increased water temperatures, reduced predator spawning activity, and lower smolt abundance could result in an increase in predation. Alternatively, later fish will be larger and have reduced vulnerability to predators.

Overall, smallmouth bass appeared to consume a small fraction of the available Chinook salmon in LWSC. The actual number of Chinook salmon in LWSC is unknown. However, if we assume a 50% survival for hatchery Chinook salmon from Issaquah Hatchery (Table 31) to LWSC, there would have been approximately 1,090,000 Chinook salmon available to predators in LWSC. Adding in UW Hatchery Chinook salmon and wild Chinook salmon, the total number would be around 1,300,000. Our estimate of predation of Chinook salmon by smallmouth bass was between 5,000 and 40,000. The predation rate would then be between 0.4 and 3.0%. Using an adjusted point estimate of 8,800 (bioenergetics model) or 14,300 (Adams model) the predation rate would be around 1%. Therefore, smallmouth bass do not appear to be a significant predator of Chinook salmon in the LWSC.

Most of the salmonids consumed by smallmouth bass in LWSC appear to be subyearling fish, either Chinook salmon, coho salmon, or sockeye salmon. A similar trend has been observed in the Columbia River and Snake River. In those areas, the downstream migration period of yearling Chinook salmon and steelhead typically occurs from mid April to mid June. Because water temperatures are relatively low and the smolts are large, predation by smallmouth bass is considered to be minor (Bennett et al. 1991). Additionally, yearling smolts typically migrate in the middle of the river channel (Dauble et al. 1989) and may be spatially segregated from smallmouth bass. Subyearling Chinook salmon, on the other hand, are considerably smaller, migrate downstream when water temperatures are relatively high, and inhabit nearshore areas (Dauble et al. 1989) like smallmouth bass. Subyearling Chinook salmon can make up as much as 59% of the diet of smallmouth bass (Tabor et al. 1993). In the LWSC, subyearling Chinook salmon, coho salmon, and sockeye salmon are probably available to smallmouth bass because they are relatively small, migrate when water temperatures have risen above 15°C, and may inhabit nearshore areas.

Comparison of predation rates of salmonids by sympatric largemouth bass and smallmouth bass has not been well studied except in Lake Sammamish (Pflug 1981) and Lake Washington (Fayram 1996). In both studies, salmonids were more important in the diet of largemouth bass than smallmouth bass. However, in this study, smallmouth bass in the LWSC had a substantially higher predation rate of salmonids than largemouth bass. In the Lake Washington study (Fayram 1996), results may have been biased due to small sample sizes. For example, much of the predation of salmonids by largemouth bass was observed in June which was based on a sample of four fish. In Lake Sammamish (Pflug 1981), hatchery salmonids were probably concentrated in the north and south end of the lake as they entered and then as they left the lake. The habitat in these areas has gentle slopes, silt and sand substrates, and dense growths of aquatic vegetation, which is more typical largemouth bass habitat (Pflug 1981). The other areas of the lake are more typical smallmouth bass habitat but smolts may not have been as concentrated there. In the LWSC the opposite occurs. In areas where the LWSC is narrow, such as the western part of Portage Bay and the northeastern part of Lake Union, smolts concentrate and the habitat has steep slopes which is more typical smallmouth bass habitat. Hubert and Lackey (1980) found that bottom slope was a major variable governing the distribution of smallmouth bass. They preferred dropoffs with a 30-45^o slope. In areas where largemouth bass predominated such as south Portage Bay and south Lake Union, smolts probably were not as concentrated.

In other studies of sympatric largemouth bass and smallmouth bass, their diets were relatively similar; however, largemouth bass were generally more piscivorous than smallmouth bass which often had a higher occurrence of crayfish in their diet. Hubert (1977) found the bass diets in Pickwick Reservoir, Alabama, were similar, especially between smallmouth bass of a particular size class (100 mm intervals; e.g. 300-399) and the next shorter largemouth bass size class (e.g., 200-299 mm). The author attributed this trend to differences in mouth size. In Long Lake, Michigan, bass diets were similar; however, largemouth bass consumed terrestrial vertebrate prey (amphibians and small mammals) to a larger extend than smallmouth bass (Hodgson et al. 1997). In Skiatook Lake, Oklahoma, (Long and Fisher 2000) and four lakes in New York State (Olsen and Young 2003), both species were piscivorous and consumed similar prey items; however, smallmouth bass consumed crayfish more often than largemouth bass and largemouth bass became highly piscivorous at a smaller size than smallmouth bass. Largemouth bass in Spirit Lake, Iowa preyed primarily on yellow perch and brown bullhead; whereas smallmouth bass preyed primarily on yellow perch and crayfish (Liao et al. 2002). In the LWSC, we found the same general patterns. Crayfish was more important in the diet of smallmouth bass than largemouth bass. Overall, largemouth bass tended to be more piscivorous than smallmouth bass.

The primary salmonid consumed by largemouth bass in the LWSC was coho salmon. In addition, Stein (1970) found coho salmon were the only salmonid consumed by largemouth bass in Lake Washington. Largemouth bass have also been reported to consume coho salmon in other systems. Scott Bonar (USGS, unpublished data) found largemouth bass were the primary predator of coho salmon in three small lakes on the Kitsap Peninsula, Washington. Additionally, Reimers (1989) suggested that the predation by introduced largemouth bass in the Tenmile Lakes system in Oregon caused the population of coho salmon to decline substantially. Largemouth bass may be an important predator of coho salmon in areas where they coexist because they may reside in similar habitats. In lentic systems, they both inhabit the littoral zone and are often associated with some type of structure such as woody debris (Mason 1974; Tabor and Piaskowski 2002; Wydoski and Whitney 2003).

The diet of northern pikeminnow in the LWSC appears to reflect an opportunistic feeding behavior. Their diet included a wide range of prey including salmonid smolts, crayfish, discarded fish remains, and marine mussels. In other systems, northern pikeminnow have also been shown to be an opportunistic forager that can take advantage of locally abundant food including plant material and live or dead fish. In the Columbia River system, northern pikeminnow have been found to feed on plant material that falls into the water, such as wheat kernels *Triticum* spp. (presumably from nearby grain elevators) (Shively et al. 1996) and the fruit of blackberries *Rubus* sp. (Tabor et al. 1993). They have been documented to quickly switch over to prey on outmigrating smolts when the smolts become abundant (Shively et al. 1996). Northern pikeminnow are known to feed on dead as well as live smolts (Petersen et al. 1994). In Lake Washington, northern pikeminnow aggregate near the mouth of the Cedar River during the early spring to prey on adult longfin smelt that are either migrating upstream to spawn or are spawned-out smelt that are dead or soon-to-be dead (Olney 1975; K. Fresh, NOAA Fisheries, unpublished data).

Based on the diet of northern pikeminnow, they appear to be an important predator of smolts in the LWSC. We are unable to fully assess their impact on salmonid populations because we were unable to get a population estimate. If we assume equal catchability between northern pikeminnow and bass, the population size of northern pikeminnow would be small and their total consumption of smolts would be also low. Most likely though, the catchability of northern pikeminnow was much lower than bass. The population estimate for Lake Washington is approximately 160,000 adult fish (Brocksmith 1999). If we assume equal number of fish per area, there would be roughly 4,200 fish in the entire LWSC but if we base the calculation on number per shoreline length there would be 16,600 fish (not including Salmon Bay or south Lake Union). Therefore, northern pikeminnow could potentially consume over 100,000 smolts and thus would be a far more significant predator than smallmouth bass and largemouth bass, combined. Additional sampling of northern pikeminnow is recommended to estimate their population size. Other techniques, such as angling, may need to be employed to collect adequate numbers of northern pikeminnow. Also, sampling near the university hatchery shortly after the release of smolts would be useful to determine if large numbers of northern pikeminnow aggregate at this site.

CATCH

In the Salmon Bay area, relatively few predators were collected. Other species such as yellow perch, pumpkinseed, black crappie, and prickly sculpin also appeared to be less common. The reason for the apparent lower abundance of fish than other areas is unclear but it is most likely due to differences habitat, water quality, or catch efficiency. Unlike the other areas, Salmon Bay was historically an estuary. According to D. Houck, King County (personal communication) the area contains extensive soft sediments unlike the other areas. Fresh et al. (2001) found that smallmouth bass rarely inhabit areas with soft sediments even if structures (piers and docks) are present. With the soft sediments, Salmon Bay may be more indicative of largemouth bass habitat. Most of the bass caught in Salmon Bay were largemouth bass and catch rates (largemouth bass per shoreline shocked) were similar to other areas in the LWSC. The total number of bass collected may also have been low because of the difficulty in sampling Salmon Bay. The area has numerous large structures and access to the shoreline was limited. Catch of bass and other species may also have been low due to the differences in catch efficiency between Salmon Bay and other areas on the LWSC.

The soft sediments of Salmon Bay may also affect bass populations indirectly by altering their forage base. Some species such as prickly sculpin that reside on the bottom may be directly affected by the soft sediments. In a survey of lentic systems in the Cedar River basin, the only locations that no cottids were observed were two small lakes that contained extensive soft sediments (R. Tabor, unpublished data). Prickly sculpin are an important forage fish in other areas of the LWSC and their low abundance in Salmon Bay could have effects on the abundance of piscivorus fishes. Additionally, the abundance and type of macroinvertebrates and marcophytes could be quite different and thus, have large effects on fish populations.

Besides habitat differences between Salmon Bay and other areas in the LWSC, there may be differences in water quality. Recent research by Houck and Crawford (2003) indicated that dissolved copper in Salmon Bay occasionally exceeds chronic criteria, primarily during the summer. Dissolved copper in other areas of the LWSC were substantially lower than Salmon Bay and did not exceed chronic criteria. The use of anti-fouling paint on large vessels in Salmon Bay has been suggested as the source of the copper. The high levels of copper are probably not a serious problem for anadromous salmonids, which only spend a short time period in Salmon Bay. However, it may be a significant factor for resident fish such as bass and northern pikeminnow. Additionally, saltwater intrusion in Salmon Bay may increase the salinity and reduce the amount of available habitat to resident fish.

Catch of smallmouth bass was lower in the Fremont Cut than either Lake Union or Portage Bay. Differences may have been due to the lack of structure in Fremont Cut. In Lake Washington, 74% of smallmouth bass were found near structure (Fresh et al. 2001). Most of the Fremont Cut shoreline had only rip rap which may have provided some habitat for some smallmouth bass but did not support the bass abundance that was present in Lake Union or Portage Bay. The size of smallmouth bass and largemouth bass in Fremont Cut was smaller than in Lake Union or Portage Bay. The size of interstitial spaces in the rip rap may provide structure for small bass but may be too small for large fish.

Catch of northern pikeminnow was considerably lower than that of smallmouth bass or largemouth bass. Differences were probably due to sampling gear bias and not necessarily due to differences in overall abundance. Northern pikeminnow probably inhabited deeper water than bass and thus may not have been effectively sampled by electrofishing equipment. This equipment can effectively sample fish to 2 m depth (depending on water clarity) and can often sample fish between 2 and 3 m deep. Below 3 m, the effectiveness of the equipment is problematic. In free-flowing sections of the Snake River and Columbia River, northern pikeminnow spend 60% of their time in water less than 3 m deep; whereas, smallmouth bass spend over 90% of their time in water less than 3 m. (Petersen et al. 2000) . Brocksmith (1999) found that northern pikeminnow in Lake Washington at night were in 12 m deep water in April and 3 m deep water in May. In 1995 and 1996, we repeatedly sampled around the Cedar River delta with an electrofishing boat and no northern pikeminnow were ever collected. However, large numbers of northern pikeminnow were caught in 1996 with gill nets. Most were caught on the bottom in 14 to 20 m deep water. Several were also caught in nets set in 2 to 8 m deep water.

Additionally, northern pikeminnow may be more active at night and thus may avoid the electrofishing boat more so than smallmouth bass. Northern pikeminnow have been observed to actively forage at night under low light conditions (Petersen and Gadomski 1994). During nighttime snorkel observations in Lake Washington in late May, smallmouth bass appeared to be inactive and could be caught with hand dip nets (R. Tabor, unpublished data).

Although northern pikeminnow were infrequently collected, they did show distinct preferences for certain areas. They appeared to be caught in areas where they may have high encounter rates with outmigrating smolts. These locations included the outflow of the UW Hatchery, Fremont Cut, and along the shore of Gas Works Park. At the outflow of the university hatchery, we collected several northern pikeminnow very close to the outflow. Unfortunately, we were unable to sample shortly after the hatchery release, but we would expect a number of northern pikeminnow would aggregate at this location shortly after a release. In the Columbia River, norther pikeminnow have been shown to aggregate in areas where salmonid smolts are concentrated and vulnerable to predation such as below dams (Poe et al.1991) and near hatchery release locations (Thompson 1959; Collis et al. 1995).

Another feature about the three main locations where northern pikeminnow were collected was that they were mostly open areas with few piers or docks. The response of northern pikeminnow to overhead structures and other types of structures is not well known. Additionally, the effect that smallmouth bass and largemouth bass have on habitat use by northern pikeminnow is not known. Because smallmouth bass and largemouth bass are somewhat territorial, they may inhibit the use of structure by northen pikeminnow. Further research on northern pikeminnow is needed to understand their habitat use in the LWSC and how shoreline development affects their distribution.

Another location we expected to collect northern pikeminnow was in the Montlake Cut, which is a narrow waterway and smolts may be especially vulnerable to predation by northern pikeminnow. Although we sampled this site three times, no northern pikeminnow were collected. Since the shoreline is essentially a vertical wall with little cover, northern pikeminnow may not inhabit this location or may inhabit deeper waters and thus may not be vulnerable to electrofishing equipment.

POPULATION ESTIMATES

The ratio of mean catch rate to population estimate was similar for all three largemouth bass and two smallmouth bass population estimates. The only location that had a markedly different ratio was north Lake Union. At this site, we appeared to have had a higher than expected number of recaptures. By chance we sampled one of the transects more than the others. This transect was sampled three times while the other transects in north Lake Union were sampled one or two times each. Several recaptures were collected along this transect and probably biased the population estimate. If we apply a similar ratio to north Lake Union the smallmouth bass population estimate is increased by approximately 1,500 fish and the consumption of salmonids is increased by 11,800 smolts (bioenergtics model; 6,250 Chinook salmon, 1,670 coho salmon, and 2,870 sockeye salmon).

An important assumption in our population estimate is that the marked fish were as vulnerable to capture as unmarked fish. Because smallmouth bass (Coble 1975) have been shown to have a restricted home range and usually return to their original home range after being marked (Pflug and Pauley 1983; Fayram and Sibley 2000), each shoreline area should have an equal chance of being sampled during the recapture phase. However, there were large areas we were unable to sample because they were underneath large docks, house boats, or other large structures or boats. On average, we were only able to sample 50% of the shoreline. If bass have a large home range then we can assume that the bass were well distributed along our transects and there was minimal bias in our estimates. However, if bass have a small home range, some percentage of the bass would be unavailable to our electrofishing equipment and we would have underestimated the population size. Kraai et al. (1991) found smallmouth bass in a medium-sized Texas reservoir had a relatively large home range, 1.3 to 43 ha. In contrast, Savitz et al. (1993) found their home ranges in a small Illinois lake were quite small, 0.07 to 0.2 ha. Savitz et al. (1993) also noted that the smallest home range is for males that are guarding their nest. Because our sampling occurred during bass spawning season and we were unable to sample many areas, there is a good chance we have underestimated the population size.

Besides potential bias due to partial sampling of the shoreline, population estimates may also be underestimated if large numbers of bass inhabit the offshore areas. Use of offshore areas has also been documented in smallmouth bass (Fayram 1996) but is usually considered to be a minor part of the population. In an Arizona reservoir, largemouth bass < 250 and > 380 mm inhabited the littoral zone; where largemouth bass 250-380 occurred in open, limnetic waters (Wanjala et al. 1986). In our sampling of the LWSC and Lake Union, we collected largemouth bass that were mostly < 250 or > 380 mm. Thus, there is a possibility that we missed largemouth bass 250-380 mm because they were in offshore areas. Further research on bass movements and behavior is needed to determine their overall distribution.

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REFERENCES

Adams, S.M., R.B. McLean, and M.M. Huffman. 1982. Structuring of a predator population through temperature-mediated effects on prey availability. Canadian Journal of Fisheries and Aquatic Sciences 39:1175-1184.

Baldwin, C.M., D.A. Beauchamp, and J.J. Van Tassell. 2000. Bioenergetic assessment of temporal food supply and consumption demand by salmonids in the Strawberry Reservoir food web. Transactions of the American Fisheries Society 129:429-450.

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, and 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.

Beauchamp, D.A. and J.J. Van Tassell. 2001. Modeling seasonal trophic interactions of adfluvial bull trout in Lake Billy Chinook, Oregon. Transactions of the American Fisheries Society 130:204-216.

Bennett, D.H., J.A. Chandler, and L.K. Dunsmoor. 1991. Smallmouth bass in the Pacific northwest: benefit or liability. Pages 126-135 *in* D.C. Jackson, editor. Proceedings of the first international smallmouth bass symposium. Mississippi Agricultural and Forestry Experimental Station, Mississippi State University, Mississippi State.

Beyer, J.M., G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish (*Ptychocheilus oregonensis*). Canadian Journal of Fisheries and Aquatic Sciences 45:548-553.

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

Boyd, C.E. 1970. Amino acid, protein, and caloric content of vascular aquatic macrophytes. Ecology 51:902-906.

Brocksmith, R. 1999. Abundance, feeding ecology, and behavior of a native piscivore northern pikeminnow (*Ptychocheilus oregonensis*) in Lake Washington. Master's thesis, University of Washington, Seattle.

Bromley, P.J. 1994. The role of gastric evacuation experiments in quantifying the feeding rates of predatory fish. Reviews in Fish Biology and Fisheries 4:36-66.

Coble, D.W. 1975. Smallmouth bass. Pages 21-33 *in* R.H. Stroud and H. Clepper, editors.

Black bass biology and management. Sport Fishing Institute, Washington, DC.

Collis, K, R.E. Beaty, and B.R. Crain. 1995. Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 15:346-357.

Cummins, K.W. and J.C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. International Association of Theoretical and Applied Limnology, Communication 18, Stuttgart, Germany.

Dauble, D.D., T.L. Page, and R.W. Hanf, Jr. 1989. Spatial distribution of juvenile salmonids in the Hanford Reach, Columbia River. Fishery Bulletin 87:775-790.

DeVries, P. 2002. PIT tagging of juvenile salmon smolts in the Lake Washington basin: second year (2001) pilot study results. Report of R2 Resource Consultants to U.S. Army Corps of Engineers, Seattle District, Seattle, Washington

Dickie, L.M. 1971. Mathematical models of growth. Pages 126-130 *in* W.E. Ricker, editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford.

Fayram, A. 1996. Impacts of largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) predation on populations of juvenile salmonids in Lake Washington. Master's thesis, University of Washington, Seattle, Washington.

Fayram A.H. and T.H. Sibley. 2000. Impact of predation by smallmouth bass on sockeye salmon in Lake Washington, Washington. North American Journal of Fisheries Management 20:683-692

Foerster, R.E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bulletin of the Fisheries Research Board of Canada 162.

Foltz, J.W. and C.R. Norden. 1977. Seasonal changes in food consumption and energy content of smelt (*Osmerus mordax*) in Lake Michigan. Transactions of the American Fisheries Society 106:230-234.

Footen, B. and R. Tabor. 2003. Piscivorous impacts on juvenile chinook, Salmon Bay Estuary, the Ship Canal, and Lake Sammamish. Proceedings of the 2003 greater Lake Washington chinook workshop, Shoreline, Washington, January 24, 2003, Seattle Public Utilities, Seattle, Washington.

Fresh, K.L. 2000. Use of Lake Washington by juvenile chinook salmon, 1999 and 2000. Proceedings of the chinook salmon in the greater Lake Washington Watershed workshop, Shoreline, Washington, November 8-9, 2000, King County, Seattle, Washington.

Fresh, K.L., D. Rothaus, K.W. Mueller, and C. Waldbillig. 2001. Habitat utilization by predators, with emphasis on smallmouth bass, in the littoral zone of Lake Washington. Draft report, Washington Department of Fish and Wildlife, Olympia.

Fresh, K.L., S.L. Schroder, and M.I. Carr. 2003. Predation by northern pikeminnow on hatchery and wild coho salmon smolts in the Chehalis River, Washington. North American Journal of Fisheries Management 23:1257-1264.

Grant, J.W.A. and D.L. Noakes. 1987. Escape behaviour and use of cover by young-of-the-year brook trout, *Salvelinus fontinalis*. Canadian Journal of Fisheries and Aquatic Sciences 44:1390-1396.

Hansel, H.C., S.D. Duke, P.T. Lofy, and G.A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Hanson, P.C., T.B. Johnson, D.E. Schindler, and J.F. Kitchell. 1997. Bioenergetics model 3.0 for Windows. University of Wisconsin Sea Grant Institute, Technical report WISCU-97-001, Madison.

Hawkins, S.W. and J.M. Tipping. 1999. Predation by juvenile hatchery salmonids on wild fall chinook salmon fry in the Lewis River, Washington. California Fish and Game 85:124-129.

He, E. and W.A. Wurtsbaugh. 1993. An empirical model of gastric evacuation rates for fish and an analysis of digestion in piscivorous brown trout. Transactions of the American Fisheries Society 122:717-730.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-393 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories, University of British Columbia Press, Vancouver.

Henderson, J.N. and B.H. Letcher. 2003. Predation on Atlantic salmon (*Salmo salar*) fry. Canadian Journal of Fisheries and Aquatic Sciences 60:32-42.

Hillman, T.W. 1989. Nocturnal predation by sculpins on juvenile chinook salmon and steelhead. Pages 249-264 *in* Don Chapman Consultants, Inc. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final Report to Chelan County Public Utility District, Wenatchee, Washington.

Hodgson, J.H., X. He, D.E. Schlinder, and J.F. Kitchell. 1997. Diet overlap in a piscivore community. Ecology of Freshwater Fish 6:144-149.

Houck, D. and B. Crawford. 2003. Overview of toxicity results to migratory adult and juvenile chinook through Lake Union. Proceedings of the 2003 greater Lake Washington chinook workshop at Shoreline, Washington, January 24, 2003, Seattle Public Utilities, Seattle, Washington.

Hubert, W.A. 1977. Comparative food habits of smallmouth and largemouth basses in Pickwick Reservoir. Journal of the Alabama Academy of Science 48:167-178.

Hubert, W.A. and R.T. Lackey. 1980. Habitat of adult smallmouth bass in a Tennessee River reservoir. Transactions of the American Fisheries Society 109:364-370.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. Journal of the Fisheries Research Board of Canada 5:448-457.

Idyll, C. 1942. Food of rainbow, cutthroat and brown trout in the Cowichan River system, B.C. Journal of the Fisheries Research Board of Canada 5:448-457.

Koehler, M.E. 2002. Diet and prey resources of juvenile chinook salmon (*Oncorhynchus tshawytscha*) rearing in the littoral zone of an urban lake. Master's thesis, University of Washington, Seattle.

Kraai, J.E., C.R. Munger, and W.E. Whitworth. 1991. Home range, movements, and habitat utilization of smallmouth bass in Meredith Reservoir, Texas. Pages 44-48 *in* D.C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agriculture and Forestry Experiment Station, Mississippi State University, Mississippi.

Liao, H., C.L. Pierce, and J.G. Larscheid. 2002. Diet dynamics of the adult piscivorous fish community in Spirit Lake, Iowa, USA 1995-1997. Ecology of Freshwater Fish 11:178-189.

Long, J.M. and W.L. Fisher. 2000. Inter-annual and size-related differences in the diets of three sympatric black bass in an Oklahoma reservoir. Journal of Freshwater Ecology 15:465-474.

Mason, J.C. 1974. Aspects of the ecology of juvenile coho salmon (*Oncorhynchus kisutch*) in Great Central Lake, B.C. Fisheries Research Board of Canada Technical Report No. 438.

Mavros, B., S. Foley, K. Burton, and K. Walter. 2000. 1999 chinook salmon survey data technical report for the Lake Washington watershed. King County Department of Natural Resources, Seattle, Washington.

McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. Journal of the Fisheries Research Board of Canada 17:655-676.

McVey, M., K. Hall, P. Trenham, A. Soast, L. Frymier, and A. Hirst. 1993. Wildlife exposure factors handbook, volume 1. Report EPA/600/R-93/187, U.S. Environmental Protection Agency, Washington, D.C.

Mesa, M.G., T.P. Poe, D.M. Gadomski, and J.H. Petersen. 1994. Are all prey created equal? a review and synthesis of differential predation on prey in substandard condition. Journal of Fish Biology 45 (Suppl. A):81-96.

Milick, J.G. 1977. Ecology of benthic insects of the Cedar River, Washington. Doctoral dissertation, University of Washington, Seattle, Washington.

Missildine, B., R. Peters, R. Piaskowski, and R. Tabor. 2001. Habitat complexity, salmonid use, and predation of salmonids at the bioengineered revetment at the Maplewood Golf Course on the Cedar River, Washington. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Office, Lacey, Washington.

Moss, J.H.H. 2001. Development and application of a bioenergetics model for Lake Washington prickly sculpin (*Cottus asper*). Master's thesis, University of Washington, Seattle.

Nilsson, N.A. and T.G. Northcote. 1981. Rainbow trout (*Salmo gairdneri*) and cutthroat trout (*S. clarki*) interactions in coastal British Columbia lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:1228-1246.

Nowak, G.M. 2000. Movement patterns and feeding ecology of cutthroat trout (*Oncorhynchus clarki clarki*) in Lake Washington. Master's thesis, University of Washington, Seattle, Washington.

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

Olney, F.E. 1975. Life history and ecology of the northern squawfish *Ptychocheilus oregonensis* (Richardson) in Lake Washington. Master's thesis. University of Washington, Seattle, Washington.

Olson, M.H. and B.P. Young. 2003. Patterns of diet and growth in co-occurring populations of largemouth bass and smallmouth bass. Transactions of the American Fisheries Society 132:1207-1213.

Patten, B.G. 1971. Predation by sculpins on fall chinook salmon, *Oncorhynchus tschawytscha*, fry of hatchery origin. U.S. National Marine Fisheries Service, Special Scientific Report, Fisheries No. 621.

Pearsons, T.N. and A.L. Fritts. 1999. Maximum size of chinook salmon consumed by juvenile coho salmon. North American Journal of Fisheries Management 19:165-170.

Petersen, J.H., C.A. Barfoot, S.T. Sauter, D.M. Gadomski, P.J. Connolly, and T.P. Poe. 2000. Predicting the effects of dam breaching in the lower Snake River on losses of juvenile salmonids to predators. Report of U.S. Geological Survey, Columbia River Research Laboratory to U.S. Army Corps of Engineers, Walla Walla, Washington.

Petersen. J.H. and D.M. Gadomski. 1994. Light-mediated predation by northern squawfish on juvenile chinook salmon. Journal of Fish biology 45(supplement A):227-242.

Petersen, J.H., D.M. Gadomski, and T.P. Poe. 1994. Differential predation by northern squawfish (*Ptychocheilus oregonensis*) on live and dead juvenile salmonids in the Bonneville Dam tailrace (Columbia River). Canadian Journal of Fisheries and Aquatic Sciences 51:1197-1204.

Petersen, J.H. and D.L. Ward. 1999. Development and corroboration of a bioenergetics model for northern pikeminnow feeding on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 128:784-801.

Pflug, D.E. 1981. Smallmouth bass (*Micropterus dolomieui*) of Lake Sammamish: a study of their age and growth, food and feeding habitat , population size, movement and homing tendencies, and comparative interactions with largemouth bass. Master's thesis, University of Washington, Seattle, Washington.

Pflug D.E. and G.B. Pauley. 1983. The movement and homing of smallmouth bass, *Micropterus dolomieui*, in Lake Sammamish, Washington. California Fish and Game 69:207-216.

Poe, T.P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420.

Purcell, M., G. Mackey, E. LaHood, H. Huber, and L. Park. 2004. Molecular methods for the genetic identification of salmonid prey from Pacific harbor seal (*Phoca vitulina richardsi*) scat. Fishery Bulletin 102:213-220.

Rand, P.S., D.J. Stewart, P.W. Seelbach, M.L. Jones, and L.R. Wedge. 1993. Modelling steelhead population energetics in lakes Michigan and Ontario. Transactions of the American Fisheries Society 52:1546-1563.

Regier, H.A. and D.S. Robson. 1967. Estimating population number and mortality rates. Pages 31-66 in S.D. Gerking, editor. The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford, UK.

Reimers, P.E. 1989. Management of wild and hatchery coho salmon in the Tenmile Lakes system. Information Report 89-5, Oregon Department of Fish and Wildlife, Portland, Oregon.

Rice, J.A., J.E. Breck, S.M. Bartell, and J.F. Kitchell. 1983. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. Environmental Biology of Fishes 9:263-275.

Rickard, N.A. 1980. Life history and population characteristics of the prickly sculpin (*Cottus asper* Richardson) in Lake Washington. Master's thesis. University of Washington, Seattle.

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

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Roell, M.J. and D.J. Orth. 1993. Trophic basis of production of stream-dwelling smallmouth bass, rock bass, and flathead catfish in relation to invertebrate bait harvest. Transactions of the American Fisheries Society 122:46-62.

Rogers, J.B. and C.C. Burley. 1991. A sigmoid model to predict gastric evacuation rates of smallmouth bass (*Micropterus dolomieui*) fed juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 48:933-937.

Rondorf, D.W., M.S. Dutchuk, A.S. Kolok, and M.L. Gross. 1985. Bioenergetics of juvenile salmon during the spring outmigration, annual report 1983. Report of U.S. Fish and Wildlife Service, Cook, Washington to Bonneville Power Administration, Portland, Oregon.

Rottiers, D.V. and R.M. Tucker. 1982. Proximate composition and caloric content of eight Lake Michigan fishes. Technical paper 108, U.S. Fish and Wildlife Service, Washington, D.C.

Savitz, J., L.G. Bardygula, T. Harder, and K. Stuecheli. 1993. Diel and seasonal utilization of home ranges in a small lake by smallmouth bass (*Micropterus dolomieui*). Ecology of Freshwater Fish 2:31-39.

Schuett-Hames, D, A. Pleus, L. Bullchild, and S. Hall. 1994. Ambient monitoring program manual. Timber-Fish-Wildlife report TFW-AM9-94-001, Northwest Indian Fisheries Commission, Lacey, Washington.

Seiler, D., G. Volkhardt, and L. Kishimoto. 2003. Evaluation of downstream migrant salmon production in 1999 and 2000 from three Lake Washington tributaries: Cedar River, Bear Creek, and Issaquah Creek. Washington Department of Fish and Wildlife, Olympia, Washington.

Sherstyuk, V.V. 1978. Some biochemical indicators and caloric content of the eggs of phytophilous fish. Hydrobiological Journal 14:54-57.

Shively R.S., T.P. Poe, and S.T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society 125:230-236.

Shrader, T. and B. Moody. 1997. Predation and competition between largemouth bass and hatchery rainbow trout in Crane Prairie Reservoir, Oregon. Information report 97-1, Oregon Department of Fish and Wildlife, Portland.

Stein, J.N. 1970. A study of the largemouth bass population in Lake Washington. Master's thesis. University of Washington, Seattle, Washington.

Stewart, D.L. and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. Canadian Journal of Fisheries and Aquatic Sciences 48:909-922.

Tabor, R.A. and J. Chan. 1996a. Predation on sockeye salmon fry by cottids and other predatory fishes in the lower Cedar River, 1996. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington.

Tabor, R.A. and J. Chan. 1996b. Predation on sockeye salmon fry by piscivorous fishes in the lower Cedar River and southern Lake Washington. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington.

Tabor, R.A., and J. Chan. 1997. Predation on sockeye salmon fry by piscivorous fishes in southern Lake Washington, 1996. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington.

Tabor, R.A., J. Chan, and S. Hager. 1998. Predation on sockeye salmon fry by cottids and other predatory fishes in the Cedar River and southern Lake Washington. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Lacey, Washington.

Tabor, R.A., S. Hager, A. Hird, and R. Piaskowski. 2001. Predation on juvenile salmonids by predatory fishes in the lower Cedar River, 1999. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Office, Lacey, Washington.

Tabor, R.A. and R.M. Piaskowski. 2002. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin, annual report, 2001. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R.A. and J.A. Scheurer, H.A. Gearns, and E.P. Bixler. 2004. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin, annual report, 2002. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R.A., R.S. Shively, and T.P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

Thompson, R.B. 1959. Food of the squawfish *Ptychocheilus oregonensis* (Richardson) of the lower Columbia River. Fishery Bulletin 60:43-58.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Wanjala, B.S., J.C. Tash, W.J. Matter, and C.D. Ziebell. 1986. Food and habitat use by different sizes of largemouth bass (*Micropterus salmoides*) in Alamo Lake, Arizona. Journal of Freshwater Ecology 3:359-369.

Warner, K. 1972. Further studies of fish predation of salmon stocked in Maine lakes. Progressive Fish Culturist 34:217-221.

Webb, P.W. 1976. The effect of size on the fast-start performance of rainbow trout, *Salmo gairdneri*, and a consideration of piscivorous predator-prey interactions. Journal of Experimental Biology 65:157-177.

Weitkamp, D. and G. Ruggerone. 2000. Factors affecting chinook populations. Report to the City of Seattle, Seattle, Washington.

Wurtsbaugh, W. and R. Tabor. 1989. Effects of fish predation on the survival of rainbow trout fingerlings in Causey Reservoir, Utah. Annual progress report (Project F-47-R-2) of Utah State University to Utah Division of Wildlife Resources, Salt Lake City.

Wydoski, R.S. and R.R. Whitney. 2003. Inland fishes of Washington. University of Washington Press, Seattle.

Zar, J.H. 1984. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Appendix A. Caloric densities (J/g) of various prey consumed by predatory fishes in the Lake Washington basin. The caloric densities are the values used in bioenergetics models.

Prey type	**Caloric density (J/g)**	**Source(s)**
Fish		
Chinook salmon	4,602	Rondorf et al. 1985
Sockeye salmon	5,333	Beauchamp et al. 1989
Other salmonids	5,770	Beauchamp and VanTassell 2001
Longfin smelt	5,774	Holtz and Norden 1977; Rottiers and Tucker 1982; Hanson et al. 1997
Cyprinidae - all species	5,218	Baldwin et al. 2000; Beachamp and VanTassell 2001
Yellow perch	2,512	Hanson et al. 1997
Sculpin (Cottidae)	4,532	Moss 2001
Unidentified fish (used sculpin value)	4,532	Moss 2001
Larval fish	3,698	Hanson et al. 1997
Fish eggs	7,379	Cummins and Wuychuck 1971; Sherstyuk 1978; Beachamp 1995
Crustaceans		
Crayfish	2,963	Cummins and Wuychuck 1971
Neomysis	3,642	Hanson et al. 1997
Daphnia	3,800	Beauchamp et al. 1995
Other crustaceans	3,344	Hanson et al. 1997
Insects		
Chironomid pupae	2,745	Cummins and Wuychuck 1971
Other aquatic insects	5,648	Roell and Orth 1993
Other		
Oligochaetes	3,180	Cummins and Wuychuck 1971
Other invertebrates	4,184	Beauchamp and VanTassell 2001
Other (detritus, aquatic macrophytes, and other material)	3,000	Boyd 1970; Cummins and Wuychuck 1971; McVey et al. 1993