Arrival Patterns and Movements of Adult Sockeye Salmon in Lake Washington: Implications for Management of an Urban Fishery

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Abstract.—The Lake Washington watershed in Washington State has several discreet breeding populations of sockeye salmon Oncorhynchus nerka that return over the course of several months and remain in the lake for up to 6 months before spawning. Depending on the arrival timing and distribution of sockeye salmon in the lake, in-lake fisheries might disproportionately exploit one population or another and might select individuals from within populations having traits that covary with arrival timing (e.g., age, size, and sex). We applied disk tags to adult sockeye salmon as they entered the lake in 2003 and 2004 and tracked individual fish with ultrasonic transmitters. Recovery rates of disk-tagged fish declined over the course of both seasons and were lower in 2004 than in 2003, suggesting that prespawning mortality was occurring because of high water temperatures. Arrival timing did not vary consistently between populations and was at most weakly correlated with life history traits (older fish tended to arrive earlier). Ultrasonic transmitters revealed that individual sockeye salmon were distributed throughout the lake in the early summer but gradually congregated near the mouth of their natal stream in the fall. Fisheries are therefore likely to exploit the populations in proportion to their overall abundance without selecting strongly for spawning date or life history traits, tending to minimize evolutionary effects within populations. However, the expansion of a hatchery on the river with the largest population has been proposed; if fisheries increase to take advantage of the enhanced population, they may have a disproportionate effect on the smaller wild populations in other tributaries.

Achieving desired harvest levels in mixed-stock fisheries is a common challenge for management. If species or populations of fish differ markedly in size, shape, or behavior, then selective fishing may be accomplished by gear modifications, restricted areas, or temporal closures (Jennings et al. 2001). If populations or species differ in migration patterns, spatial and temporal closures can allow managers to avoid the overexploitation of the less-abundant or less-productive group. For example, three distinct stocks of lake whitefish Coregonus clupeaformis in Lake Michigan inhabited different parts of the lake, so regional rather than lakewide management was beneficial (Scheerer and Taylor 1985). However, the homeward migration routes of population complexes of Pacific salmon Oncorhynchus spp. often overlap greatly at sea and in river systems (Quinn 2005), posing challenges for managers seeking sustainable fishing rates (National Research Council 1996). This can be especially problematic in situations where a smaller or less-productive population is fished in common with a larger or more-productive population. As salmon populations migrate towards their respective natal river systems, some spatial separation usually occurs, but this facilitates management only if the fishing takes place beyond the point at which the populations diverge.

Natural differences in run timing can sometimes be used to allow selective exploitation of salmon populations with similar spatial distributions. For example, populations of sockeye salmon O. nerka that spawn in different parts of the Fraser River, British Columbia, show distinct patterns of arrival in freshwater, upriver migration, and spawning (Killick 1955), and the differences are key elements in the successful management of these populations (Woodey 1987). Likewise, populations of Chinook salmon O. tshawytscha...
breeding in different parts of a river system often have distinct arrival patterns (e.g., Kenai River: Burger et al. 1985; Columbia River: Keefer et al. 2004). However, many populations remain mixed as they migrate to their spawning streams. For example, enhanced and unenhanced runs of sockeye salmon return to the mouth of the Skeena River, British Columbia, at the same time, making it difficult to focus fishing efforts on any single population (McDonald 1981). In addition, these sockeye salmon are intermingled with other salmonid species (Sprout and Kadowaki 1987), further complicating fishery management. Within a single lake system, salmon populations that spawn in discrete habitats at different times may enter simultaneously (e.g., Iliamna Lake, Alaska: Jensen and Mathisen 1987) or may exhibit marked segregation in timing of migration (e.g., Bear Lake, Alaska: Boatright et al. 2004). Therefore, the tendency of populations to segregate or intermingle during migration must be determined for each population complex and cannot be assumed on the basis of studies conducted elsewhere.

Return timing and spawning dates are under genetic control in salmon (Smoker et al. 1998; Quinn et al. 2000; Sato et al. 2000), though environmental conditions also play a role (Hodgson et al. 2006). Adults migrate when environmental conditions such as temperature and flow are most suitable for their survival, and they spawn when temperature and flow will optimize survival of embryos and juveniles (Brannon 1987). Consequently, some populations return to freshwater long in advance of spawning to avoid potentially lethal high temperatures later in the season (Hodgson and Quinn 2002; Quinn 2005). Not only are the patterns of migration and spawn timing important characteristics of salmonids, but other traits (e.g., age, size, energy content, and sex) are often correlated with run timing (Quinn 2005). For example, older, larger Atlantic salmon *Salmo salar* often return to freshwater before the smaller, younger individuals (Shearer 1990); similar but less-dramatic differences are also known in Pacific salmon (e.g., Molyneaux and DuBois 1998). Because traits such as size and age at maturity are heritable, the timing of a fishery may disproportionately take one part of a population—such as larger and older fish—and leave a greater proportion of another group (e.g., the smaller, younger fish) to spawn.

In recent decades, artificial propagation to supplement salmonid populations has increased as part of efforts to compensate for habitat loss, enhance fishing success, or achieve other goals (Mahnken et al. 1998). Hatchery populations can often sustain higher harvest rates because fewer gametes (and therefore fewer adults) are required for a given level of juvenile production relative to the gamete requirements of wild populations (National Research Council 1996). However, if hatchery and wild stocks cannot be differentiated (e.g., by external marking) or are not separated in space or time, then wild stocks could be overharvested if fishing rates are set to maximize harvest of the hatchery population (Wright 1981).

The sockeye salmon spawning in the Lake Washington system in Washington State (Figure 1) presents significant management challenges that exemplify the problems described above. There are several distinct spawning populations, the largest of which is also enhanced by a hatchery. Sockeye salmon enter Lake

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**FIGURE 1.—**Map of Washington State and the Lake Washington watershed, where the arrival timing and movements of sockeye salmon were studied in 2003 and 2004.
Washington from late May to late August, and arrival peaks in early July (Hodgson and Quinn 2002). The fish hold in the lake below the thermocline all summer (Newell and Quinn 2005) and spawn in September–January. The great majority (annual 1997–2004 average = 85%) of Lake Washington sockeye salmon return to the Cedar River, which flows into the south end of the lake. The rest spawn in tributaries that enter the north end of the lake and along some of Lake Washington’s beaches. In 2003 and 2004, the Cedar River spawner proportions were 97% and 88%, respectively (Steve Foley, Washington Department of Fish and Wildlife [WDFW], Mill Creek, personal communication).

Sport and tribal commercial fisheries for sockeye salmon occur intermittently in Lake Washington, in nearby portions of Puget Sound, and in the waterway between the lake and Puget Sound; fisheries are allowed when the number of sockeye salmon entering Lake Washington is projected to exceed the escapement goal of 350,000. In an effort to stabilize declining populations and increase the number of sockeye salmon available for fisheries, a temporary hatchery was established in 1991 on the Cedar River and currently incubates up to 17 million eggs annually. The hatchery’s capacity is proposed to increase to 34 million eggs with the construction of a permanent facility. Because the hatchery-produced fry cannot be externally marked, fisheries cannot selectively release wild sockeye salmon and retain hatchery-produced fish. Without knowing the spatial or temporal migration patterns of the different populations within the lake, fisheries implemented to fully harvest the more robust Cedar River population could disproportionately affect the smaller and less-productive wild populations and could also select for certain life history traits that covary with timing.

To facilitate management of Lake Washington sockeye salmon, we addressed the following questions related to the time of entry into the lake and movements within it. First, do the north- and south-end populations differ in timing of arrival to freshwater? If so, managers could open a fishery at a time when the lake contains mostly the enhanced Cedar River population. Second, is entry into the lake related to spawning date? If migration timing and spawn timing are correlated, then fisheries might affect the overall temporal distribution of the populations. Third, is entry timing related to the size, sex, or age of the fish? Such information would help managers determine whether and how population traits are affected if a segment of the run is fished at a higher rate. Fourth, are the sockeye salmon originating from north- and south-end spawning areas segregated or mixed in the lake before spawning? If they segregate, spatial closures might help protect the less-productive northern populations. Finally, although we did not estimate survival between lake entry and spawning, our results revealed patterns of mortality apparently related to thermal conditions.

**Methods**

In 2003, 1,815 adult sockeye salmon were tagged between 12 June and 19 August; in 2004, 2,996 were tagged between 15 June and 10 August. Tagged fish made up 0.84% of the run in 2003 and 0.74% in 2004, based on estimates at the Hiram M. Chittenden Locks (Muckleshoot Indian Tribal Fisheries Office, unpublished data); the temporal distribution of tagging was approximately proportional to the run. Fish were trapped in the fish ladder at the locks (Figure 1), transferred to a trough padded with foam, and bathed in a continuous flow of water. Two 19-mm disk tags printed with a unique number and address for tag return were attached below the dorsal fin with a nickel pin. Date, time of capture, sex, and fork length were recorded for all fish, and a scale sample for age determination was taken from every third fish to assure a random sample. After tagging, the fish were held by hand in the water on the upstream side of the ladder until they swam away vigorously.

Disk tags were recovered from carcasses on the spawning grounds and from live fish trapped at the Cedar River hatchery’s broodstock collection weir. The weir was located 10.2 km upstream from the lake and generally operated during mid-September through mid-November, depending on flows. Crews from WDFW floated the Cedar River several times per week during early October through December to recover tags (Figure 1). Additionally, some stretches of the Cedar River system that were not suitable for rafting (including a spawning channel at Ron Regis Park) were surveyed by foot frequently during the spawning season. Bear and Cottage Lake creeks were walked approximately once per week during the spawning season (late-September–October) in both 2003 and 2004. The East Fork of Issaquah Creek was also surveyed approximately every 1–2 weeks during these months. Tags collected from the sport and commercial sockeye salmon fisheries in 2004 were subtracted from the total tagged that year for purposes of analysis.

A subsample of the fish (30 in 2003; 78 in 2004) also received acoustic transmitters (Vemco, Inc.) inserted into the stomach. The battery life of tags used in 2003 was 80 d; in 2004, tag life was 280 d. All tags had an individual code that could be identified with a hydrophone, and each tag was tested before deployment. Acoustic receivers were placed around the Lake Washington basin to detect and record fish swimming.
within a radius of approximately 500 m around the receiver. In 2003, two receivers were placed on the north side of the Evergreen Point bridge (State Road [SR] 520), two on the south side of the Interstate-90 (I-90) bridge, one at the mouth of the Sammamish River at the north end of the lake, and one at the mouth of the Cedar River (Figure 1). In 2004, we placed an additional receiver on SR-520, one on a buoy east of Sand Point, and an additional five receivers on the Cedar River to record fish movements into and up the river (Figure 1). Data (date, time, and individual code of any detected fish) were downloaded monthly from the receivers onto a PC. Receivers were deployed between 19 June and 2 July in 2003 and were retrieved on 11 December 2003. In 2004, we set out the receivers on 28 June. Two receivers were lost; data were last downloaded on 3 August from the receiver east of Sand Point and on 29 September from the receiver on the west end of I-90. The other receivers were recovered on 20 November. Receivers placed on SR-520 and on the buoy in the north end of the lake were considered the “north receivers,” and those on the I-90 bridge were the “south receivers.”

In addition to the stationary receivers, we used a mobile receiver on a boat to search for fish in the lake. Three survey routes were run two or three times per week from mid-July to September in 2003 and from August to September in 2004; the surveyed areas were situated (1) north of SR-520, (2) south of SR-520 and west of Mercer Island, and (3) south of SR-520 and east of Mercer Island. On each route, we stopped at predetermined locations and recorded any detectable transmitter codes before moving to the next station. To maximize the probability of detecting fish, we chose locations that were close enough that a fish detected at the edge of one location might be detected at another (i.e., overlapping ranges of the circles of detection).

The diverse data collected in this study were analyzed in various ways depending on the objectives. Because arrival timing data approximated normal distributions, we used unpaired t-tests to examine the null hypothesis that fish subsequently recovered in the Cedar River and north-end tributaries had entered with similar timing (day of the year). Linear regression analysis was used to determine whether the arrival date at the locks was correlated with the date of entry onto the spawning grounds. For this analysis, we used only data on fish trapped at the weir on the Cedar River because this provided a standard point of arrival on the spawning grounds, unlike recoveries of live and dead fish, for which the entry date could not be known precisely. To test the null hypothesis that size would not vary over the migration period, we used linear regression after separating the data by age and sex in each year. Age composition data were presented as the cumulative proportion that arrived by a given date because this reflects the population of fish that would be vulnerable to fishing on that date. The data on in-lake movements, detected by a combination of fixed and mobile receivers were used to determine the spatial and temporal patterns of movement within the lake by fish that subsequently ascended the Cedar River or one of the north-end tributaries. Specifically, we were interested in the extent to which there was a seasonal progression of spatial segregation in the lake related to the eventual spawning areas. Finally, using a chi-square test, we compared the proportions of sockeye salmon with disk tags and transmitters that were recovered and detected, respectively, in 2003 and 2004.

**Results**

**Traits Associated with Migration Timing**

To determine whether the spawning populations differed in arrival timing, we examined data from north-end populations (combined \( n = 10 \) recoveries each in 2003 and 2004) and the Cedar River (\( n = 246 \) in 2003 and 203 in 2004). According to these data, 50% of Cedar River fish had entered freshwater (i.e., the median date) by 6 July in 2003, but the median arrival date of north-end fish was not until 29 July (Figure 2). A t-test of these results revealed a significant mean difference (16 d) between median entry dates of these two populations \((P = 0.004)\). However, this difference was not seen in 2004, when the median entry dates were 1 July for Cedar River fish and 29 June for north-end fish. The mean difference in median entry date for the two populations in 2004 was only 1.8 d \((P = 0.733)\). Recoveries from the north-end population complex were too few for statistical analysis; in 2003, there were six recoveries from Lake Sammamish itself (fisheries), two from Cottage Lake Creek, and one each from the Bear and Issaquah Creek systems. In 2004, there were eight recoveries from the Issaquah Creek system and two from the Bear Creek system.

Based on data from tagged fish caught at the Cedar River hatchery weir, entry and spawning dates were not linearly related in either 2003 \((n = 65, P = 0.78)\) or 2004 \((n = 95, P = 0.19)\). No nonlinear relationships were evident (Figure 3). For example, fish tagged in early July were recovered at the Cedar River weir from mid-September to mid-November in both years.

The age distribution (as inferred from scale analysis) indicated that older fish arrived earlier. The proportions of age-5 fish entering at the beginning of summer in 2003 and 2004 were higher than the final proportions (Figure 4). For example, by late June 2003, approximately 65% of the males that had returned to Lake
Washington were age 5; however, by the time the run was complete, only 45% of the fish were age 5, indicating an increased proportion of younger fish later in the run. The average length at a given age increased slightly over the migration period in 2004 for age-4 males (0.50 mm/d; \( P < 0.001, r^2 = 0.041 \)), age-5 males (1.16 mm/d; \( P < 0.001, r^2 = 0.154 \)), and age-4 females (0.43 mm/d; \( P < 0.001, r^2 = 0.036 \)). In 2003, however, size at age was not correlated with arrival date for any combination of age and sex. In 2003, the proportion of males entering the Lake Washington system increased slightly as the season progressed (slope = 0.003, \( P = 0.001, r^2 = 0.327 \)), but no trend was evident in 2004 (\( P = 0.362 \)).

**In-Lake Movements**

We located 29 of the 30 tagged fish released with transmitters in 2003 and 36 of the 78 tagged fish released in 2004. The mobile receivers detected 22 fish in 2003 and 22 in 2004. Fixed receivers at the mouth of the Cedar River detected only 3 fish ascending in 2003 and 18 in 2004. Five fish tagged with transmitters were recovered at the weir or as carcasses in 2003, but none of the transmitter-tagged fish was recovered in 2004.

No fish were detected entering the Sammamish River, as would be necessary to reach the north-end tributaries, and no tagged fish with transmitters were recovered from north-end tributaries. Thus, movement data were available only for Cedar River fish.

In both years, total detections of fish increased as fish entered the lake but decreased as they ascended the Cedar River to spawn. There was also a progressive shift from fish utilizing the entire lake early in the season (though no fish was detected at the northernmost stationary receiver in the lake) to greater use of the south end of the lake later in the season (Figure 5). In 2003, most fish were initially detected north of SR-520 on the stationary receivers but their final detections occurred in the south end of the lake. All of the 29 initial detections north of SR-520 were made 1–21 d after tagging (mean = 5.8 d, SD = 5.9 d, median = 4 d). Of the 29 fish detected, 25 were later found south of SR-520 and 4 were detected only in the north end of the lake. Ten fish swam back and forth under SR-520 at least three times; nine of these fish had final detections in the south end of the lake. Of those nine, three were still in the north end of the lake after 1 September. Fifteen fish swam from the north end of the lake to areas south of the bridge and were never again detected in the north.

The results in 2004 were similar to those in 2003; most fish were first detected north of SR-520, but their
final detections occurred in the south end of the lake. The first detections of the 36 fish occurred between 1 and 134 \(\text{d} \) after tagging (mean = 17.66 \(\text{d} \), SD = 27.6 \(\text{d} \), median = 6.5 \(\text{d} \)). Of these, 17 fish were detected south of SR-520 and no subsequent northern detections were made. Fifteen fish moved under the bridge more than once; 12 of these fish had their final detections in the south end of the lake. Eight of the 12 fish occupied the north end of the lake on or after 1 September, and 3 were detected there in October. Four fish were never detected south of SR-520. Eight fish were detected swimming up the Cedar River; one of these entered the river on 11 October 2004, left the river on 17 October, and was detected north of SR-520 on 18 October.

Data from tracking with the mobile receiver corroborated the results from fixed receivers. In both years, detections with the mobile receiver were scattered throughout the lake for the first 2 months of tracking but then were concentrated south and west of Mercer Island in September. We divided the lake into three sections, using the bridges as borders for each section: north of SR-520 (north), between SR-520 and the I-90 bridge (middle), and south of the I-90 bridge (south). We considered each transect point visited in each section on a given day to be one unit of effort. In both years, detections with the mobile receiver were scattered throughout the lake for the first 2 months of tracking but then were concentrated south and west of Mercer Island in September. We divided the lake into three sections, using the bridges as borders for each section: north of SR-520 (north), between SR-520 and the I-90 bridge (middle), and south of the I-90 bridge (south). We considered each transect point visited in each section on a given day to be one unit of effort. In both years, detections with the mobile receiver were scattered throughout the lake for the first 2 months of tracking but then were concentrated south and west of Mercer Island in September. We divided the lake into three sections, using the bridges as borders for each section: north of SR-520 (north), between SR-520 and the I-90 bridge (middle), and south of the I-90 bridge (south). We considered each transect point visited in each section on a given day to be one unit of effort.
the north. In 2004, detection rates were highest in the south end of the lake in both August and September and increased in all sections over time.

Fish did not move quickly during any part of the tracking season. Only once did we observe a fish moving during the mobile tracking surveys. A fish detected on the northwest side of Mercer Island was found 4 h later at the south end of the island, about 9 km away. Otherwise, fish were generally found in approximately the same location for several days before moving to another part of the lake.

Recovery Rates

We did not seek to estimate mortality of adult sockeye salmon in the lake before spawning. However, we observed trends in the recovery rate of tagged fish over the course of both seasons and a difference between years that suggested possible mortality patterns. Notably, the percentage of sockeye salmon tagged at the locks and recovered in any of the spawning sites decreased from about 19% during late June in 2003 to 7.5% by the end of the tagging period (Figure 6). The overall recovery rate in 2004 (7.4%) was lower than that in 2003 (17.9%, \( P < 0.0001 \)), and the 2004 recovery rate decreased from 9.8% to 0.90% during the season. The decreases in recovery rate coincided with increases in water temperature (daily mean of hourly records from a sensor located 5.2 m below the water’s surface in the large lock: U.S. Army Corps of Engineers, unpublished data) within each season (Figure 6), and the lower recovery rate in 2004 coincided with warmer temperatures. Temperatures were similar between years after mid-July, but a lower proportion of tagged fish was recovered in 2004. The effort expended to recover tags was similar between years, so the lack of recoveries from the late part of the migration period was not a consequence of sampling bias. Moreover, a much lower percentage of transmitter-tagged fish was detected in the lake in 2004 (46.2%) than in 2003 (93.3%, \( P < 0.0001 \)) despite the presence of additional receivers in 2004, which should have increased the detected percentage. In an effort to locate these “missing” fish, we searched the area below the locks with a mobile receiver and found 10 fish that were not subsequently detected in the Lake Washington system. Repeated detections of these transmitters strongly indicated either that the fish were dead or that the tags had been regurgitated.

Discussion

In many salmon population complexes, the arrival sequence of discrete breeding units is a key component of fishery management (e.g., Fraser River: Killick 1955; Woodey 1987). This linkage between migration and spawn timing can occur even in systems with a single lake, such as Bear Lake, Alaska (Boatright et al. 2004). If the sockeye salmon spawning in the Cedar River (including the hatchery) had consistently entered the Lake Washington system earlier (or later) than the smaller populations of wild sockeye salmon spawning in the tributaries at the north end of the lake, then fishing periods could be designed to reduce harvest rates on northern populations. The Cedar River fish entered earlier than the north-end fish in 2003 but not in 2004. In the absence of further information, the conservative conclusion from a statistical standpoint is that the populations have similar migratory timing and that temporal closures are unlikely to protect populations from the north-end tributaries. However, given the desirability of protecting those smaller populations from overfishing, it seems appropriate to conclude that they may differ in timing and that further research will be needed to determine which year (2003 or 2004) displayed the more representative pattern. Furthermore, the conclusion that the populations did not differ in timing in 2004 was based on the fish that were recovered (rather than, for example, genetic analysis of fish sampled as they entered the lake), and recovery rate varied with arrival date. If the late-arriving north-end sockeye salmon died before spawning (especially in 2004), then the only recovered representatives of these populations would have been those that entered early, and a difference might have been masked.

We also detected no correlation between the dates of arrival and spawning within the Cedar River population. In contrast to sockeye salmon in the northern part of the species’ range, Lake Washington sockeye salmon return to freshwater several months in advance of spawning, apparently to avoid the warm tempera-
Significant trends were detected in age composition, size at age, and sex ratio for at least some combinations of sex, age, and year. However, the correlations were generally very weak (i.e., date explained little of the overall variation in the trait) and were largely determined by differences early in the season, when relatively few fish were arriving. Therefore, our results suggest that fisheries would not strongly affect the trait distribution of the populations. In general, decisions about whether or not to open fisheries in this system and how many sockeye salmon can be caught are based on historic run timing patterns and in-season assessments. As a result, fisheries do not occur at the very beginning of the run; by the time an opening occurs (typically in mid-July), the lake already contains a considerable diversity of sockeye salmon in terms of size, age, population composition, and eventual spawning dates.

The movements of individual sockeye salmon in the lake and their eventual recovery locations indicated that we probably implanted transmitters only in Cedar River fish. In general, the fish were broadly distributed when they entered the lake; about half of the detections in July occurred in the northern part of the lake. Later in the summer, migration of fish towards the southern area of the lake was gradual rather than abrupt. In both years, the Cedar River fish were broadly distributed in the lake in July and August, when fisheries might occur. Therefore, if north-end fish migrated to the south to the same extent that south-end fish migrated to the north, spatial closures (e.g., north of the SR-520 bridge) would probably not be effective in reducing fishing pressure on north-end populations. In the future, if many sockeye salmon return and fishing rates are high, it will be particularly important to monitor the smaller systems to ensure that sufficient numbers of spawners are reaching these areas to sustain the populations.

Finally, although it was not our goal to estimate the levels and patterns of prespawning mortality, the proportion of tagged fish that were recovered declined over time in both years, coinciding with increasing temperatures. In addition, the recovery rate was much lower in 2004 than in 2003, and temperature rose more rapidly in 2004. Not only were fewer tagged fish recovered on spawning grounds in 2004 than in 2003, but also far fewer fish with transmitters were detected in the lake in 2004 (46% versus 97%) despite the greater receiver coverage. We cannot determine the fate of fish that were not recovered or detected; we also cannot determine whether the survival rates of untagged fish were similar to those of the fish we handled. However, many sockeye salmon populations at the southern end of the species’ distribution, including Lake Washington, migrate into freshwater before temperatures peak along the migratory corridor (Hodgson and Quinn 2002). Migratory patterns (e.g., Major and Mighell 1967; Quinn and Adams 1996) indicate avoidance of high temperatures, and elevated prespawning or en route mortality rates have been associated with high temperatures in the Fraser River (Gilhousen 1990) and Columbia River (Naughton et al. 2005) systems.

The low recovery rate of tagged sockeye salmon in 2004 was consistent with other, albeit indirect, evidence that significant prespawning mortality took place (Eric Warner, Muckleshoot Tribal Fisheries Department, personal communication). Estimates of sockeye salmon runs, whether based on counts at the locks, in freshwater fisheries, or on the spawning grounds, are neither completely accurate nor precise. All use different methodologies, and some difference between the count at the locks and the sum of in-lake catch and spawning ground counts is normal. However, in 2004 the discrepancy was the greatest on record; almost 200,000 more sockeye salmon were estimated at the locks than were subsequently accounted for. Moreover, dead and moribund sockeye salmon were seen both below and above the locks in 2004. The number of carcasses was insufficient to account for this level of loss; however, most dead salmon sink rather than float, so it was not possible to determine the true number. Summer temperatures in Lake Washington and nearby streams have shown a warming trend over the past several decades (Quinn et al. 2002; Winder and Schindler 2004); thus, to the extent that the Lake Washington populations are experiencing thermal stress, conditions in the future may worsen.

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