Straying of adult sockeye salmon, *Oncorhynchus nerka*, entering a non-natal hatchery

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Salmonid fishes tend to return to their natal site ("home") for reproduction (topic reviewed by Quinn and Dittman, 1992; Quinn, 1993). Odors learned by juveniles during freshwater residence and downstream migration guide adults during the final stages of homing migration (Hasler and Scholz, 1983; Dittman and Quinn, 1996), although adults also respond to spawning site characteristics (Blair and Quinn, 1991) and odors of conspecifics (Newcombe and Hartman, 1973; Honda, 1982; Groot et al., 1986). However, some salmonids do not return to their natal site, but instead "stray" and spawn elsewhere (Quinn, 1993).

The terms "homing" and "straying" are defined by the endpoints of migration (i.e. the natal or non-natal site, respectively), but during their migration some salmonids ascend one stream, only to later leave and spawn elsewhere (Ricker and Robertson, 1935; Ricker, 1972). Mature salmonids respond to the stimulus of imprinted odors with positive rheotaxis and move downstream when they no longer detect home odors (Johnsen and Hasler, 1980); therefore movement up a non-natal stream does not necessarily mean that the fish will spawn there. It may be natural for salmon migrating up complex river systems to ascend non-natal streams for a brief distance before the absence of homestream odors triggers negative rheotaxis. However, the behavior of some fish is not adequately explained by such "proving" behavior. For example, 16% of the sockeye salmon (*Oncorhynchus nerka*) radio-tagged by Burger et al. (1995) in Tustumena Lake that eventually spawned in a particular tributary, initially entered a different tributary and stayed there for up to one week. In addition, 21% of the fish that spawned on the shoreline of the lake had previously entered a tributary stream. These fish might be "exploring" (actively seeking different sites and comparing their attributes) or "wandering" (searching in the absence of stimuli).

Unfortunately, the principal methods for studying homing fail to distinguish straying from exploring or other related behavior patterns. One approach is to collect adult salmon from spawning grounds, displace them to another spawning site or to a nonspawning area, and monitor their subsequent movements. Most of the fish returned to the site of their capture (e.g. Hartman and Raleigh, 1964; McCart, 1970; Varnavskiy and Varnavskiy, 1985; Blair and Quinn, 1991), and the authors assumed but did not verify that the capture site was home. Another approach is to capture and track adults as they move upstream to their spawning site (e.g. Berman and Quinn, 1991; Burger et al., 1995). In these studies, the final spawning location is assumed to be the natal one but this also is not verified.

The primary alternative approach to capturing and marking adult salmon is to mark them as juveniles and monitor the locations where they subsequently spawn (e.g. Quinn and Fresh, 1984; Quinn et al., 1991; Pascual and Quinn, 1994; Vander Haegen and Doty, 1995). The origin of these salmon is known, but once they enter a hatchery, they cannot leave and are only identified as strays after they are killed. Much of what we know about the frequency of straying is based on data from hatchery populations, but these data reveal little about the processes of homing and straying and may not represent wild populations (Quinn, 1993). Information on the extent to which salmon that enter a non-natal hatchery would leave, if given the opportunity, would provide insights into migratory behavior and the potential biases of estimating the extent of straying from hatchery populations.

The University of Washington hatchery (UWH) provides an excellent opportunity to study homing, exploring, and straying of salmon. The UWH releases chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon smolts each spring. Sockeye salmon are abundant elsewhere in the Lake Washington watershed, and a few enter the UWH although they are not reared there. In our study, all adult sockeye that entered the UWH were tagged and released just outside the hatchery. If they were proving or exploring, we would not expect them to re-enter the UWH. However, if they returned repeatedly after release, it would indicate that they would

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probably spawn at this non-natal site. We also tagged and released chinook salmon to compare the behavior of salmon that originated elsewhere (the sockeye) with that of salmon that presumably originated from the hatchery (the chinook).

Methods

The UWH is located approximately 10 km from Puget Sound, Washington, on the north side of Portage Bay, in the Lake Washington system (Fig. 1). It produces chinook and coho but not sockeye salmon. However, an average of eight sockeye salmon (range 4–18) entered the pond each fall during the years of this study (1992–97). Over this period, the Lake Washington system has had a mean total sockeye escapement of 175,893 (range 122,415–400,000).[1] The main spawning areas within the watershed are the Cedar River, Issaquah Creek, and Bear Creek, and all sockeye salmon spawn in the watershed upstream from the UWH outfall (Fig. 1; Hendry et al., 1996), principally in October and November.

During the years of our study, an average of 1299 chinook salmon (range 458–2229) entered the UWH, principally from early October through mid-November. Analysis of coded wire tagging (CWT) data has revealed a very high fidelity of UW salmon for the hatchery, and very low levels of straying of non-natal chinook salmon into the UWH (>>99% of the fish entering the hatchery had been released from it; Quinn and Dittman, 1992). We therefore assumed that chinook salmon entering the hatchery had been produced there but a few might have been produced elsewhere.

[1] Egan, R. 1998. Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501. Personal commun.

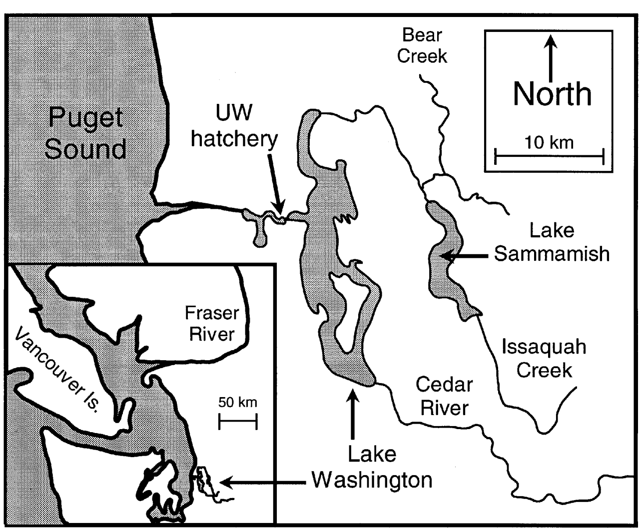

Figure 1

Map of the Lake Washington drainage, showing locations of the University of Washington (UW) hatchery and the major tributaries used by spawning sockeye salmon. Insert indicates the drainage's location in northwest Washington.

Twice each week during the fall, the UWH pond was partially drained and all the salmon were seined into a small area. All sockeye salmon and a subsample of the chinook salmon (in 1994–96) were transferred from the seine to a live box in the pond. These fish were tagged with a T-bar tag on each side in the musculature just below the dorsal fin and quickly released within 10 m of the ladder leading into the hatchery. All tagged chinook salmon were males (1 year olds in 1994; 2 year olds in 1995 and 1996) and releases were spread throughout the course of the run. Returning tagged fish of both species were recaptured during the seining of the pond. Those in good condition were released once more outside the hatchery but those with extensive fungus on their bodies were sacrificed. Fish that returned a third time were killed, regardless of their condition.

Results

Between 1992 and 1997, 48 sockeye salmon (28 males and 20 females) entered the UW hatchery and were tagged and released (Table 1). The percentage of these fish that returned to the hatchery varied from 0% to 37.5% among years with an overall mean of 20.8% (Table 1). Of the ten sockeye salmon that returned after their first displacement and that were displaced a second time, five (50%) returned again. The sex ratio of the sockeye salmon straying into the hatchery (58% males) was similar to that of those returning after displacement (60% males).

From 1994 to 1996, 132 male chinook salmon were tagged and released from the UWH (Table 1). The proportion of chinook salmon that returned after displacement did not differ among the three years (χ^2=0.015, 2 df, P>0.99, overall mean=77%, Table 1). The percentage of sockeye salmon returning after displacement was much smaller than that of the chinook salmon (20.8% vs. 77.3%; χ^2=48.5, 1 df, P<0.005). Of the chinook salmon that returned after release, 65% returned a second time.

Discussion

Our finding that most of the sockeye entering the UWH appeared to be proving or exploring rather than

Table 1

Number of adult sockeye and chinook salmon tagged and released from the University of Washington hatchery (1992–97) and numbers returning to the hatchery once and twice. Numbers in parentheses represent percentages of returning fish: percentages of those returning once are based on the total number released; percentages of those returning twice are based on the number returning once.

Species	Year	Number tagged	Numbers of fish returning: Once	Numbers of fish returning: Twice
Sockeye	1992	4	0 (0)	0 (0)
	1993	6	1 (16.7)	0 (0)
	1994	8	1 (12.5)	0 (0)
	1995	4	1 (25.0)	1 (100)
	1996	18	4 (22.2)	4 (100)
	1997	8	3 (37.5)	0 (0)
	Total	48	10 (20.8)	5 (50.0)
Chinook	1994	32	25 (78.1)	13 (52.0)
	1995	39	30 (76.9)	17 (56.7)
	1996	61	47 (77.0)	36 (76.5)
	Total	132	102 (77.2)	66 (64.7)

straying in the true sense is helpful in interpreting the movements of salmon during the final stages of their homing migration. Most of the sockeye (38 of 48) that entered the UWH and were released did not return again. From our data we cannot determine which term (proving, exploring, or wandering) best describes their behavior. However, five out of ten of the sockeye that returned once returned a second time after displacement. We do not understand the motivation for the behavior of these fish but interpret their persistence as evidence that they would have spawned at the site and thus were considered strays in the true sense.

Why did only 10 of 48 sockeye salmon re-enter the UWH? Were the others unable to locate the hatchery or did they die prior to re-entry? The proportion of chinook salmon returning to the UWH after displacement (77%) was much higher than that of sockeye salmon, suggesting that the UWH was not difficult to find and re-enter after displacement. The proportion of chinook salmon returning in this study was similar to or higher than those reported in previous studies that displaced chinook about 5 km from the UWH (Whitman et al., 1982; Brannon et al., 1986, Quinn et al., 1988). A few of the tagged sockeye in the present study returned over two weeks after release, implying that the sockeye had sufficient time to find and re-enter the UWH before they were too weak.

The 48 sockeye salmon that initially entered the UWH were only 0.005% of the total run of sockeye salmon to the Lake Washington system during the years of this study. We do not infer that this extremely low rate of straying or exploring is representative of spawning sites within this or other lake systems. The absence of odors from conspecific juveniles and trace odors from adults emanating from the UWH might make it less attractive than rivers perennially used by sockeye (Groot et al., 1986), and the small discharge and lack of appropriate habitat for spawning might also deter non-native sockeye from entering. Likewise, the proportions of sockeye salmon straying and exploring in our study may not be representative of those for natural systems.

Entry of sockeye salmon into UWH may differ in some respects from their behavior in natural systems but exploring and straying are characteristic of salmon. On the basis of our results, many of the salmon that enter non-natal hatcheries and that are classified as strays might have left if given the chance. Studies of straying based on recoveries in hatcheries may thus overestimate straying rates, at least in some cases (Quinn et al. 1991). The lack of quantified estimates of proving or exploring behavior makes it difficult to assess whether the high proportion of these patterns found in our study is typical of sockeye or Pacific salmon in general. The distinction between straying and exploring is important to the management of Pacific salmon because CWT-based straying estimates from hatchery populations are commonly used to model interactions between hatchery and wild populations (Grant, 1997), and this subject needs further research.

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