Movements by Adult Coho Salmon in the Lower Elwha River, Washington

Authors: Burke, Brian J., Frick, Kinsey E., Moses, Raymond E., and McHenry, Michael L.

Source: Northwest Science, 82(sp1) : 119-127

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/0029-344X-82.S.I.119

Brian J. Burke[1], **Kinsey E. Frick**, NOAA Fisheries, Northwest Fisheries Science Center, Fish Ecology Division, 2725 Montlake Boulevard East, Seattle, Washington 98112

Raymond E. Moses, and **Michael L. McHenry,** Lower Elwha Klallam Tribe, Fisheries Department, 51 Hatchery Road, Port Angeles, Washington 98363

Movements by Adult Coho Salmon in the Lower Elwha River, Washington

Abstract

The Elwha and Glines Canyon dams caused a dramatic decline in the numbers of all species of native Pacific salmonids (*Oncorhynchus* spp.) in the Elwha River. During the fall of 2005 and 2006, we radiotagged 49 adult coho salmon (*O. kisutch*) and tracked their movements between the Elwha River mouth and Elwha Dam (7.3 rkms). Half of all tagged fish were never relocated, likely due to emigration from the river. The remainder tended to migrate quickly and directly to one or two areas saturated with large woody debris and gravel, known to be high quality spawning habitat, and remain there. However, 7 of the 13 tagged fish in 2005 made multiple upstream and downstream movements prior to spawning. No tagged fish in either year migrated farther upstream than a rock weir approximately 4.9 km from the river mouth and 2.4 km downstream from the Elwha Dam, possibly indicating a migration barrier for coho salmon. We did not detect qualitative differences in migration behavior between hatchery and unknown-origin fish, but we did find that males moved slightly larger distances after tagging than females (average, 3.6 km for males, 2.5 km for females, t-test, $P = 0.41$). A large flow event on 6 November 2006 caused 8 of 11 tagged fish residing in the river to emigrate; none of these fish returned. Results both confirm ideas of coho salmon biology and raise concerns regarding environmental impacts on coho salmon recolonization following dam removal.

Introduction

Homing and straying by Pacific salmonids are well documented migration behaviors (Groot and Margolis 1991; Quinn 1993, 2005; Dittman and Quinn 1996). Although homing is often considered to be the successful outcome of migration, straying is the mechanism by which salmon recolonize newly accessible areas (Rieman and Dunham 2000, Hendry et al. 2004). Creation of newly accessible habitat can result from multiple factors (e.g., natural river restructuring, habitat restoration), but one of the increasingly common opportunities for colonization is removal of artificial barriers such as dams (e.g., Anderson and Quinn 2007).

Prior to the construction of the Elwha and Glines Canyon dams, the Elwha River supported large populations of all major native Pacific salmonids (*Oncorhynchus* spp.; Pess et al. 2008), including some of the largest Chinook salmon (*O. tshawytscha*) in the Pacific Northwest (FERC 1991). Currently restricted to the lower 7.3 km of river (hereafter lower Elwha River), these salmonid populations are in low abundance, are supported primarily by hatcheries, or have been extirpated (DOI 1996). Dam removal is currently being planned and will provide fish access to over 50 km of high quality habitat in the mainstem Elwha River and in several tributaries that were historically used by salmonids (DOI 1995, Gregory et al. 2002, Pess et al. 2008). Monitoring adult salmonid migration behavior, determining the potential for individual fish to 'stray' to newly accessible areas, and identifying reach-scale river use by hatchery and wild fish can help scientists and managers optimize salmon recovery efforts. Spawning habitat surveys for Chinook and pink (*O. nerka*) salmon and steelhead trout (*O. mykiss*) are conducted annually in the lower Elwha River. However, high river discharge and turbidity during winter months inhibit traditional visual surveys, so reach-scale habitat use by adult coho salmon (*O. kisutch*) in the lower Elwha River is currently unknown.

Historically, coho salmon made up about 9% of the Elwha River salmonids, but they now represent over 50% of salmonids in the system (Pess et al. 2008) and their relative importance to the river ecology and to the local Elwha-Klallam native people has grown. The middle and upper reaches of the Elwha River can support high densities of coho salmon, given the general habitat

[1]Author to whom correspondence should be addressed:
E-mail: brian.burke@noaa.gov

characteristics in this region of the Olympic National Park (Pess et al. 2002). Moreover, coho salmon are one of the initial salmonid colonizers in newly opened habitats, regardless of whether the barriers to movement are natural or artificial (Milner et al. 2001, Pess et al. 2003). Consequently, documenting habitat use and behavior for these fish is particularly important.

The Elwha River coho salmon population is heavily supplemented by hatchery outplants (750,000 juveniles per year; McHenry et al. 2000). Indeed, a terminal fishery is sustained primarily by the hatchery stock. However, the relative contribution of wild and hatchery fish to current population production is unknown. Although the stock targeted for restoration is the existing in-basin mixed-origin population, comprised of about 80% hatchery fish (PNPTC et al. 2007), one of the coho salmon restoration strategies is to rely on 'natural spawning of adults' (Ward et al. *In Press*). Hatchery outplanting after dam removal will be restricted to the middle and lower reaches of the river, but it is unknown whether these fish will recolonize the newly accessible upper reaches (Ward et al. *In Press*). Hatchery fish have recently been documented straying into (recolonizing) newly accessible areas almost immediately after gaining access to them in the Cedar River, WA (Anderson and Quinn 2007). Because hatchery and wild coho salmon are known to behave differently during spawning (Fleming and Gross 1992), understanding behavior of both hatchery and wild populations of coho salmon will be important for predicting and evaluating the effects of dam removal on species distribution, population abundance, and recovery.

Few data are available regarding adult salmonid movements in the Elwha River. In the middle and upper reaches of the river, Wampler (1984) released radio-tagged steelhead and tracked their prespawn movements, demonstrating directed seasonal upstream movement patterns. However, no such data exist for the lower river or for coho salmon. Annual redd surveys for salmon and steelhead provide little data on prespawn movements, and no survey is performed for coho salmon due to high winter flows and turbid water.

We quantified pre-spawning movement patterns of adult coho salmon using radiotelemetry techniques. Our goals were to describe fish migration behavior and document reach-scale river use. In addition to determining river reaches used by coho salmon in the lower Elwha River, we wanted to describe pre-spawning movement and exploratory behavior, both in the mainstem and in the various side channels. We also wanted to document any differences (e.g., propensity to 'stray') between hatchery fish and fish of unknown-origin to aid in future management of these two Elwha River coho salmon groups.

Methods

Study Area

The Elwha River flows north out of the Olympic National Park into the Strait of Juan de Fuca (Figure 1) with an average flow of about 1,500 cfs (but fluctuates seasonally between about 200 and 20,000 cfs). The river has a small estuary, tidally-influenced to about rkm 0.6. The Elwha Dam at rkm 7.3 does not provide fish passage; all tracking was therefore restricted to the lower river. Parts of this segment of the river, particularly between rkm 1.0 and 3.0, are extremely dynamic, with braided side channels that shift in location and size annually. An artificial channel at rkm 0.5 is used as an intake to the Elwha tribal hatchery. Similarly, the state-run hatchery outflow is at rkm 3.9, but no coho are released from this hatchery. An artificial water diversion for the city of Port Angeles (referred to as the rock weir) at rkm 4.9 is approximately 1.5 m high with a notch (approximately 2 m wide) in the middle. Although some coho salmon historically occurred above this weir, none have been documented there since reinforcement of the structure in 2002.

Fish Collection and Tagging

All Elwha River hatchery coho salmon are fin-clipped, and since 2006 (2003 brood year), all fish have been coded-wire tagged. However, we could not definitively distinguish between naturally-produced fish and unclipped fish from other hatcheries that had strayed into the Elwha River; we therefore refer to unclipped fish as unknown-origin fish. While we targeted wild fish with the timing of collection (wild fish tend to migrate later in the year), we tagged all fish captured. We collected fish using gill nets in the Elwha River at two locations: rkm 2.3 in 2005 and rkm 0.6 in 2006 (Figure 1). Between 7 November and 5 December 2005, we captured, radio tagged, and released 14

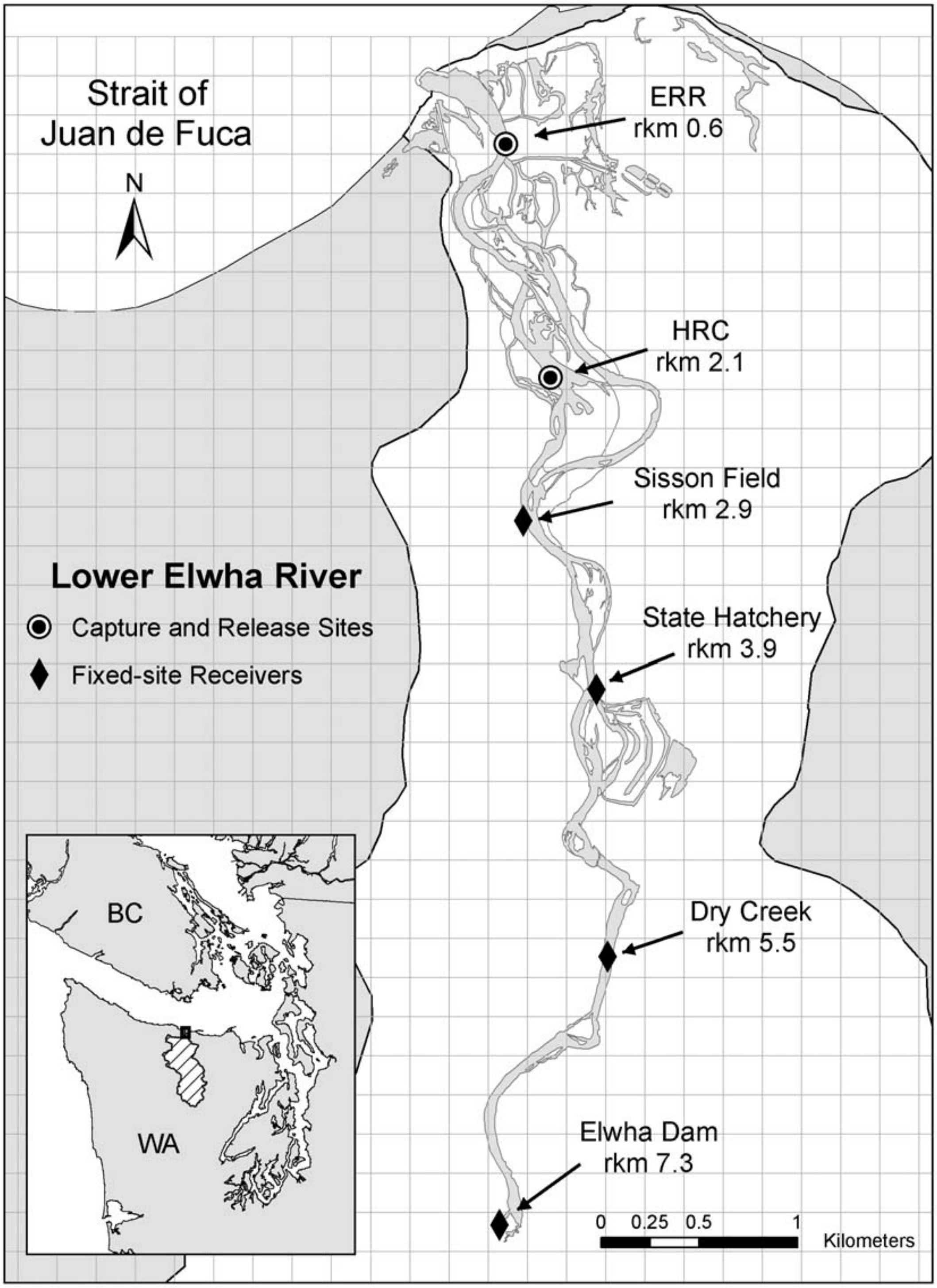

Figure 1. Map of Lower Elwha River showing fixed radiotelemetry receiver sites (diamonds) and capture and release locations (circles). ERR = End of the Reservation Road, HRC = Hunts Road Channel. Grid cells are 200 m^2. Hatched area in inset represents the Elwha River Watershed.

adult coho salmon (11 male, 3 female). Five fish were of known hatchery origin (clipped adipose fin or coded wire tag) and the remaining 9 fish were of unknown origin. We released these fish on three separate days: four fish on 7 November, five fish on 8 November, and five fish on 5 December 2005. In 2006, we released 3 groups of fish: 13 during 18-19 October, 16 during 25-26 October, and 6 on 1 November. Of the 35 fish tagged in 2006, 17 were females and 18 were males; 15 of the 35 were hatchery fish.

Immediately following net activity, we retrieved and lightly anesthetized fish with clove oil (eugenol) at a concentration of 20 ppm (0.02 ml/L) until operculation slowed and fish started to lose equilibrium (approximately 3 min). We then measured the fish (FL), determined sex using visual characteristics, and took a tissue sample (dorsal fin clip) for future genetic analysis.

We sutured a radio transmitter (2.0 g in air, 0.2 g in water, 6V Pisces, Grant Systems, Inc.) through the cartilage at the base of the dorsal fin of each fish (as in Wertheimer and Evans 2005). The transmitter was positioned to lie flat against the body to minimize drag. Transmitters were semi-cylindrical, measuring 3 cm in length and 0.5 cm in diameter, and had holes on each end through which the suture material could be secured. We oriented the 30-cm stainless steel transmitter antennas posteriorally, but they did not extend past the caudal fin. Digitally coded signals were transmitted every 5 s to allow identification of each transmitter for 120 days.

After tagging, we moved fish to an in-river hoop net, where they were held until release later that day (a minimum of 30 min). Time from capture to placement in the recovery net was usually less than 20 min and time from anesthetization to placement in the recovery net was less than 10 min. We released all fish within 10-20 m of the capture and tagging location.

Data Collection and Analysis

We employed a combination of fixed-site receivers and mobile tracking on foot or from a vehicle to locate tagged fish in the river. We distributed four fixed-site receivers (Orion, Grant Systems Engineering, King City, Ontario, Canada) along riverbanks from rkm 2.9 upstream to the Elwha Dam at rkm 7.3 (Figure 1). Much of the habitat below rkm 2.9 was either not accessible or seasonally inundated, preventing us from fixing equipment in these areas. Each receiver had an aerial Yagi antenna and was powered by three 12-V deep cycle marine batteries, which we changed and recharged every 10 to 12 days from November through January. In 2006, we added solar panels to reduce the number of battery changes required. We downloaded data from fixed-site receivers monthly and transferred them to an Oracle database. Every 5 to 10 days, we mobile tracked along accessible river banks and side channels in an effort to get finer detail on fish movements and to access tagged fish in areas that were not in range of a fixed-site receiver, including the lower 2.9 km of the river. We mobile tracked fish on 17 separate occasions between 8 November 2005 and 8 March 2006, and on 14 occasions between 24 October and 28 December 2006. We recorded detection locations on a 50 m^2 grid overlaid on the river. For data presentation, we combined these into 200 m^2 grid cells (Figure 1). Accuracy during mobile tracking is not known; however, based on some initial testing, we believe that most relocations were recorded within 50 m of the true fish location. Similarly, we designed the fixed-site antennas to detect only transmitters that were within 50-100 m.

Much of the data from fixed-site receivers consisted of noise records, which are environmental radio signals that are mistaken for transmitter signals and recorded on the receivers. Before analyzing fixed-site radiotelemetry data, we eliminated detections not associated with frequency/code combinations from our project. We then organized all remaining detections for a given fish into blocks by detection site and date. Within a site, we distinguished between blocks by searching for periods of time of 20 min or more between any two consecutive detections at that site. Because noise records often occur alone or in small numbers and real detections usually occur in larger numbers (hundreds to thousands), we removed from the data set any blocks containing fewer than 8 records. Finally, we summarized the data blocks by selecting the first and last detection dates from each block, the number of records in the block, and the number of transmissions per minute for each block. We considered mobile tracking records to be genuine transmitter detections and did not subject them to the above data processing.

Results

Average length of tagged coho salmon in 2005 was 73.3 cm (range 66.0 cm to 83.5 cm) and was not correlated with sex. However, hatchery fish were slightly shorter than unknown-origin fish (70.8 vs. 75.6 cm, t-test: $P = 0.212$). Average length in 2006 was 73.9 cm, did not differ between sexes, and unlike 2005, was not related to origin (74.8 cm for hatchery fish, 73.2 cm for unknown-origin fish).

In 2005, we did not relocate 1 of the 14 fish, which was a relatively small unknown-origin male tagged on 7 December. The remaining fish were detected by mobile tracking from 1 to 14 times and by the fixed sites from 1 to 25 separate times per fish (mean of 14 total distinct detections per fish). Cumulative movement by individual fish varied from tens of meters to almost 12 kilometers, going both up- and downstream (Figure 2). The majority of fish were last detected in the Hunt Road Channel (HRC) area, where they had been collected, tagged, and released (Figure 2).

In 2005, only one fish (hatchery-origin) moved downstream towards the mouth of the river and entered the Elwha Hatchery 17 days after release. Five fish remained in the general release area, making only small movements (< 1 km) to and from various side channels (Figure 2). Three of these were unknown-origin fish and two were hatchery fish. Their short movements stopped between early February and early March in conjunction with the end of the spawning season. The remaining seven fish made > 2-km movements upstream (at least as far as the state hatchery at rkm 3.9) and most of them made several up-and-back movements, each up to a kilometer (Figure 2). At least two of these fish (one hatchery, one unknown-origin) swam to a rock weir at around rkm 4.9, the farthest any of the tagged fish migrated. None of our tagged fish were detected upriver of the weir. Five of the fish that made larger-scale movements ultimately returned to the area where we released them and remained there. All movements greater than 200 m stopped by late December at the onset of high winter flows.

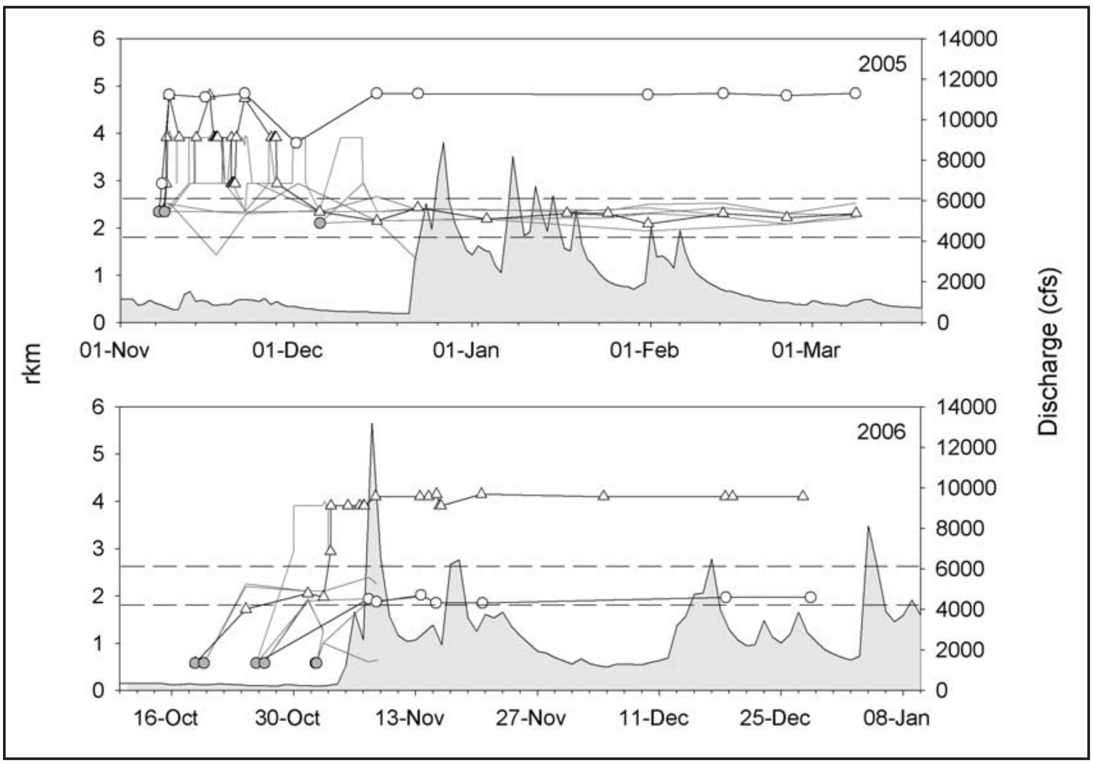

Figure 2. River kilometer of all tagged fish (gray lines) and river discharge (gray area) over time for 2005 (top panel) and 2006 (bottom panel). Two representative tracks are highlighted by black lines and symbols (triangle or circle) in each panel. Gray circles represent releases. Dashed lines encompass the HRC area.

TABLE 1. Average distance traveled (km) by individual fish (sample size in parentheses).

	Study Year	
	2005	2006
Females	3.77 (3)	1.57 (4)
Males	4.33 (11)	2.37 (7)
Combined	4.2 (14)	2.1 (11)

In 2006, we only detected 11 of the 35 tagged fish. Although the reason for the low detection rate is unknown, there are several possible explanations. First and most probable, fish may not have been from the Elwha River and may have been only temporarily straying into the river when we captured and tagged them (High et al. 2006). Unlike 2005, our capture location was just inside the mouth of the river in 2006, increasing the probability of capturing fish from other systems. Another possible explanation is that the transmitters failed. We noticed two problems with a subset of the transmitters: 1) the antenna was easily removed, preventing the transmission and 2) the waterproof housing was compromised. However, we inspected all transmitters prior to use, and removed most or all of the damaged ones.

Of the fish we relocated in 2006, many were only detected for a short period of time after tagging and only two fish were detected in the river after mid-November (Figure 2). Unlike tagged fish in 2005, movements in 2006 tended to be infrequent and of shorter distances (Figure 2, Table 1). Fish also tended to not move as far upstream in 2006 as we observed in 2005; only two fish were detected farther than 3 river kilometers upstream and no fish was detected as far as the rock weir at rkm 4.9 (Figure 3).

On 6 November 2006, the Elwha Basin received a large amount of rain resulting in a peak flow of almost 21,000 cfs. Of the 11 transmitters we were detecting prior to this storm event, we could only locate 3 afterwards. We believe the other eight fish were washed out of the river and into the Strait of Juan de Fuca. None of these fish were detected returning to the Elwha River. Shortly after the flood event, biologists from the Olympic National Park flew over both the Elwha and Dungeness Rivers (the Dungeness River is about 40 km east of the Elwha River) searching for the fish using mobile receivers, but did not find any of them (Steve Corbett, Olympic National Park, personal communication).

Only two fish were detected as far upstream as rkm 3.9 in 2006, one hatchery and one of unknown-origin (Figure 3). Similarly, only two fish were detected in the river after mid-November: one hatchery and one of unknown-origin. One of these fish was also among the two fish that migrated upstream of rkm 3.9. As in 2005, the fish that remained in the river after the onset of winter flows made no larger-scale movements (> 200 m). Two hatchery fish returned to the Elwha hatchery within 10 days of release and were spawned there.

In both years, females traveled less total distance than males (Table 1). This trend held for all combinations of year and fish origin except one—female hatchery fish in 2005 moved more than male hatchery fish (average: 4.9 km for females, 2.1 km for males). Most tagged fish stopped

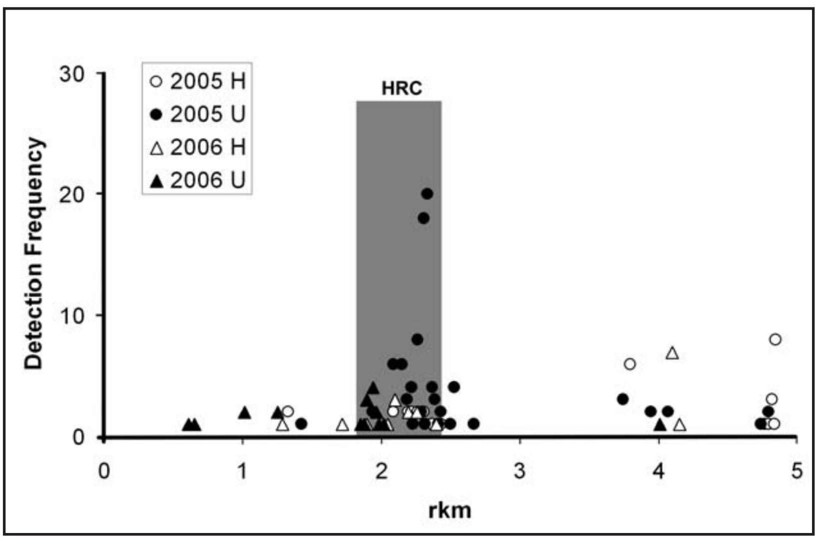

Figure 3. Frequency of tagged fish detections by mobile tracking at various river kilometers. The shaded area represents the Hunts Road Channel (HRC) area. H = hatchery origin, U = unknown origin.

moving during November and December, but six fish (tagged in 2005) were detected moving through much of February and into March 2006.

Discussion

This study represents the first effort in the lower Elwha River to document prespawn movement patterns and reach-scale river use for adult coho salmon. We tracked fish movement through much of the lower Elwha River and documented a tendency by coho salmon to locate themselves in the HRC. As in previous studies (e.g., Anderson and Quinn 2007), we showed that male fish travel larger distances prior to spawning, perhaps in search of habitat or potential mates. Although these results indicate that coho salmon in the lower Elwha River behave similar to coho salmon in other systems, we also found some surprising results, such as a lack of difference in movement rates between hatchery and unknown-origin fish and a large impact of high flow events on salmon movements.

Our fixed-site receivers were efficient at detecting most fish passing nearby; we know of only two cases where fish passed by the receivers undetected (based on detections at other receivers). Similarly, mobile tracking proved very effective at locating most fish. However, in the winter months, high river flows prevented access to some of the complex side channel habitat near HRC (Figure 1). It is possible that the fish we never relocated remained in this stretch of river or in inaccessible side channels (though we cannot rule out other possibilities, such as the fish exiting the river or transmitter failure). Small-scale movements (<200 m) were difficult to detect, both because of the relocation accuracy and the frequency of our mobile tracking efforts (about every 7 to 10 days). However, we believe we captured the large-scale movements (>200 m) of these fish.

Coho salmon commonly exhibited one of two qualitatively distinct movement patterns. More than half of the tagged fish for which we had good information spent the entire season (October to January) in the HRC area (regardless of whether we released them in the HRC or near the mouth of the river). The small-scale movements within the HRC may have been related to searching for a mate (males) or searching for spawning habitat (females; Anderson and Quinn 2007). Other fish made larger, kilometer-scale movements, perhaps in search of spawning habitat upstream. These fish may have been proving (Griffith et al. 1999), where fish swim upstream past natal spawning grounds until the lack of positive stimuli is noticed, then return downstream. Indeed, many of the male fish made large movements and ultimately returned to the HRC area. These fish may also have been exploring; had they found spawning habitat or potential mates upstream, they may have remained there. Anderson and Quinn (2007) also found increased movement by male coho salmon during recolonization of the Cedar River in Washington. Such exploratory movements could be critical to recolonization of the middle and upper reaches of the Elwha River. Interestingly, only one female coho salmon swam as far upstream as the rock weir at rkm 4.9 and none of the fish approached Elwha Dam. All kilometer-scale movements ceased by the onset of winter flows, though whether this is coincidence or results of a causative relationship, we do not know.

Regardless of whether fish made kilometer-scale movements or remained where we released them, most tagged fish were last detected in habitat dominated by large woody debris and complex braided channels (Figure 2). The HRC area, where the majority of fish ended up, breaks the main channel into at least four smaller channels. Many of these are further divided by log jams and islets, creating pockets of shallow water where flows are generally less than the average river flow (see Pess et al. 2008). The river in this area contains a mixture of riffles and small pools and the substrate is mostly gravel. Similar habitat is largely absent from other areas in the lower Elwha River because the dams hold back large woody debris and small rocks (Wunderlich et al. 1994, Webster et al. 1979). Coho salmon are known to seek out small streams with pool/riffle transitions that contain medium to small gravel substrate for spawning (Groot and Margolis 1991).

Behavior did not vary with fish origin; however, sample sizes were small (particularly in 2006). Results concerning the effect of origin on adult coho salmon migration behavior were therefore inconclusive. It should be noted, however, that 6 of the 11 hatchery fish for which we have good data were last detected in the HRC area along with the unknown-origin fish and 2 more just upstream of that area (i.e., only 3 of 11 hatchery-origin fish returned to the hatchery). This could indicate mixed spawning between hatchery and wild fish, particularly in the habitat around the HRC.

Although coho salmon have previously been known to ascend the Port Angeles water diversion weir (rkm 4.9) in small numbers, none have been documented above this weir since reinforcement of the structure in 2002. Indeed, none of our tagged fish migrated past it. This structure will be eliminated in conjunction with dam removal operations and replaced with an engineered riffle that meets fish passage requirements for all species (EREFR 2006). However, it is important to consider these small, but potentially serious, structures as potential impediments to migration of coho salmon.

Other migration barriers may emerge as dam removal progresses. For example, turbidity can deter fish from entering a river (Quinn and Fresh 1984, Bell 1986, Pess et al. 2008). It is estimated that turbidity in the Elwha River during dam removal will increase from current peak levels of about 800 nephelometric turbidity units (NTUs) to as much as 25,000 NTUs for the first few years following dam removal (DOI 1996). Furthermore, extremely high or low water discharge or temperature may obstruct adult coho salmon in the Elwha River.

Given that coho salmon migrate during the fall and winter, high flow may not inherently hinder migration. High flow events in the Elwha River occur in the late fall, mostly due to heavy rains and warm temperatures. Peak flows above 10,000 cfs are not uncommon (USGS 2007). However, the storm event on 6 November 2006 coincided with loss of contact with 8 of 11 tagged fish, and the probable emigration of these fish from the river. With the frequency of these high flow events (peak flows exceeded 21,000 cfs about every 4 years on average since 1920; USGS 2007) and the expected increase in turbidity during and after dam removal (DOI 1996), the potential detrimental effects to coho salmon migration should be incorporated into recovery and planning efforts (e.g., Good et al. 2008).

Acknowledgements

We thank several people for help with the field work for this project, including Sonny Sampson, Mel Elofson, Kim Guilbault, Mary Moser, Bruce Jonasson, Byron Iverson, Mark Kaminski, Larry Ward, and Keira Fullerton. Thanks to Aimee Fullerton, Doug Dey, JoAnne Butzerin, George Pess, and two anonymous reviewers for reviewing earlier drafts of this manuscript. Funding for this work came from an Internal Grant Program at the Northwest Fisheries Science Center, NOAA Fisheries and from the Elwha Klallam Tribe.

Literature Cited

Anderson, J. H. and T. P. Quinn. 2007. Movements of adult coho salmon (*Oncorhynchus kisutch*) during colonization of newly accessible habitat. Canadian Journal of Fisheries and Aquatic Sciences 64:1143-1154.

Bell, M. C. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, Portland, OR.

Department of the Interior (DOI). 1995. Elwha River ecosystem restoration, final environmental impact statement. NPS D-253A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Department of the Interior (DOI). 1996. Elwha River Ecosystem Restoration Implementation, Final Environmental Impact Statement. NPS D-271A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Dittman, A. H. and T. P. Quinn. 1996. Homing in Pacific salmon: Mechanisms and ecological basis. Journal of Experimental Biology 199:83-91.

EREFR (Elwha River Ecosystem and Fisheries Restoration). 2006. Environmental Species Act—Section 7 Consultation Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation. National Marine Fisheries Service. Seattle, WA.

FERC (Federal Energy Regulatory Commission), Office of Hydropower Licensing. 1991. Draft Environmental Impact Statement, Glines Canyon (FERC No. 588) and Elwha (FERC No. 2683) Hydroelectric Projects, Washington.Washington (DC): Office of Hydropower Licensing.Report no. 94-18970.

Fleming, I. A. and M. R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (*Oncorhynchus kisutch*): does it differ? Aquaculture 103:101-121.

Good, T. P., J. Davies, B. J. Burke, and M. H. Ruckelshaus. 2008. Incorporating catastrophic risk assessments into setting conservation goals for threatened Pacific salmon. Ecological Applications 18(1):246-257.

Gregory, S., H. Li, and J. Li. 2002. The conceptual basis for ecological response to dam removal. Bioscience 52: 713-723.

Griffith, J. N., A. P. Hendry, and T. P. Quinn. 1999. Straying of adult sockeye salmon, *Oncorhynchus nerka*, entering a non-natal hatchery. Fishery Bulletin 97:713-716.

Groot, C. and L. Margolis, editors. 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia, Canada.

High, B., C. A. Peery, and T. C. Bjornn. 2006. Temporary staging of Columbia River summer steelhead in cool water areas and its effect on migration rates. Transactions of the American Fisheries Society 135:519-528.

McHenry, M., J. Petersen, and R. McCoy. 2000. Elwha River project: A summary of restoration activities during 1999-2000. Elwha Klallam Tribe report to the Washington State Salmon Recovery Funding Board, Port Angeles, WA.

Milner, A. M. and G. S. York. 2001. Salmonid colonization of a new stream in Kenai Fjords National Park, southeast Alaska. Archiv fur Hydrobiologie 151:627-647.

Pess, G. R., D. R. Montgomery, E. A. Steel, R. E. Bilby, B. E. Feist, and H. M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Washington, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 59:613-623.

Pess, G. R., T. J. Beechie, J. E. Williams, D. R. Whitall, J. I. Lange, and J. R. Klochak. 2003. Chapter 8. Watershed assessment techniques and the success of aquatic restoration activities. Pages 185-201. *In* R.C. Wissmar and P.A. Bisson (editors), Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. American Fisheries Society, Bethesda, MD.

Pess, G. R., M. L. McHenry, T. J. Beechie, and J. Davies. 2008. Biological impacts of Elwha River dams and potential salmonid responses to dam removal. Northwest Science 82 (Special Issue):72-90.

PNPTC (Point No Point Treaty Council). 2007. 2007 Management framework plan and salmon runs status for the Strait of Juan de Fuca region. Report by Washington Department of Fish and Wildlife and Makah Tribe.

Quinn, T. P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18:29-44.

Quinn, T. P. and K. Fresh. 1984. Homing and straying in Chinook salmon *Oncorhynchus tshawytscha* from Cowlitz River Hatchery, Washington. Canadian Journal of Fisheries and Aquatic Sciences 41:1078–1082.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Seattle.

Rieman, B. E., and J. B. Dunham. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9:51-64.

USGS (United States Geological Survey). 2007. USGS Real-Time Water Data for USGS 12045500 Elwha River at McDonald bridge near Port Angeles, WA. Available online at http://waterdata.usgs.gov/nwis/uv?12045500. (Accessed 24 May 2007).

Wampler, P. L. 1984. Radiotelemetry assessment of adult summer run steelhead behavior following release in the Upper Elwha River. U.S. Fish and Wildlife Service. Fisheries Assistance Office, Olympia, WA.

Ward, L., P. Crain, B. Freymond, M. McHenry, D. Morrill, G. Pess, R. Peters, J. A. Shaffer, B. Winter, and B. Wunderlich. *In Press*. Elwha River Fish Restoration Plan—Developed pursuant to the Elwha River Ecosystem and Fisheries Restoration Act, PL 102-495. NOAA Technical Memorandum, Northwest Fisheries Science Center, Seattle, WA.

Webster, J. E., E. Benfield, and J. Cairns, Jr. 1979. Model predictions of effects of impoundments on particulate organic matter transport in a river system. *In* J. Ward and J. Stanford (editors), The Ecology of Regulated Streams. Plenum Press, New York. Pp. 339-364.

Wertheimer, R. H., and A. F. Evans. 2005. Downstream passage of steelhead kelts through hydroelectric dams on the Lower Snake and Columbia Rivers. Transactions of the American Fisheries Society 134:853-865.

Wunderlich, R. C., B. D. Winter, and J. H. Meyer. 1994. Restoration of the Elwha River ecosystem. Fisheries 19(8):11-19.