COMMENTARY

Ocean and dam influences on salmon survival

Ray Hilborn[1]
School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195

The Decline of Columbia River Chinook Salmon

The Columbia River in the Pacific Northwest has been the site of the world's most expensive effort in ecological management and restoration. Primarily using revenues from the hydroelectric system, roughly $400 million have been spent annually on the fish and wildlife program in the Columbia Basin, most of it on salmon. Much of this funding goes to operate hatcheries and modify the operation of dams, but also to a research program that, over the last four decades, has funded thousands of scientists and supported a number of technical advances, including three tagging techniques that have revolutionized our ability to understand the freshwater and marine life of salmon.

One of these techniques is the use of acoustic tags on juvenile salmon. In PNAS, the article by Rechisky et al. (1) reports how these acoustic tags are used to measure survival of juvenile salmon in their early ocean life. The tags are implanted in thousands of juvenile salmon and arrays of acoustic listening devices detect their passage down the Columbia River and their northward ocean migration. Before the development of acoustic tags, the ocean was essentially a black box. Using earlier tagging techniques, individual fish were marked and nothing was known of them until they returned from the ocean, when the small stainless steel tags, known as coded wire tags, were either seen by physical inspection for a missing adipose fin, or passively interrogated tags were electronically detected at a range of a meter or two as the fish pass up fish ladders. The ocean distribution of fish could be inferred when coded wire tag-marked fish were caught, but the timing and location of ocean mortality remained unknown.

The decline of Columbia River salmon is a well-documented story of the conflict between industrial-scale human activity and wild resources (2). A combination of overharvesting, loss of habitat because of land-use changes and impassable dams, changes in ocean conditions, and dam construction, has led to a loss of most of the once great migrations of wild salmon on the Columbia. The Columbia River was known for the largest runs in the world of the largest of the Pacific salmon, the Chinook or "king" salmon, and the "kings" are still a primary focus of restoration efforts.

The story of the Chinook salmon on the Columbia River can be told in two phases. At first, using catches as a measure, the development of industrial fishing brought about a substantial decline. Then the Grand Coulee Dam (1942) totally blocked the upper river to salmon migration, and the four mainstem dams (beginning with the Bonneville Dam in 1937) on the lower Columbia flooded considerable habitat and proved a significant barrier to both the upstream passage of adults and the downstream migration of juveniles despite the construction of fish ladders. By 1960, the Chinook salmon runs were less than 10% of what they had been a century earlier.

The second phase began in 1960. Four more dams were completed on the Snake River (between 1962 and 1972), resulting in another major decline in the runs of Chinook spawning in the headwaters of the Snake River. Thanks to the fish ladders that allow us to very reliably count the fish passing upstream, scientists were able to estimate the number of adult fish that return for each adult spawner (sometimes called recruits per spawner) and also the smolt-to-adult ratio that is a measure of the fraction of juveniles migrating downstream that survive both migration and life in the ocean to return. Both recruits per spawner and smolt-to-adult ratio declined dramatically in the late 1970s, coinciding with the completion of the four Snake River dams, to the point where, even though there was no harvest, stocks kept declining and appeared to be on a trajectory toward extinction (3). In 1992, the major stock of Chinook salmon spawning in the Snake River watershed was placed on the Endangered Species list.

Is it the dams?

Although considerable efforts have improved the downstream survival of juvenile salmon and ocean conditions appear to be more favorable now, why is the survival rate of juvenile Chinook salmon from the Snake River still so much poorer than that of the Chinook from farther down the Columbia?

The most common assumption was that the passage past the dams was the culprit. However, the new tagging techniques, both passively interrogated tags and acoustic, let scientists estimate the passage mortality, and Welch et al. (4) showed, to the surprise of many, that the survival of Snake River juvenile salmon down the Snake and Columbia Rivers was comparable to survival of juvenile Chinook salmon down the Fraser River in Canada, where there are no dams. Therefore, if the dams are not killing the Snake River fish, why do they do so poorly?

It was also thought that the downstream passage through dams stresses the fish, which would reduce their survival in early ocean life. The present report (1) again uses the acoustic technology to measure survival through the first 485 km of ocean migration and finds no evidence for delayed mortality of Snake River Chinook compared with Yakima River Chinook that do not pass through the Snake River dams. The difference in survival between the Snake and Yakima Chinook must be found at a later point in their ocean life.

One question was clarified and gave rise to another: perhaps it is time to step back and look a bit more broadly. The comparison in downstream survival of Chinook in the Fraser and Columbia Rivers was both surprising and informative. However, there are other lessons for the Columbia River to be drawn from the Fraser River. Fraser River, and indeed most southern British Columbia Chinook salmon, declined dramatically in the 1970s and 1980s because of a combination of overharvesting and poor ocean survival (5). Survival of Canadian hatchery Chinook was measured by coded wire tags, and plummeted from as high as 5% in the mid-1970s to about 1% by the mid-1980s (6). As many have noted, there was an overall decline in survival of Chinook salmon during this period that coincided with

Author contributions: R.H. wrote the paper.

The author declares no conflict of interest.

See companion article on page 6883.

[1]E-mail: rayh@u.washington.edu.

a warming of the ocean and an increase in survival of Alaskan salmon (7, 8).

Even more interesting are the differences in survival of Chinook salmon upstream in the Fraser River and close to the ocean. In the 1970s Canada built a number of Chinook hatcheries, both near the ocean and the mouth of the Fraser as well as hatcheries much higher up in the river, comparable in travel distance to the Snake River Chinook on the Columbia (9). These upriver Fraser River Chinook hatcheries had abysmal survival. The Quesnel Hatchery, located 650 km up the Fraser River averaged barely 0.1% survival from 1981 to 1989. The Spius Creek hatchery, located 315 km up the Fraser averaged 0.5% survival over the same period. These numbers are far lower than survival of juvenile Chinook from hatcheries in Canada located at or near tidewater, which were up to 10-times higher. Although these survival data of Fraser River Chinook are derived from hatchery stocks, it is certainly suggestive that the pattern of declining ocean survival with distance up-stream may be a phenomenon found in places other than the Columbia River and may ultimately not be related to the hydro-electric system.

Rechisky et al. (1) are unique in having made a significant advance in measuring early ocean survival of upstream and downstream fish in the Columbia River. As the authors point out, some methodological questions are still unanswered: perhaps all of the salmon do not migrate north toward the acoustic detectors, and perhaps there remain some size-specific survival differences that cause bias because the smallest of the juvenile salmon cannot be fitted with the acoustic tags. It is indeed one of the major concerns about the acoustic tagging that only larger fish can be tagged. Although the authors have made a number of efforts to reduce this problem, the concern remains that the tagged fish may not be representative of the total population from the same location who are, on average, smaller than those tagged.

Rechisky et al. are unique in having made a significant advance in measuring early ocean survival of upstream and downstream fish in the Columbia River.

The importance of dams in the Columbia River has deeply divided the scientific community, with very reputable scientists on both sides of the debate. Those arguing that dams are the major problem with Snake River Chinook salmon will remain unconvinced by this study and the earlier work of Welch et al. (4). Extensive efforts to bring these two scientific communities together have proved unsuccessful, and by now it is hard for outside observers to see what kind of data will resolve the differences in perspective.

Overall, Chinook salmon are doing poorly throughout their range, from the Yukon River to the Sacramento. Although there are more salmon in the ocean now than any time in the past (10), the boom in salmon has been in pink, chum, and sockeye, while the freshwater river-rearing coho and Chinook have declined. It may be that with current ocean conditions many stocks of Chinook salmon cannot survive, and that the geographic range of Chinook may contract and the long-distance migrating Chinook of the southern rivers may not persist.

1 Rechisky EL, Welch DW, Porter AD, Jacobs-Scott MC, Winchell PM (2013) Influence of multiple dam passage on survival of juvenile Chinook salmon in the Columbia River estuary and coastal ocean. *Proc Natl Acad Sci USA* 110:6883–6888.

2 Montgomery DR (2003) *King of Fish: The Thousand Year Run of Salmon* (Westview Press, Boulder, CO).

3 Kareiva P, Marvier M, McClure M (2000) Recovery and management options for spring/summer Chinook salmon in the Columbia River basin. *Science* 290(5493):977–979.

4 Welch DW, et al. (2008) Survival of migrating salmon smolts in large rivers with and without dams. *PLoS Biol* 6(10):e265.

5 Fraser FJ, Starr PJ, Fedorenka AY (1982) A review of the Chinook and coho salmon of the Fraser River, in *Canadian Technical Report of Fisheries and Aquatic Sciences* (Canadian Department of Fisheries and Oceans, Ottawa), p 129.

6 Coronado C, Hilborn R (1998) Spatial and temporal factors affecting survival in coho and fall Chinook salmon in the Pacific Northwest. *Bull Mar Sci* 62(2):409–425.

7 Francis RC, Hare SR (1994) Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: A case for historical science. *Fish Oceanogr* 3(4):279–291.

8 Mantua NJ, Hare SR, Zhang Y, Wallace JM, Francis RC (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull Am Meteorol Soc* 78(6):1069–1079.

9 Winton J, Hilborn R (1994) Lessons from supplementation of Chinook salmon in British Columbia. *N Am J Fish Manage* 14(1): 1–13.

10 Ruggerone GT, Peterman RM, Dorner B, Myers KW (2010) Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. *Mar Coast Fish: Dyn Manag Ecosyst Sci* 2(1):306–328.