Comment on "Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon"

Brian E. Riddell, *et al.*

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Comment on "Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon"

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Krkošek *et al*. (Reports, 14 December 2007, p. 1772) claimed that sea lice spread from salmon farms placed wild pink salmon populations "on a trajectory toward rapid local extinction." Their prediction is inconsistent with observed pink salmon returns and overstates the risks from sea lice and salmon farming.

Krkošek *et al*. (*1*) reported that sea lice (*Lepeophtheirus salmonis*) spread from salmon farms in the Broughton Archipelago (BA), British Columbia, Canada, have placed wild pink salmon (*Oncorhynchus gorbuscha*) populations "on a trajectory toward rapid local extinction" and that "a 99% collapse in pink salmon population abundance is expected in four salmon generations." Their conclusions follow directly from their data selection process. Specifically, they defined the sea lice exposure period to begin in 2000 [$n_i(t-2)$], the year with the historic highest escapement of pink salmon in the BA; they excluded the 2004 pink salmon return; they excluded the Glendale River pink population, the largest producer of pink salmon in the BA; and they attributed all differences in wild pink salmon mortality between exposed and unexposed populations to sea lice infection, ignoring other potential sources of between-year variation in survival.

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Pink salmon have a fixed age at maturity of 2 years, resulting in discrete (i.e., isolated) returns or lines in even- and odd-numbered calendar years. In the BA, the two lines differ substantially in abundance and trend (Fig. 1). Even-year pink salmon reached historic high returns in 2000 but then dropped to record low returns in 2002 (*2*). The odd-year line for the seven streams analyzed in (*1*) (Fig. 1B) had been declining since the early 1980s. Returns to the excluded Glendale River exhibited an inverse pattern increasing sharply until 2001. The Glendale population then declined to about 160,000 spawning adults in 2003 and increased slightly in 2005 and 2007.

Krkošek *et al*.'s prediction of rapid extinction only holds if the exposure period is defined to begin in 2000, the year of highest abundance, and returns after 2002 and 2003 are misrepresented. In particular, they excluded data for the 2004 pink return, based on their belief that it was aided by "nonrandom management action" (fallowing of the salmon farms during spring 2003) and cited (*3*) as justification. However, the argument in (*3*) is that the strong 2004 return reflected exceptional ocean survival for pink salmon over the entire life cycle, not just the out-migration period. Inclusion of 2004 data (and updating the data with preliminary 2007 returns) would have slowed the rate of decline in Krkosek *et al*.'s analysis but not the downward trend in pink abundance since 2000. The latter is fully determined by their choice to begin the exposure period in 2000.

Krkošek *et al*. excluded pink salmon returns to the Glendale River as an artificially enhanced river but chose to include returns to the enhanced Kakweiken River. The Glendale River dominates pink production in the BA, accounting for up to 90% of pink salmon returns in odd years and 40 to 70% in even years. Juvenile pink salmon originating from the Glendale River would constitute the majority of juvenile salmon passing salmon farms in the BA and would be as susceptible to infection as other populations. In fact, an alternative explanation for the declines reported in (*1*) is competition from the Glendale population, which could also limit the productivity and recovery of interacting populations, as suggested for other areas (*4*).

Krkošek *et al*. further suggested that mortality of pink salmon due to sea lice is "commonly over 80%." Sea lice were estimated to account for most natural mortality in 2002, 2003, and 2005 [table 1 in (*1*)]. This mortality would occur within 60 days of ocean entry, whereas pink salmon rear in the ocean for another 16 months before returning. All British Columbia species of salmon that entered the sea during spring 2005 suffered exceptionally poor marine survival. This fate was shared by pink salmon populations from the "unexposed" region, as demonstrated by the large negative deviations for 2006 in figure 2 in (*1*). Although sea lice infection may be one cause of juvenile mortality, other mortality factors that could exacerbate or compensate for early juvenile mortality should also be considered, particularly those that could have differed between the exposed and unexposed regions. In such ecological studies, the possibility of ecological pseudoreplication is difficult to avoid and should not be ignored.

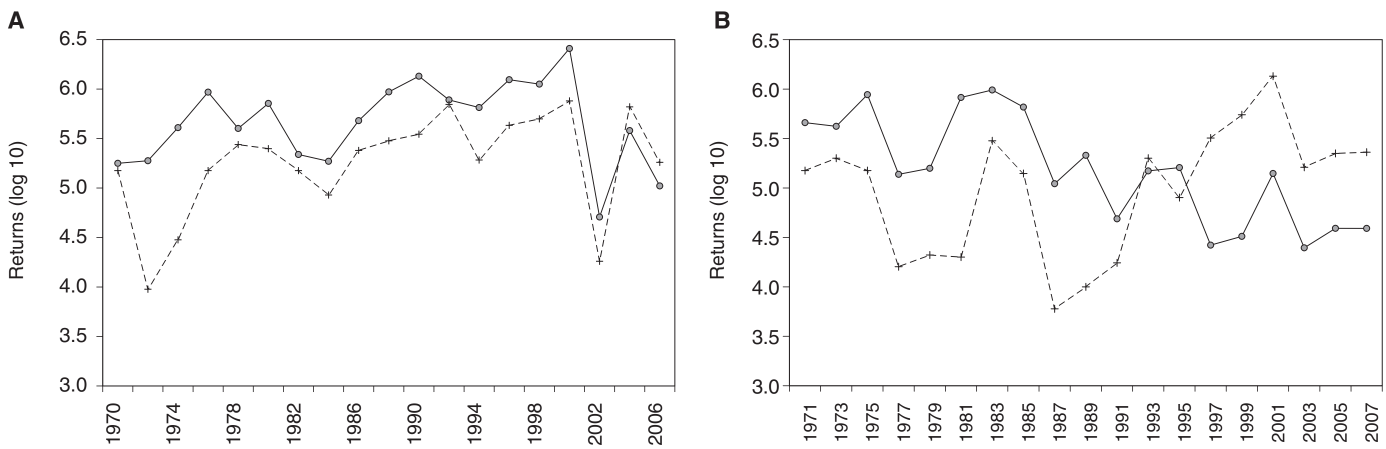

Fig. 1. Time series of pink salmon returns (total estimated number of spawners) to the BA streams included in Krkosek *et al*. (circles and solid line) and to the Glendale River (crosses and dashed line). (**A**) Even year only for adult return years 1970 to 2006. (**B**) Odd years only for adult return years 1971 to 2007. Returns are presented in a log 10 scale because of the large range of return abundances (*6*).

Krkošek *et al.*'s statements of extinctions and 99% loss of production are erroneous. They examined a subset of the BA streams but excluded the largest pink salmon production system. Their conclusions should have been kept in the context of the subset they selected. They could refer to extirpation of production from some streams but not extinction of pink salmon in the BA. Although a loss of production from some streams is undesirable, that loss is replaceable. The BA includes a large mix of small streams to large glacial river systems, but there is no detectable genetic difference between populations within even- and odd-year lines (*5*). Consequently, core populations within lines can recolonize streams that have been extirpated without loss of genetic diversity. Further, intervention by human manipulations can deliberately enhance such exchanges and are frequently conducted for Pacific salmon.

Krkošek *et al.* overstated the risks to wild pink salmon from sea lice and salmon farming. Furthermore, their predictions are inconsistent with recent observations of pink salmon returns to the Broughton Archipelago. Their alarming statements of extinction of pink salmon in the BA are only possible with highly selective use of the available data and extrapolation of their results to all pink salmon in the BA. In assessing and managing pink salmon in the BA, all potential impacts on the productivity of these pink populations, including sea lice, should be acknowledged in developing an effective management strategy.

References and Notes

1. M. Krkošek *et al.*, *Science* **318**, 1772 (2007).
2. Pacific Fisheries Resource Conservation Council, 2002 Advisory: The Protection of Broughton Archipelago Pink Salmon Stocks; available from www.fish.bc.ca/files/SalmonAquaculture-Broughton-Advisory_2002_0_CompleteR_20.pdf.
3. R. J. Beamish *et al.*, *ICES J. Mar. Sci.* **63**, 1326 (2006).
4. R. Hilborn, D. Eggers, *Trans. Am. Fish. Soc.* **129**, 333 (2000).
5. Data from the Department of Fisheries and Oceans, Canada; available from www.pac.dfo-mpo.gc.ca/sci/mgl/data_e.htm.
6. Data available as supporting material on *Science* Online.

Supporting Online Material

www.sciencemag.org/cgi/content/full/322/5909/1790b/DC1
Tables S1 and S2

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