Salmon-farming impacts on wild salmon

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Concerns have been raised about the impact of farmed fish on wild fish through a range of mechanisms including disease and the impact of fish that escape from farms (1). Although Alaska has banned salmon farming and Washington has developed only a very small industry, British Columbia, with an extensive network of protected inlets, has developed a very large salmon-farming industry, now considerably bigger in terms of tons produced than the wild salmon production there. The salmon-farming industry is a significant and growing part of the local economy with the potential to grow to the scale that has occurred in Norway and Chile. In this issue of PNAS, Krkošek *et al.* (2) present data to show that migrating juvenile salmon are infected by sea lice as they pass salmon farms and that such sea lice infestations cause significant mortality. Their article provides support for those who oppose net-pen aquaculture of salmon within the range of wild salmon, and the results will undoubtedly intensify the debate on the impact of salmon farms on wild fish.

To understand the significance of the new results on the public-policy issue, we must consider two questions. First, are there possible flaws in the experimental design that could cause the effect estimated in the article to be exaggerated? Second, what evidence is there for population-level effects of sea lice from salmon farms on wild populations?

Appropriate Controls

The data presented by Krkošek *et al.* (2) strongly indicate the infection of wild salmon as they pass areas where there are salmon farms and that lice infestation leads to significant mortality. The authors argue that the lice abundance in the absence of farms is uniform and use the evidence of low infestation rates of salmon landward of salmon farms as their control. The underlying hypothesis is that there is a “background” infection rate and that salmon farms provide hot-

spots of infection as wild salmon pass the farms. The three principal elements of the experimental method are replication, control, and randomization. From previous work (3), we now have replication of the basic observation that migrating juvenile salmon become infected with sea lice as they pass salmon farms. A better control would be to follow salmon down migration paths where there are no salmon farms; if the model of Krkošek *et al.* (2) is correct, there should be only background infection rates along such migratory corridors. However, the concept of controls is inexorably tied into the issue of randomization of treatments. It seems unlikely that salmon farms are located randomly; rather, some sites in the inlets of British Columbia are probably better for salmon farms than others. If the habitats that are preferred for salmon farms are also habitats that contain naturally high sea lice concentrations, then the infection rates landward of salmon farms, and indeed migration corridors without any salmon farms, may not be appropriate controls. The obvious next step in understanding the impact of salmon farms on sea lice infection is to monitor wild populations migrating down corridors without salmon farms.

Population-Level Impacts

The bigger policy question is the population-level impact of salmon farms on the wild salmon in British Columbia. More broadly, this impact would likely also occur in other countries such as Norway, Scotland, and Ireland that have both large salmon-farming operations and wild salmon. Beamish *et al.* (4) have shown that wild pink salmon in central British Columbia had an exceptionally high ocean survival rate in 2003 despite the presence of a large number of salmon farms in their migration corridor. They argue that this finding means that salmon farms and wild salmon can coexist without significant impact on the wild salmon. Krkošek *et al.* (2) make no specific claims or calculations regarding

population-level impacts, but they state, “as aquaculture continues its rapid growth, this disease mechanism may challenge the sustainability of coastal ecosystems and economies.” The larger-scale impacts of salmon farming on wild populations have not been answered by Krkošek *et al.* (2), but given the intensity of salmon farming in central British Columbia and the high infection and mortality rates they observed, their data would seem to support an important population-level impact.

The next step will be (i) to analyze the number of wild salmon migrating past salmon farms and the number that do not and (ii) to use the mortality estimates weighted by the proportion of the total wild populations that are exposed to salmon farms to estimate theoretical population-level impacts. These calculations would need to be reconciled with the observations in ref. 4. One possibility is that the mortality impact of sea-lice infestation depends on the condition of the juvenile salmon, which likely varies widely from year to year. Beamish *et al.* (4) showed that the survival of juvenile salmon migrating in 2003 was much higher than in other recent years. The mortality experiments of Krkošek *et al.* (2) were done in 2004 and 2005. Levin *et al.* (5) showed that the competitive impact of hatchery salmon on wild salmon was much stronger in years of poor ocean condition, which may be true for the impact of sea-lice infestation. The results of Levin *et al.* could potentially reconcile the conflicting observations of high mortality caused by sea lice in 2004 and 2005 and the very high survival rates of wild salmon juveniles in 2003.

There is little doubt that salmon net-pen farming and other forms of net-pen aquaculture will continue to grow around the world. Political responses have been highly variable, ranging from outright banning to wholesale support. The article by Krkošek *et al.* (2) is an important step in providing better scientific information for such policy decisions.

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