The history, science and future of stocking

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We have been stocking salmon for a long time. From the middle of the nineteenth century salmon managers have been collecting adults from rivers, breeding them in hatcheries, rearing their offspring to some age, then releasing those offspring back into rivers to interact with wild-born fish. When we started stocking Darwin and Wallace were still developing their ideas about how natural selection drives adaptive evolution. Mendel was breeding peas to uncover the simplest principles of inheritance. By breeding and rearing salmon in hatcheries, we were driving maladaptation by artificial selection before we even understood adaptation by natural selection.

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During the first half of the twentieth century paleontologists, evolutionists, ecologists, and geneticists drew upon the ideas of the early naturalists to study everything from fruit flies to dinosaurs. By the middle of the twentieth century this collective effort culminated in a period known as the Evolutionary Modern Synthesis. The goal of naturalists changed from naming and counting organisms to understanding how animals came to be, and not to be.

Salmon managers were not paying attention. They were busy refining and industrializing hatchery technology, resulting in the first collateral catastrophe of stocking: the damming of many of the world's great salmon rivers. Had we not been able to build huge hatcheries to replace fish lost by building dams, surely fewer would have been built— public outrage and commercial fishers wouldn't have allowed it. But when hatcheries offered society the promise of electricity, water for irrigation and drinking, *and* salmon, destroying river ecosystems was easy.

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Not content with domesticating the freshwater phase of the salmon life cycle, salmon managers then applied hatchery technology to the saltwater phase. The result was the second collateral catastrophe of stocking: salmon aquaculture. The industry emerged during the golden age of ecology. Methodological and technological advances helped test and expand the ideas of the Modern Synthesis. At universities, departments of zoology and botany became departments of ecology, evolutionary biology, and environmental management. The field of conservation biology emerged to inspire early environmental legislation. Ecology now stood next to chemistry and physics as a world-changing science.

Still, salmon managers paid no attention. Until 1977. That year Reginald Reisenbichler and John McIntyre published the results of a simple experiment. They put eggs from wild and hatchery steelhead together in stream enclosures and hatchery ponds and asked which survived better where. Wild fish survived better in the stream enclosures and hatchery fish survived better in the hatchery ponds. The result offered a simple conclusion that should have been obvious for over a century: if wild salmon are put in a hatchery and exposed to artificial selection, they will become adapted to the hatchery environment and thus maladapted to the wild. This conclusion, in turn, supported two predictions. The first was that if a wild population is supplemented with hatchery fish, the per-capita number of smolts the population's adults produce is reduced and, as a result, the number of returning adults is reduced. Stocking reduces a population's productivity. The second prediction was that this damage could be ameliorated if only local, wild-born fish are used as brood stock.

It is hard to overstate the importance of these two predictions. They have guided hatchery management and stocking science ever since. For hatchery proponents it was a win-win. Where wild salmon don't matter, we can stock. We can establish domesticated hatchery populations, clip the adipose fins of stocked juveniles, and offer commercial and sport fishers salmon to harvest. Where wild salmon do matter, we can still stock. We can use wild broodstock and integrated hatchery populations, and get more adults without damaging the wild population.

The first prediction is really just the fundamental principles of evolutionary and population ecology reworded: adding maladapted individuals to a population reduces population productivity. Five decades of research suggests the second prediction turns out to be false. Whether domesticated hatchery fish or wild brood stock are used to produce juveniles for stocking, returning hatchery adults reduce population productivity by the same per-capita amount. But the mechanisms are different. Stocking with juveniles from domesticated hatchery populations reduces population productivity mainly because the fish are so maladapted (think aquaculture escapees) that hatchery adults produce only about 10% as many offspring as wild adults. Stocking with juveniles from wild brood stock reduces population productivity in part for the same reason — salmon become maladapted after a single generation in the hatchery, and first-generation hatchery adults will produce only half as many offspring as wild fish. But there is also another mechanism. Because they are relatively fit, such hatchery adults (or their offspring) will also interbreed with wild fish, making their offspring maladapted as well!

There is one scenario where it *might* be rational to *consider* imposing stocking on a wild salmon population: when a population is so small that it is at risk of imminent extirpation from "demographic stochasticity". When there are tens (not hundreds) of adults, a population may disappear due to simple bad luck. If, by chance, all the adults fail to reproduce at the same time, then poof, the population is gone. This is only a concern for very small populations that cannot be "rescued" by immigrants from neighbouring populations. Two things happen when such a population is stocked. First, to meaningfully increase adult population size, the ratio of hatchery fish to wild fish must be large, so the evolutionary damage inflicted through genetic introgression is severe and population productivity declines rapidly and dramatically. Second, the wild-born offspring of the hatchery adults and hybrids of hatchery-wild crosses will have adipose fins, and thus be available for use as "wild" brood stock. Such serial intergenerational exposure to artificial selection results in a toxic evolutionary cascade: a small, increasingly maladapted and decreasingly productive wild population. In many regards the worst possible thing that managers can do to a small wild salmon population is to subject it to a demographically meaningful wild broodstock conservation stocking programme.

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So what do we do when confronted with an unequivocal evidence-based scientific consensus that stocking compromises the evolutionary integrity and ecological status of wild salmon populations? We keep stocking.

The glaring disconnect between scientific consensus and management practice reveals that the "stocking problem" is a social, political and economic one. We thus need to identify, understand and challenge the pathologies that compel and perpetuate irrational management interventions. I offer a few reasons why we stock when we know we should not. Embracing alliteration, my "Seven Hs" elaborate on the "Four Hs" threatening wild salmon more generally: Habitat, Harvest, Hydropower, Hatcheries.

Habit. We stock mostly because we stock. It is far easier to build a hatchery than close a hatchery. Hatcheries bloat agency budgets and provide jobs. Bad habits are hard to break.

High. People love fish like drugs: the more the better. Salmon hatcheries engage, inspire and inform. For anglers, school children, tourists and politicians, a salmon hatchery can't possibly be bad for salmon.

Hubris. Gary Meffe's original description of large, industrial hatcheries as manifestations of "techno-arrogance" applies to all stocking. We cannot resist using technological interventions to "solve" ecological problems.

Honour. No one likes to admit being wrong. Agencies, corporations, organisations and individuals have staked their reputations and resources on hatcheries. Intransigent pride can compel otherwise rational actors to behave irrationally.

Hope. Blind faith sees no evidence. No matter how much evidence we compile demonstrating stocking harms wild populations, people will hope — that *their* stocking programme or river or salmon are somehow different, immune from the fundamental rules of evolutionary and population ecology.

Heresy. If hope is understandable, the cynical dismissal of evidence-based scientific consensus is indefensible. Science denial afflicts society more generally, making it acceptable, even admirable, to dismiss scientific consensus as no more valid than a personal opinion.

h-index. Salmon biologists share the blame. We are judged in part by our papers. Increasing our Google Scholar *h-index* (the number of papers *h* with at least *h* citations) requires publishing more, and more interesting, papers. We are trained to seize any funding, amplify uncertainty, and state our conclusions cautiously and objectively. At best, we tacitly support stocking just to do our jobs. If offered money to study stocking, we don't say "No, you dummies, stop!" We take the money, joke about the dummies spending it, and write the best papers we can. At worst, we amplify managerially irrelevant uncertainty ("I can never be certain") in betrayal of the precautionary principle, or refuse to forcefully articulate the scientific consensus in the name of apolitical objectivity ("It is not a scientist's place to judge management"). Stocking science is political. Scientists who study stocking have a responsibility to be so too.

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Despite these challenges, there is reason for hope. The citizens of most nations lucky enough to have native wild salmon have decided that the evolutionary integrity and ecological status of wild salmon matter. The majority of native wild salmon populations are officially protected by potentially powerful environmental legislation. Furthermore, every nation (except of course the United States) has signed the Convention on Biological Diversity, and has thus committed to managing wild salmon through the rational, evidence-based application of the precautionary principle.

So how do we reduce the future threat of stocking to wild salmon?

We need to be rational. The scientific evidence is clear: stocking is punitive not mitigative. Many stocking programmes are initiated because a dam is built, or habitat is lost or degraded, or chemicals are spilled, or a population is overfished, or marine survival is low. We need to honestly acknowledge our mistakes, accept environmental variation and climate change, then address those threats we can. Subjecting what wild fish remain to stocking is almost always some combination of dumb, wasteful and damaging.

We need to be precautionary. The North Atlantic Salmon Conservation Organization (and its member states) *still* lists stocking as a tool of rebuilding programmes for wild salmon populations below their "Conservation Limit". But populations below their Conservation Limit will rarely be at risk of imminent extirpation. Conservation Limits are aligned to the carrying capacity of a population's river. A population with tens of thousands of adults can be below its river's carrying capacity and thus fail to meet its Conservation Limit. Those salmon need stocking less than they need bicycles.

We need to be realistic. We will not quit stocking any sooner than we will quit burning coal. But we can at least admit that when we do it, we don't care about wild salmon. So if we want a fish farm on Iceland's Ronga so people can fly from around the world to catch and kill salmon, that is ok. And when Oregon (USA) decides to manage some rivers for harvesting hatchery fish, and others for catching and releasing wild fish, that is ok too.

We need to be brave. It is possible to stop stocking. In 2014 Natural Resources Wales ended salmon and sea trout stocking across the entire country of Wales despite an overwhelming majority of consultees wanting stocking to continue. The angling community was outraged. Just as when people were told they had to wear seatbelts or couldn't smoke in pubs, the clamour fades.

We need to be grateful. For all the direct and indirect damage that hatcheries and stocking have inflicted upon wild salmon, we now have the technology to create salmon zoos. Complete life-cycle captive breeding programmes have, and will have, a place in maintaining live gene banks, saving populations from extirpation, and preserving unique evolutionary lineages. Be it Sockeye salmon from remote Idaho (USA) lakes that have been decimated by hydropower, or Atlantic salmon in the Bay Fundy (Canada) disappearing due to aquaculture, we can now maintain those populations in captivity. It may not always be rational to do so, but we can do so.

We need to be optimistic. Salmon are ecologically resilient and evolutionarily adaptable and have huge native ranges in the world's richest nations. Across most of those ranges we have done everything in our power to get rid of them. And we have mostly failed. Large populations of all species exist, and viable populations remain throughout much of their historic ranges. Left alone salmon will colonize habitat made available and their populations will grow. Even with the climate emergency, there is reason to believe the 21st century will be better for salmon than the 20th. Ranges will expand North, where freshwater habitat is least damaged. We will build fewer dams than we remove, we will manage our land and rivers better, we will kill fewer wild adults at sea, and aquaculture will transition to closed-containment production. And we will stock less.

Wild salmon will be with us forever. As thanks, we owe them better.

Further Reading:

R.R.Reisenbichler and J.D.McIntyre, 'Genetic Differences in Growth and Survival of Juvenile Hatchery and Wild Steelhead Trout, *Salmo gairdneri*, Journal of the Fisheries Research Board of Canada 34.1 (January 1977), pp.123–8.
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