STEPHANIE PEACOCK

Fish in troubled waters

In concert with **Drs Mark Lewis** and **Martin Krkošek**, **Stephanie Peacock** describes the team's collaborative research to understand the decade-long questions of if and how farmed salmon are impacting wild populations in Pacific Canada

What are the key aims of your current research?

We seek to understand how parasites, amplified by open-net salmon farming, impact wild salmon in Pacific Canada. Understanding if and how a burgeoning aquaculture industry may affect this important resource is an important conservation question.

You were the first to report evidence of a population-level effect of sea lice from salmon farms on wild salmon. Previously this relationship was disputed, can you explain why?

Data indicated that salmon populations in regions of aquaculture had declined concurrently with sea louse epidemics. The implications were that the spread of parasites from farmed salmon could have harmful effects on wild salmon populations and, by extension, the ecosystems and human communities that depend on wild salmon.

Some people would still dispute that relationship. Our analyses of wild salmon survival in relation to sea lice are correlational and not the result of controlled manipulative experiments. There is always the possibility that salmon populations in areas of aquaculture declined due to some other factor that happened to occur at the same time as sea louse infestations. However, no such factors have been identified. There have been manipulative experiments in Europe where out-migrating salmon are treated with drugs that prevent sea louse infestations, and those groups of treated fish almost always have higher survival rates than untreated groups. Together, correlative analyses in Canada and experimental results from Europe paint a clear picture.

What methods do you employ in your work?

One of the most important aspects of this work has been regular monitoring of out-migrating juvenile wild salmon for sea lice. That is the most direct measure of the potential for impact on wild salmon. We have been able to collect these data non-lethally, returning salmon samples to their migration routes after a quick look at them under a hand lens in clear plastic bags. This method is almost as accurate as lethal sampling, takes far less time and money and saves thousands of fish each year.

Are there repercussions associated with local extinction of pink salmon? How likely is this scenario?

Each fall, when salmon return to spawn, they flood terrestrial ecosystems with key oceanic nutrients and are a food source for many other species. Similarly, when salmon eggs hatch in the spring, those small fish are a feast for other fish and birds. If the salmon disappeared, charismatic species like killer whales, bald eagles, bears and wolves would likely leave the area, or die.

Dire predictions of louse-induced extirpation have not yet been realised, buying some time for industry to develop more permanent solutions, such as closed-containment aquaculture. Chemically treating farmed salmon is working for now, but sea lice can evolve resistance to drugs and have done so in other regions, such as Atlantic Canada and Europe.

Why do scientists encounter challenges with conveying their concerns to industry?

Aquaculture is a for-profit industry, and conserving wild salmon comes with a cost that could stand in the way of profit margins. For example, a move to closed-containment aquaculture would completely remove the potential for disease interactions between wild and farmed salmon, but right now that technology is expensive for salmon farms. Public pressure can be very effective at encouraging industry to change their perspective on wild salmon conservation. The industry needs people to buy their product, and so if people are concerned about the impacts that product might have on wild salmon, then both industry and government will respond to address those concerns.

This has presented a unique challenge for us as scientists. It hasn't been enough to publish our findings in a scientific journal and move on. Part of our job is to make the research accessible to stakeholders, policy makers and the public so that they can make informed decisions.

How will your research benefit wild salmon moving forward?

Despite challenges, great progress has been made over the past decade in understanding the transmission of sea lice between farmed and wild salmon, and subsequent impacts on wild salmon populations. As new pathogens emerge with the potential to spread between wild and farmed salmon, it's important to remember the lessons we've learned by studying sea lice, and not reinvent the wheel.

A salmon farm in the Broughton Archipelago, 2012. Photo credit: Stephanie Peacock

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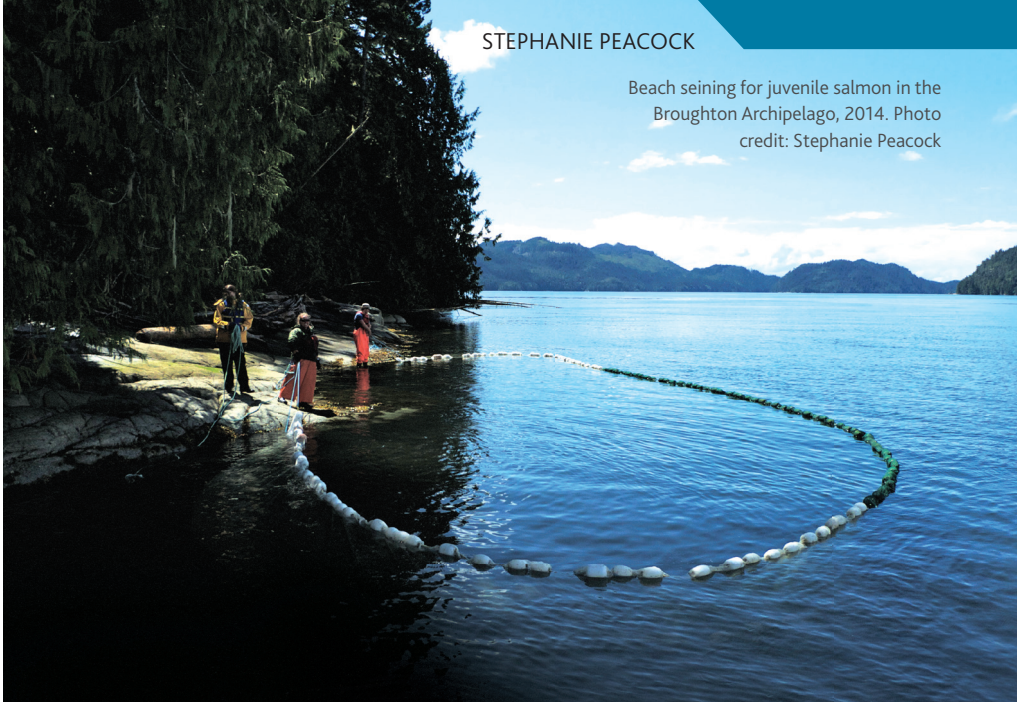

Beach seining for juvenile salmon in the Broughton Archipelago, 2014. Photo credit: Stephanie Peacock

Balancing salmon

According to researchers at the **University of Alberta** and **University of Toronto**, small management changes on salmon farms can have big benefits for the wild salmon population of Pacific Canada

WILD SALMON IN Pacific Canada are an important ecological, cultural and economic resource. One human activity that currently threatens wild salmon populations is open-net salmon farming. Open-net salmon farms hold fish in pens that allow the flow of water, and any pollutants or pathogens, into the coastal environment. Over a decade ago, fishermen and biologists in the Broughton Archipelago, in British Columbia, Canada, noticed sea louse parasites (*Lepeophtherius salmonis*) appearing in large numbers on migrating juvenile pink and chum salmon. This observation motivated researchers to investigate the potential link between these parasites on wild salmon and the burgeoning salmon farming industry. Could sea lice transmit between farmed and wild salmon? If so, what were the implications for the survival of wild salmon populations?

These questions have proved difficult to answer, with predation, competition, climate, disease and fishing all muddying the waters. "It's really detective work, trying to figure out what's happening with these salmon populations. The data on wild salmon numbers in rivers and catch in fisheries, although abundant, are often patchy and imprecise," Stephanie Peacock from the University of Alberta, Canada, explains. Even with perfect data, it can be difficult to determine the unintended consequences of sea louse epizootics on salmon farms. Host fish in the wild interact with the broader ecosystem and secondary impacts, for example, predation susceptibility, can be important.

LOOKING FOR LICE

In 2003, an interdisciplinary team of biologists and mathematicians comprising Drs Mark Lewis (University of Alberta), John Volpe (University of Victoria) and Martin Krkošek (University of Toronto), among others, joined forces to apply their diverse skillsets to the problem. The need to bring together quantitative models, observational datasets and field experiments necessitated expertise from a range of scientific disciplines. The team sought answers to the observed increases in sea lice on migrating juvenile salmon in the Broughton Archipelago. They intended to determine if and how salmon farms in the surrounding area might be contributing to the parasite outbreaks, and impacting the health of the wild salmon populations.

At the time, the possibility that sea lice from salmon farms were harming wild populations was vehemently disputed by government and industry, who were understandably reluctant to admit such a stumbling block in the midst of the 'blue revolution'. Even if salmon farms were transmitting lice to wild fish, they argued, there still needed to be evidence that the lice were affecting the survival of the wild populations.

Krkošek and his team were the first to report evidence of population-level effects of lice from farmed salmon on wild pink salmon in a 2007 paper in the journal *Science*. They predicted that if sea louse epizootics continued, pink salmon could disappear from the Broughton

THE IMPACT OF FARMED SALMON ON WILD SALMON POPULATIONS IN PACIFIC CANADA

OBJECTIVE

To understand how sea louse parasites, amplified by open-net salmon farming, impact wild salmon in Pacific Canada.

KEY COLLABORATORS

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FUNDING

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STEPHANIE PEACOCK is a PhD candidate in Biological Sciences at the University of Alberta. Her doctoral research uses a combination of modelling, long-term datasets and field-based experiments to understand parasite impacts on wild salmon.

DR MARK LEWIS is a mathematical ecologist at the University of Alberta. His work investigates problems in ecology and environmental biology using mathematical and statistical models.

DR MARTIN KRKOŠEK is an ecologist at the University of Toronto. He works on problems in fisheries, epidemiology, and conservation.

In an area of research that is so closely linked to both industry and local communities, striking a balance that benefits everyone is a difficult task

Archipelago within four generations (eight years). Despite this, controversy surrounding the relationship continued, in part because the data implied a correlation between the onset of salmon farming and pink salmon declines, and was not the result of a controlled manipulative experiment. To add confusion, another group of scientists analysed the same data with contradictory results implying that sea lice had no effect on wild pink salmon. So, were pink salmon in the Broughton Archipelago really at risk?

In response, Krkošek, Lewis and others re-analysed the pink salmon data from their 2007 study, also taking into account data from coho salmon. This research corroborated the team's earlier findings that lice were being transmitted from farmed salmon to the wild populations, showing that effects can be measured at the population level. Furthermore, their study showed that the conclusions from contradictory reports were flawed, because of low statistical power to detect an effect of sea lice on pink salmon.

IN THE PINK

In 2014 wild pink salmon are still returning to rivers in the Broughton Archipelago. Most would agree that this is good news, but what does it mean for those dire predictions made in 2007? Subsequent work by Peacock, Krkošek and Lewis has found that changes in the timing of louse treatment on salmon farms has benefited wild salmon. They have been able to measure a reduction in sea lice not only on farms, but directly on juvenile wild salmon. To do this, they assessed thousands of migrating juvenile wild salmon for lice from 2001-09. These data were collected non-lethally by examining living salmon under hand lenses before returning them to the wild.

The switch to treating farmed salmon in autumn and winter, as opposed to spring, resulted in a significant decrease in the number of sea lice on farmed salmon at the crucial period when juvenile wild salmon were migrating past farms. The wild juveniles are particularly susceptible to lice at this young age. The researchers found earlier treatment resulted in fewer lice on wild juveniles, and consequently halted the precipitous declines in wild salmon survival. Mortality rates for juvenile pink salmon due to lice fell to less than 4 per cent after farmed salmon were treated in the winter months, reiterating the relationship between wild and farmed populations.

However, chemically treating farmed salmon will never be a permanent solution. Parasites can quickly evolve resistance to drugs, and this has happened in other regions, like Atlantic Canada and Europe. The prediction of a population wipe out has not yet been realised, buying time for industry to find a more permanent solution. Peacock and her colleagues argue that the only way to completely prevent disease transmission from farmed populations to wild salmon is to transfer the farmed fish stock to closed-containment aquaculture, but this is expensive. In an industry driven by profit margins, conserving wild salmon populations could stand in the way of financial success.

CHALLENGES PAST AND PRESENT

Despite the challenges in understanding the relationship between aquaculture and wild salmon populations, progress has been made. One of the biggest hurdles has been to engage with industry and policy makers to promote data sharing and implement recommendations: "In the case of salmon and sea lice, a lack of openness between industry and the scientific community was a major barrier early on," Peacock comments. "Although this is still a barrier, relationships between industry, government and scientists have improved in recent years and data have been made more available."

The researchers also emphasise the challenge of communicating their findings outside of the scientific community. In this field, part of the modern scientist's job is to make their work accessible to stakeholders, industry experts, policy makers and members of the public so that their science can affect change. The most effective way to encourage change from industry is to get the public on board with the environmental message. In an area of research that is so closely linked to both industry and local communities, striking a balance that benefits everyone is a difficult task.

Moving forward, it is vital to continue to monitor wild salmon populations and to apply what has been learned from sea lice to emerging infectious diseases. As aquaculture continues to expand in Canada and around the world, there is the potential for new pathogens to emerge, for present ones to evolve, and for novel interactions between wild and farmed fish. Much like the industry built on this animal, the ecosystems that salmon support are in a delicate balance.