Marine Policy 74 (2016) 205–212

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

# Risk and precaution: Salmon farming

Alexandra Morton[a,*], Richard Routledge[b]

[a] Raincoast Research Society, Box 399, Sointula, BC, Canada V0N 3E0
[b] Department of Statistics and Actuarial Science, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada V5A 1S6

ABSTRACT

The salmon farming industry uses coastal, temperate marine waters to culture salmon in flow-through net pens. As marine currents pass through salmon farms, pathogens are carried in both directions between two highly contrasting environments. When wild fish are infected with pathogens spilling from the farm environment, the natural mechanisms that work to prevent epizootics become inoperative. The 18-year decline of Canada's largest salmon fishery, on Fraser River Sockeye Salmon, triggered a comprehensive federal commission to determine the cause. Two of the recommendations from this commission call for removal of the salmon farms from the Discovery Islands of British Columbia (BC), a bottleneck in the Sockeye Salmon migration route, if the evidence indicates that the industry generates greater than minimal risk of serious harm to the Fraser River Sockeye Salmon. Risk is interpreted as a probability and 'minimal risk', in the context of the Precautionary Principle, as a cut-off level on the strength of the scientific evidence needed to justify precautionary measures. Here the available evidence of the risk caused by sea lice and viruses from salmon farms on wild salmon is considered. From this perspective, the evidence is unambiguous. Salmon farms in the region of the Discovery Islands generate greater than minimal risk of serious harm to Fraser River Sockeye Salmon. Furthermore, there is no evidence that the risk factors identified are specific to Fraser River Sockeye Salmon, as many of them apply to other areas and salmon species in the north eastern Pacific and globally.

## 1. Introduction

The threat to ecological systems posed by agricultural activity is significant [3]. The risk of pathogen transmission from farmed to wild salmon has been demonstrated [17,44], and open-net sea-pen salmon culture is recognized as a coastal ecosystem modifier across trophic levels [18], epidemiologically linking vastly separated wild salmonid populations [43]. There is also a long history of large-scale, unforeseen, negative consequences due to accidental import of exotic pathogens [45]. It is the primary cause for disease emergence in wild fish [93], with potentially irreversible effects [91]. [26] reported reduced survival and abundance of wild salmonids for all populations exposed to salmon farms in North America and Europe as compared to both (i) unexposed populations in Alaska and the western Pacific and (ii) less-exposed regions within salmon farming countries.

Marine waters are an exceptionally efficient pathogen dispersion medium [86]. Thus pathogens may pose particularly severe risk to ocean biodiversity [64]. When an infective agent enters a farmed environment, it is released from critical limits to growth. If allowed to spill back into the wild environment, it can generate unnaturally elevated local pathogen levels [72]. Indeed, salmon farms have been described as 'pathogen culturing facilities' [4].

In addition to elevating local pathogen levels, feedlot-type environments promote an increase in virulence [22,45]. Increased virulence of pathogens in farm salmon has been observed with viral haemorrhagic septicaemia virus VHSV [23], infectious salmon anemia virus, ISAV [74] and *Flavobacterium columnare* [82].

When assessing the threat posed by salmon farm-origin pathogens to wild fish, one must look beyond direct mortality, as subclinical infections can have unforeseen ecological consequences, e.g. reduced feeding success or weakened predator avoidance [91].

The salmon farming industry has imported 30 million Atlantic salmon eggs into BC from Norway, Scotland, Ireland, eastern Canada and the USA since 1985 [20]. The majority of salmon reared in net pens in BC are Atlantic salmon of the Norwegian Mowi strain [100].

### *1.1. Fraser river sockeye salmon (*Oncorhynchus nerka*) population decline*

The 18-year, more than three-fold decline in productivity of the Fraser River Sockeye Salmon (number of adult Sockeye Salmon divided by the number of spawning adults in the parent generation) triggered the $37 million federal Cohen Commission Inquiry (Fig. 1). While reduction in fishing ensured that a viable numbers of spawners entered

* Corresponding author.

http://dx.doi.org/10.1016/j.marpol.2016.09.022
Received 11 July 2016; Received in revised form 12 September 2016; Accepted 12 September 2016
Available online 26 September 2016

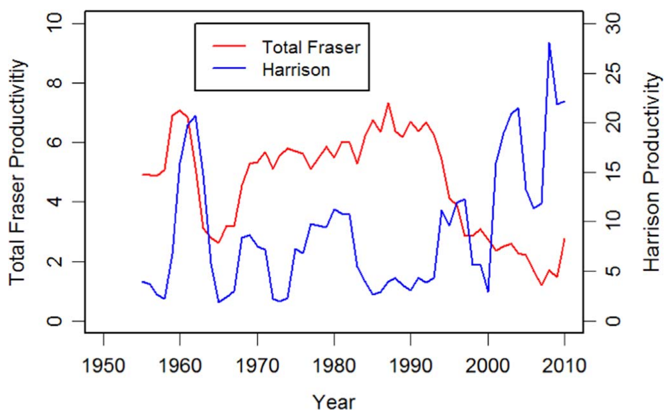


**Fig. 1.** Comparison of historic productivity between total Fraser River Sockeye Salmon and the Harrison River Sockeye Salmon component. This is a four-year moving average of total adult returns per spawner (not including the minor jacks component) divided by the total spawning adults in the parent generation 4 years before. Return year is the last year of the four used to produce the moving average. The horizontal dashed line indicates the productivity at which the population can replace itself without any fishing pressure, i.e. returns/spawner=1. (Data Courtesy of the Pacific Salmon Commission).

the river annually and freshwater survival from spawners to juveniles was high, the survival rate during the marine phase, from smolts to spawners, was very poor [79]. By contrast, the Harrison River component of this total demonstrates a surprising contrasting pattern of increasing productivity over roughly the same time period (Fig. 1).

There are two known marine migration routes for juvenile Fraser River Sockeye Salmon after they leave the river. The route used by most of these populations appears to be north along the eastern shore of Vancouver Island [96]. The DNA of the Harrison River Sockeye Salmon [96], however, has been identified only along the alternate route on the west side of Vancouver Island (Fig. 2). The two different migration routes represent contrasting exposure to farmed salmon. The group migrating along eastern Vancouver Island are exposed to a series of the heaviest concentrations of salmon farms in BC, while fish migrating along the southern route are largely unexposed.

### *1.2. Cohen commission of inquiry into the decline of the sockeye salmon in the fraser river*

The Cohen Commission produced 75 recommendations [13] to reverse the decline of the Fraser River Sockeye Salmon. Two of these recommendations, 18 and 19, specify conditions for the removal of salmon farms from a specific region of the BC coast, called the Discovery Islands (Fig. 2). These recommendations are based on evaluation of the risk to Fraser River Sockeye Salmon posed by salmon farms sited in a bottleneck-type area on their migratory corridor.

**Recommendation 18**: If at any time between now and September 30, 2020, the minister of fisheries and oceans determines that net-pen salmon farms in the Discovery Islands [on a major juvenile migration route for Fraser River sockeye salmon] pose more than a minimal risk of serious harm to the health of migrating Fraser River sockeye salmon, he or she should promptly order that those salmon farms cease operations.

**Recommendation 19**: On September 30, 2020, the minister of fisheries and oceans should prohibit net-pen salmon farming in the Discovery Islands unless he or she is satisfied that such farms pose at most a minimal risk of serious harm to the health of migrating Fraser River sockeye salmon. ….

The risks associated with the salmon farming industry to be evaluated for the Discovery Islands region are threefold; (i) risk of introduction of exotic pathogens, (ii) risk of amplification of exotic or endemic pathogens and parasites, and (iii) risk of pathogen mutation to higher levels of virulence.

The Cohen Commission recommendations offer remedy to a global societal issue – how to manage risk when common resources and private industry collide. Below is a framework for assessing risk portrayed by the scientific literature on the impact of salmon farms on Fraser River Sockeye Salmon in the region of concern, the Discovery Islands.

### *1.3. Minimal risk*

The invocation of Recommendation 18 requires evidence of “more than minimal risk of serious harm”. Recommendation 19 reverses the burden of proof and recommends a date for a specific action unless evidence is produced that can demonstrate that the risk of serious harm is indeed minimal.

There are two questions related to these recommendations:

- Is there currently sufficient evidence to invoke Recommendation 18?
- What sort of evidence would be needed by September 30, 2020 to nullify Recommendation 19?

Step one is to assess formal statements of ‘risk’ to determine an appropriate interpretation of ‘minimal risk’ and then survey currently available evidence associated with this risk and assess its strength in light of this interpretation.

In order for a ‘risk’ to be judged as minimal, the only interpretation of several provided by either the Oxford English Dictionary (www.oed.com accessed July 9, 2016) or Merriam-Webster's Dictionary (http://www.merriam-webster.com accessed July 9, 2016) is as a probability – in this context as the probability of serious harm to wild Pacific salmon. Probability is also the only technical definition of ‘risk’ reported by [9] to be in common, non-technical usage and so ‘risk’ as a probability.

The question then becomes: How large must a probability become before it is judged as greater than ‘minimal’? In this case, Justice Cohen [14] used, in his words, “the precautionary principle to guide [his] consideration of the appropriate response to the risks that salmon farms pose to the future sustainability of Fraser River sockeye.” This principle is used to guide the appraisal of whether the risk of serious harm to the Fraser River Sockeye Salmon is minimal.

By the strictest definition, ‘minimal’ means as small as possible. However, this interpretation must be dismissed because, if there is any uncertainty whatsoever, the only way to achieve minimal risk of serious harm would be to routinely ban any human activity that might conceivably cause harm. As critics of the Precautionary Principle have pointed out (e.g., [92,97], such a rigorous interpretation would rule out innovation of any sort, and would even stifle discovery [39]. Therefore it is more reasonable to use the alternative interpretation of ‘minimal’ as either very small or negligible.

The key question in assessing the evidence associated with the Commission's Recommendations 18 and 19 then becomes: Is the probability of serious harm more than negligible? Experience informs us of two inherent difficulties in answering such a question. First, the nature of the uncertainties is typically so profound that the probability is incalculable [37], e.g., argue against using methods of formal risk analysis to estimate probability of serious harm, pointing to the common theme of unanticipated surprises, such as the role of CFC's as catalysts in the destruction of stratospheric ozone. Such unidentified factors cannot be incorporated in any rigorous way into a calculation of the probability of serious harm. They promote the adoption of an attitude of humility and vigilance in the presence of such ‘ignorance’ of the often-complex nature of the underlying dynamics.

With a formal calculation of such probabilities off the table, one is left with a qualitative assessment of the viability of the evidence pointing to the potential for serious harm. The primary question then becomes: Does the viability of the available evidence exceed some appropriate minimal threshold above which a reasonable person might view the risk of serious or irreversible harm as greater than minimal? This is indeed the key question in many similar instances [31].