Summary of Scientific Papers on Impacts of Open Net Pen Farming on Wild Populations and the Natural Environment*

As new and relevant science becomes available, it will be added to this document. This review is not meant to be an exhaustive review of the literature, however it is intended to cover the most recent and pertinent research on the impacts of open net pen salmon aquaculture.

General Impacts

- A meta-analysis of wild salmon mortality in rivers adjacent to salmon farms found an increase of 50% mortality over populations with no farming near by (Ford & Myers 2008). The study collected data globally, and proposed several mechanisms for this increase mortality, several of which are discussed below.
- The February 2012 Royal Society of Canada report on Canadian marine diversity summarizes peer reviewed literature and makes the following conclusions regarding the impacts of aquaculture in Canada on biodiversity

Major Findings on Aquaculture impacts on Canadian Biodiversity (RSC 2012)

- Aquaculture of finfish (e.g., salmon) and shellfish (e.g., mussels) typically affect marine biodiversity at localized scales (less than tens of kms), although farther-reaching impacts are possible.
- Wild bottom-dwelling organisms and their habitat can be affected by organic wastes and chemical inputs, such as antibiotics, anti-foulants, and pesticides.
- Exchange of pathogens between farmed and wild fish can seriously threaten the persistence of wild fish populations.
- Interbreeding between wild fish and escapees of the same species threatens the reproductive capability and recovery potential of wild populations of conservation concern.
- Open-sea net pens have far greater potential and realized negative consequences to marine biodiversity than closed-containment facilities.
- The primary biodiversity concern associated with shellfish aquaculture is the farming of non-native species in Canadian waters and the high density of culture in some regions.

Sea Lice and Wild Salmon

- Sea lice are copepod crustaceans which live on the outside of salmon and feed on their mucous, skin and blood. Though most ocean-going adult salmon carry sea lice, juveniles in coastal waters do not (Chapter 5, Royal Society of Canada 2012).
- Migrating juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) were sampled as they passed a salmon farm on their migration to the open ocean. Infection pressure for sea lice was up 73 times greater near the farm than ambient levels; likelihood of infection was found to be above ambient levels up to 30 km surrounding the salmon farm. Additionally, sea lice already infecting the wild juveniles were able to reproduce during their migration and re-infect the juveniles which increases the range of the farm's effect on infection to 75 km Krkošek et al. (2005).
- Fish infected with sea lice face increased mortality due to a reduced ability to avoid capture and a general decline in fitness, which can result in increased predation risk (Krkošek et al. 2011).
- There is evidence that the increased abundance of sea lice on fish farms has had a negative impact on the general productivity of wild salmon populations in the Broughton Archipelago, BC (Krkošek et al. 2011a), though this is still a matter of some debate.
- While there has been little research done on the effects of sea lice surrounding salmon farms on the east coast of Canada, it is unreasonable to assume that performing the same studies here

would not yield similar results. Of course, there are ways of controlling sea lice by way of pesticides which unfortunately introduce a number of additional problems.

Pesticides

- The most common treatment for sea lice is the coating of food pellets with a chemical called emamectin benzoate, also known as SLICE®. Research on the effects of SLICE® on non-target species is relatively limited.
- In Nova Scotia, the main concern surrounding the use of SLICE® is its potential impacts on the American Lobster (*Homarus americanus*) which is an incredibly important to the area as a commercial species. Research shows the lethality of emamectin benzoate to American Lobsters at standard industry concentrations is quite low (Burridge et al. 2004).
- However, there is significant evidence of other harmful but non-lethal effects. Waddy et al. (2002) found that 44% of female lobsters exposed to small doses of emamectin benzoate moulted prematurely, and those which were carrying eggs aborted their brood. This would seriously affect the reproductive ability of wild lobsters near salmon farms and could have a profound effect on Nova Scotia's lobster fishery.
- The question of whether wild lobsters would eat enough of the medicated salmon feed to induce premature moulting still remains to be conclusively answered (Waddy et al. 2007; Waddy et al. 2007a).
- All referenced studies have been performed on adult lobsters, but the effects of this pesticide on lobster larvae is yet to be confirmed.
- In 2009 Slice® ceased to be effective treating sea lice in southwest New Brunswick, leading to increased reliance on other treatment option (Burridge et al., 2010).
- In New Brunswick, in addition to Slice®, a number of pesticides have been administered through "bath treatments", which is the application of a sea lice treatment product directly to the water containing the fish either in a tarped pen (enclosed bottom), skirted pen (open bottom) or a well boat.
- Salmosan® (active ingredient azamethiphos) is currently approved for emergency use in New Brunswick, Nova Scotia, and Newfoundland and Labrador. Burridge et al. (2008) shows that repeated short term exposure to azamethiphos can have lethal and sub-lethal effects on American lobsters.
- Alpha Max® (active ingredient Deltamethrin, a pyrethroid insecticide) was approved for emergency use in 2009 and 2010, but is currently not in use. Fairchild et al. (2010) report that "Pyrethroid insecticides are among the most toxic insecticides known" and that "Among the pyrethroid insecticides, deltamethrin is often the most toxic to crustaceans" (p.iv). In lab conditions Fairchild et al. (2010) found lobsters to be susceptible to deltamethrin at much lower concentration than the recommended treatment dose.
- In 2009 and 2010 there were a number of incidents of dead and dying lobsters found in traps pens and pounds in southwestern New Brunswick. Cypermenthin, a pesticide used in salmon aquaculture but not approved for use in Canada, was detected on these lobsters. A New Brunswick based salmon aquaculture company and three of its executives are facing significant charges under the Fisheries Act in relation to these lobster kills.

Disease

- Because sea lice reduce the fitness of salmon, it leaves them vulnerable to other parasites and disease. The most problematic disease in Atlantic-based salmon aquaculture is the infectious salmon anemia virus (ISA). As the name suggests this causes severe anemia in the fish caused by a binding of the virus to red blood cells. Once infected, there is no treatment and the fish will die. ISA is easily transmitted by blood, feces or possibly passive transmission from seawater (Nylund et al. 1994).

- Sea lice are likely the most prevalent cause of ISA transmission between fish. The virus can be passed from salmonid parent to offspring through vertical transmission (Vike et al. 2008).
- Though the ISA virus is endemic to the Atlantic, transmission and prevalence of this disease is greatly increased on salmon farms due to the high density at which the fish are kept. This poses a huge threat to wild salmon stocks which are already struggling, as it increases the chance of infection and therefore death, particularly when the farm is located near an estuary frequented by a wild population.

Escapes & Gene Transfer

- Open net pen fin fish farming can lead to frequent escapes which can occur as a result of storms or equipment malfunctions. Escapes can have severe impacts on wild populations of salmon. Morris et al. (2008) compiled a series of studies and found that escaped farmed salmon had been found in 87% of the rivers studies within a 300 km radius of aquaculture sites in eastern North America. This included 11 rivers that were home to endangered populations.
- Fleming et al. (2000) found that farmed Atlantic salmon (*Salmo salar*) were competitively and reproductively inferior to their wild counterparts, with less than one-third the reproductive success. Despite their decreased ability to compete, the farm fishes still were able to compete with the native population, as its productivity decreased by more than 30%.
- Hindar et al. (2006) developed a model from a number of experiments on the effects of escaped farmed salmon and their simulations showed significant changes in wild salmon populations within only a few generations and that recovery from this would be quite unlikely.
- McGinnity et al. (2003) found that the interaction and hybridisation of farmed and wild salmon caused an overall fitness depression and could result in the development of an “extinction vortex” in a vulnerable wild population.
- Burridge et al. (2011) assessed the temporal changes in the genetic make up of a population of Atlantic salmon in the Bay of Fundy. The study found a decrease in loci under selection over time, suggesting that the genetic integrity of the wild population may be altered. This could lead to a decrease in the population’s adaptive ability.
- In a review of numerous studies, Carr and Whoriskey (2000) stated that one particular population from the Magaguadavic River in the Bay of Fundy was extremely fragile as a result of small egg depositions and reduced numbers of juveniles.
- In a study of other freshwater streams in New Brunswick, Carr and Whoriskey (2006) found that freshwater hatchery escapees were found in 75% of streams near hatcheries. In the Magaguadavic River, escapees outnumbered wild juveniles in most years.
- Suggestions from the Carr and Whoriskey (2000) review included improving gear to completely eliminate escapements, sterilizing the fish used in aquaculture or creating emergency response teams to trap escapees soon after the event.

Pollution

- With such a high concentrations of fish, large amounts of waste will inevitably accumulate on the bottom under a sea cage. In a study on the effects of rainbow trout (*Oncorhynchus mykiss)* sea cages in Ontario, the invertebrate abundance beneath the cages was significantly reduced (Rooney and Podemski, 2009). There was also a reduction in species richness as a result of organic loading, though both these effects were quite localized.
- Farms in shallower coastal waters tend to have smaller footprints, their impacts tend to be much more intense due to decreased dispersal of waste in shallower waters (Giles, 2008).
- The feed given to farmed Atlantic salmon contains a number of trace metals, including copper, zinc and cadmium, and concentrations of these metals in the sediments below sea cages show high levels of contamination by these metals in a study on Scottish salmon farms (Dean et al 2007). These levels exceeded those deemed acceptable by the Scottish Environmental Protection

Agency suggesting that the abundance of these metals would likely have adverse effects. In this case, the high levels of zinc were directly associated with the fish farm.

- Copper, which is also used in anti-fouling on the sea cages, has been found to have significant effects of the physiology of spiny lobsters, causing alterations to the muscle, gills and heart, as well as having impacts at a cellular level by creating chromosomal aberrations (Maharajan et al. 2011; Maharajan et al. 2012). These effects could seriously impact the survival of American lobsters in the proximity of salmon farms.
- Both zinc and copper have toxic effects on some marine copepods and could also affect recruitment of lobsters by decreasing the survival of larvae (Bielmyer et al. 2006; Lauer & Bianchini 2010; Wong & Pak 2004).

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