PEER REVIEWED

Defining and Monitoring Atlantic Salmon "Health"

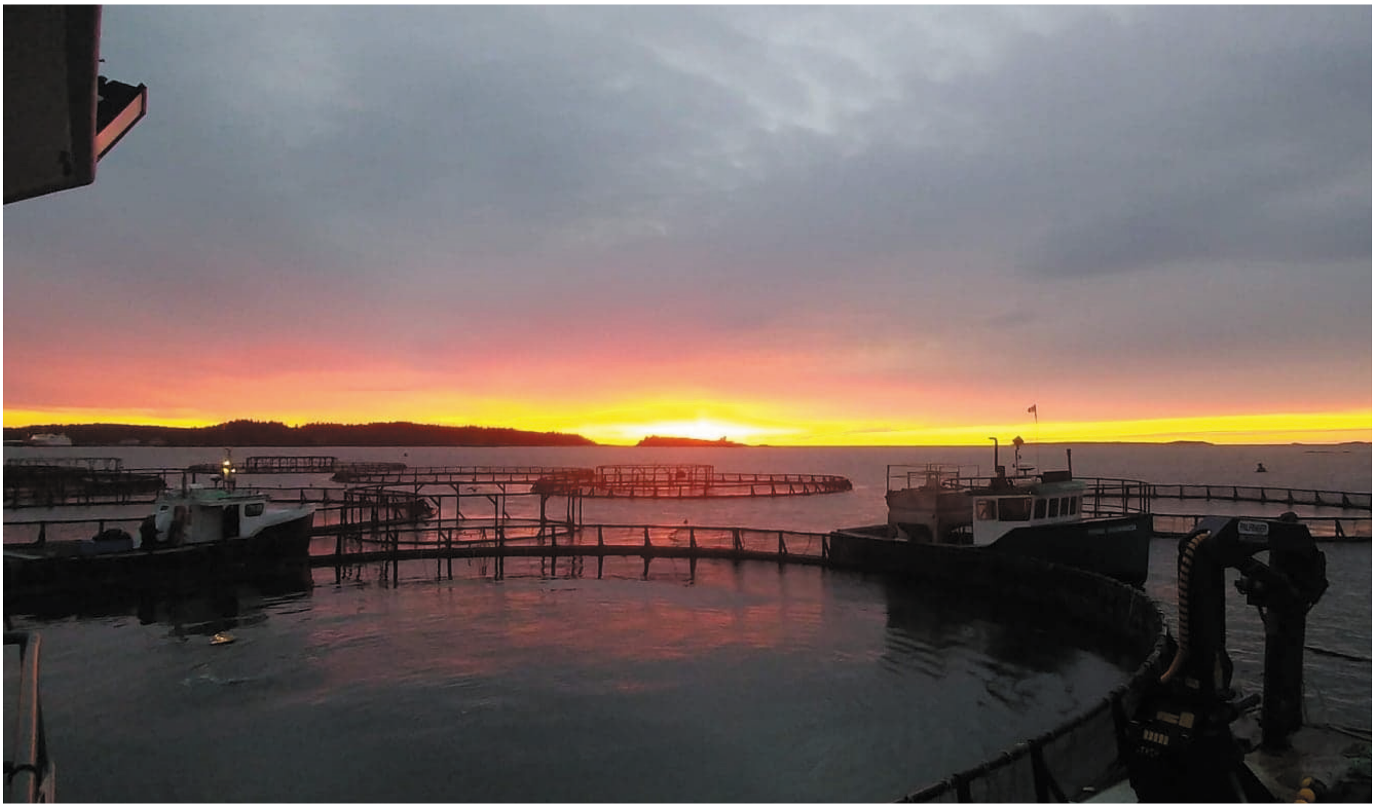
Farming of Atlantic salmon (*Salmo salar* L.) is predominantly carried out in Norway, Chile, Scotland, and Canada. Biphasic in nature, salmon are raised in freshwater inland sites and then typically transferred to saltwater net pens. Whilst production of salmonids contributes only 4.4% to global seafood supply, production of Atlantic salmon has increased by >800% since 1990. Despite being regarded as the most industrialised aquaculture sector, bearing lower risk (economic and biological) than production of other aquatic species, Atlantic salmon culture faces several challenges spanning engineering of culture systems to the assessment and monitoring of stock health.

Output

Farming in an open environment, such as the sea, has several advantages and disadvantages. For instance, intrinsically, production does not require environmental maintenance, which has clear economic and environmental benefits; however, many factors including temperature cannot be controlled. Therefore, when environmental conditions are sub-optimal, significant economic and biological costs can be incurred. In extreme conditions, mortalities are observed and husbandry stress can lead to outbreaks of disease. Furthermore, pathogen exposure through wild reservoirs and passive horizontal drift takes place between sites which are hydrodynamically linked. Unlike the production of terrestrial livestock species, the isolation of infected individuals and populations is not possible in aquaculture production systems, which can lead to high profile culls of stocks, e.g. infectious salmon anemia virus outbreaks in Scotland in 2008 and Chile in 2013. Although culls and remarkably high mortality events are atypical, and despite rapid improvements in culture of the species, full cycle mortality rates of 15–20% are often reported, which is greater than in other intensely cultured species such as in poultry at 3–5% mortality. Losses are multifaceted and are continuously being addressed and improved within the industry. One key area for advancement is in the definition, assessment and routine monitoring of fish health.

Pathogen Screening

Screening of populations for the presence of aetiological agents of infectious disease is ubiquitously utilised in salmon culture. Indeed, all producers incorporate routine pathogen screening in their individual health monitoring programmes. Furthermore, mandatory testing is also performed by governmental agencies to understand livestock status and identify any risks to wild populations. Analytical methodologies depend on the company, management area, country, and the specific pathogen(s) of interest. However, reverse transcription polymerase chain reaction (RT-PCR) is by far the most widely utilised method for screening. This method is comparatively sensitive and quick compared to other assays, e.g. ELISA, and bacterial and viral isolation respectively. However, for many pathogens, positive detection by RT-PCR may not infer clinical outbreaks or immediate risk of such. Therefore, monitoring of pathogen profiles and inferred loads (by gene target copy number) are continuously being improved, as is the understanding of interactions when multiple pathogens are present and R1 of these diseases. Typically, fish tissues collected for pathogen detection are accrued through lethal sampling which can lead to a reluctance for proactive screening of live fish. In an effort to minimise lethal sampling, small percentages (< 0.1%) of total populations are sampled or, a screening bias introduced when only moribund and/or dead fish are sampled. When mortalities begin to rise on sites, sampling of larger numbers of animals often occurs but such practices are reactive and can leave minimal scope for successful intervention. Whilst the aquatic environment and ex vivo stability of disease agents can leave stocks vulnerable, it also



A typical Atlantic salmon net pen production site in Eastern Canada

offers the opportunity for monitoring of the environment to understand risk in a non-invasive manner. Indeed, dramatic advances in biosensors and methods for pathogen detection in water column, waste, and biofilms have been made in the last five years. Despite this, a focus on pathogens and clinical disease – rather than health – reduces the welfare and economic benefits of any monitoring regimen.

Health

The presence of pathogens does not infer clinical disease, nor does their absence infer good health. Histopathological examination of tissues remains the gold standard for defining diseases and normality. However, the destructive nature of sampling has associated issues that can limit the effectiveness of proactive stock screening as previously mentioned. Non-destructive gross examination is now utilised in all health screening regimens with health and welfare indicators used to identify stock quality and any abnormalities. Recently, gross examination procedures have become more sophisticated and standardised, though, at best, these are semi-quantitative in nature and sensitivity is dependent on presentation of the disease. Despite this, recent advances in facial recognition and automated monitoring technology has led to interest in how gross indicators can be monitored *in situ*. This is an exciting area of research, which has the potential to revolutionise the way in which we think about and monitor salmon health. Identifying abnormalities is comparatively simple to defining a normal, healthy salmon. This is true in philosophical and analytical senses. For instance, the use of clinical biochemistry, routine in animal and human health monitoring, has increased dramatically with its usefulness in identifying multiple pathological conditions, diseases, and responses to treatment/interventions. However, despite recent efforts, standardised reference intervals are not yet established for the Atlantic salmon. This is made complex given salmon's anadromous and ectothermic nature, which means many analytes alter in abundance based on life stage and environmental conditions. Furthermore, biochemical markers have typically been transferred from other species based on ontology, which may not always be accurate and the methodologies themselves may not be transferable. It is possible that performing assays in a manner as one would for mammalian species at 37ºC is not directly transferable to a fish sampled at 5ºC. Indeed, individual variability, as well as inter and intra assay CV, is greater in fish, which may be in part due to analytical methodology rather than biological variance. Despite this, blood, mucus, and tissue biopsy sampling offer the ability to assess a greater proportion of a population as the sample collection is non-destructive, and the use of these methods is anticipated to increase through time.

As biological boundaries continue to be pushed in the salmon farming industry, decreasing risks to stocks and increasing product quality are intrinsically linked to proactive health monitoring. Further development and standardisation of analytical methods offer a promising scope for growth. Recent advancements in multiple technologies and how we think about salmon health have led to dramatic improvements in productivity. These developments, coupled with the industry's openness to improvement, make this an exciting time in aquatic animal health.

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