THE INCONGRUENCE OF ANIMAL WELFARE AND OPEN AQUACULTURE SYSTEMS

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Abstract

The Principles of Organic Production and Handling section of the NOSB's Policy and Procedures Manual states: "The basis for organic livestock production is the development of a harmonious relationship between land, plants, and livestock, and respect for the physiological and behavioral needs of livestock. This is achieved [in part] by…promoting animal health and welfare while minimizing stress."[1] Given the importance of and commitment to animal welfare in organic agriculture, we address the currently unresolved compatibility of open net pens with organic aquaculture. Significant fish welfare problems presently exist in open systems due to water quality, escapes, parasites, and predation.

Since fish are in intimate contact with their surroundings, additional welfare issues may arise from the lack of environmental controls in open net pens. There is also concern that biofouling may harm nearby wild aquatic species. Because "wastes" can include all metabolites of the fish, the topics of ecological responsibility and assimilation of waste are combined into a discussion of water quality.

Though it may be difficult to pinpoint the exact prevalence of escapes at this time, the appearance of farmed fish in marine catches confirms they happen. Regardless of rates, there are inherent welfare issues associated with farmed fish escapes. Particularly concerning problems are the escapees' competition against wild populations for limited resources and the possibility of genetic dilution threatening the integrity of local stocks.

The level of sea lice infestation on wild fish is not generally considered threatening. However, sea lice are a ubiquitous and often serious problem in intensive cage aquaculture due to the high fish densities in which lice can thrive. There is considerable evidence that infectious sea lice levels imposed by salmon farms are orders of magnitude greater than ambient levels. Additionally, wild migrating fish in the vicinity are at higher risk of contracting and suffering from lice infections, which may contribute to their declining populations.

High concentrations of fish in confined areas inevitably attract predators. As such, predation is a widespread problem reported to cause substantial loss or damage to captive fish in open systems. Although the nature and frequency of predation varies markedly amongst farm sites, surveys indicate that pinniped predation is considered to be the most serious problem. Currently, a long-term, effective method of predator control does not exist, thereby making this a serious issue worthy of immediate resolution.

As welfare problems associated with open aquaculture systems run contrary to the precepts of organic production and are presently unresolved, open systems should not be permitted. With further work into the issues associated with water quality, escapes, parasites, and predation significant improvements could

be made in these systems to protect the welfare of fish, though net pen culture is likely to never be compatible with organic principles.

INTRODUCTION

One of the concerns with rearing fish in open cage net pen systems is whether or not open systems can be compatible with organic farming. Unlike land-based closed aquaculture systems, there is limited or no control over water quality or the aquatic environment in open waters, thus, fish in net pens are subject to whatever the caged-environment provides in terms of oxygen levels, pollutants, and temperature. The Principles of Organic Production and Handling section of the NOSB's Policy and Procedures Manual states: "The basis for organic livestock production is the development of a harmonious relationship between land, plants, and livestock, and respect for the physiological and behavioral needs of livestock. This is achieved [in part] by…promoting animal health and welfare while minimizing stress."[2] Given the importance of and commitment to animal welfare in organic agriculture, we address the currently unresolved compatibility of open net pens with organic aquaculture. Significant fish welfare problems presently exist in open systems due to water quality, escapes, parasites, and predation.

Fish react to challenges such as poor water quality, competition from escapees, parasitic infection, and predation through their stress responses, which can manifest as physiological and behavioral changes. The responses can be short- or long-term and may indicate poor welfare. The response by fish to stressful conditions is a survival mechanism in which the animals focus energy on survival in the short-term, but may compromise their survival in the long-term.[3] Welfare analysis is complex. Though no simple link exists between stress and welfare, concerns for welfare should be heightened in the presence of a coordinated stress response influenced by specific conditions.[4] This topic was addressed in a recent review of issues in fish welfare:

> Where fish cannot escape a stressor, or where the stressful stimulus is episodic or intermittent, prolonged activation of the stress response has deleterious consequences. These include loss of appetite, impaired growth and muscle wasting, immunosuppression and suppressed reproduction. Clearly, observing such changes provides strong indications that the well-being of the fish has been significantly compromised.[5]

Following a stressful event, the plasma level of the primary stress hormone in fish, cortisol, typically increases proportional to the duration and magnitude of the stressor.[6,7] If the stressful event is brief, the level of cortisol can return to baseline within a few hours; however, when faced with chronic stress, elevated cortisol levels may persist throughout the duration of the stressor.[8] Cortisol can therefore provide a measure of the duration or intensity of the stress response.[9]

Repeated or long-term stressors that cannot be avoided may lead to diminished immune function, disease resistance, growth, and reproductive health.[10] The immunosuppressive effect of cortisol may result in increased mortality[11] and reduced appetite and energy diversion may lead to impaired growth and fitness.[12] These stress responses can also be cumulative or additive if confronted with multiple stressors.[13]

A primary goal of the organic aquaculture industry should be identifying possible challenges in open systems, such as controlling water quality, fish escapes, parasite infestation, and predation on farmed fish, to determine if they can be eliminated to comply with the organic principles of promoting animal health and welfare while minimizing stress. Because of problems inherent to open net pens, it is likely that they will never align with organic principles.

WATER QUALITY

Because of their intimate environmental contact, net pens affect and are affected by their surroundings. Degraded water quality in and around net pens may impact the health and welfare of both cultured fish and wildlife. The relationships between environment, welfare, and disease are complex, but the problems fish face due to acute and chronic stress from poor water quality is relatively straightforward.[14]

Water quality is often considered one of the most important factors contributing to fish health.[15] A fish's gills have a large surface area so as to efficiently extract oxygen from water. This feature also makes the animals highly sensitive to pollution and poor water quality.[16] Since fish are in such close contact with and physiologically adapted to the environment, optimal water conditions for health and welfare should mirror the parameters of their typical surroundings, including temperature, dissolved oxygen (DO), pH, salinity, levels of organic and inorganic substances, and light.[17] Conditions that merely set limits on toxicity should not be the defining characteristics, though those limits may be easier to assess.[18,19]

Optimal water conditions can vary depending on the species, age, and size of the animals, as well as their history of exposure to dissolved products.[20] When fish remain in sub-optimal waters for extended periods, chronic stress has been shown to reduce growth and reproductive performance, and increase susceptibility to disease and parasites.[21,22] Intensive systems, which often fail to provide optimal environments, may lead to decreased health and increased stress and mortality.[23]

Respiration and waste production deteriorates water quality. Respiration decreases the dissolved oxygen (DO) content and increases carbon dioxide, and fish wastes increase levels of ammonia, nitrate, nitrite, and suspended solids.[24,25] Accumulation of nitrite in the water can alter respiration by decreasing blood oxygen transport capacity.[26] Hypoxia and low levels of DO may trigger the stress response in fish.[27] Altered levels of other chemicals, including ammonia and carbon dioxide, can disturb fish physiology, causing impaired gill and kidney function, and may increase respiration, which will pass more water over the gills and potentially exacerbate the effects of toxicity.[28,29,30,31]

Poor water quality can also lead to injuries in the gills, increasing susceptibility to bacterial infection.[32] Bacterial growth may hinder gas exchange to the point of death.[33] Stressful water and environmental conditions, such as exposure to inappropriate DO levels or stocking densities, are also correlated with two types of blood infections, furunculosis and motile *Aeromonas* septicemia (MAS), though it is possible that management of rearing conditions can mitigate these outbreaks.[34]

Because a fish's body temperature is typically within a few degrees of the water temperature, any temperature increase will increase its metabolic rate and demand for oxygen.[35] When water temperatures increase, oxygen levels must be carefully managed, as DO capacity is inversely proportional to temperature.[36] As a result, water temperature conditions for farmed fish must be closely monitored[37] to reduce hypoxia-associated stress at higher temperatures.[38] At the other extreme, stress induced by lower temperatures can suppress the immune system and reduce feeding, which are both potentially deleterious to fish welfare.[39,40] While analysis and adjustment of water quality in general can improve the welfare of farmed fish in closed systems, adjustment of water quality is often not practical in open net pens.

Impacts of water flow

The flow of water through and around net pens can influence the welfare of both the fish inside and adjacent wild species. In net pens, water transport through the net from the surrounding environment via currents, tides, or cage movement adjusts water quality.[41,42] This exchange must be sufficient to remove metabolites, food, and feces, and replenish sufficient levels of DO.[43] Flow restrictions can prevent O_2 from being replenished in and around the net pen and can reduce the amount of waste products that are removed by the receiving waters.[44]

Water exchange can be hindered by net fouling, the mesh size of the net, shape of the local ocean floor, configuration of pens, and stratified density layers. Reduced water exchange and circulation has been linked to oxygen depletion,[45] reduced and heterogeneous growth, negative changes in the kidneys and gills, and suppressed disease resistance.[46,47] The water emanating from trout farms has been found to have DO levels up to 30 percent lower than the surrounding water.[48] It is apparent that the complex relationship between reduced flow through cages and the exchange of O_2 and waste with the environment requires further study to determine the significance of differing factors and their contributions to this problem.[49]

Pollution

Pollution from open systems can have negative effects on wild fish and the surrounding ecosystem. Untreated outputs from net pens flow from the enclosures into the environment, typically devoid of attempts to reclaim, capture, or process the pollutants.[50] The main outputs from netpens are suspended solids of fecal material and uneaten feed.[51]

To illuminate the scope of the problem, many authors have estimated the number of humans that would produce the quantity of pollutants created by fish farms. One study finds that a 200,000 fish salmon farm releases enough nitrogen to equal the untreated sewage of 20,000 people, phosphorus for 25,000 people, and fecal matter for 65,000 people.[52] The equivalent total organic load from trout farms in Denmark has been compared to the raw sewage of 500,000 people.[53] The entire Scottish salmon aquaculture industry produces enough nitrogen and phosphorous to equal the sewage of 3.2 million and 9.4 million people respectively.[54]

The impacts these pollutants have on the aquaculture system's physical and biological surroundings are determined by the nature of the outputs and the properties of the receiving environment. Factors influencing these impacts include the size of the farm and the size, amount, and moisture content of the feed and feces, which determine dispersal around the farm and into the environment.[55]

Eutrophication (nutrient enrichment or hypernutrification) can occur as a result of these pollutants. Feed and fecal matter have high levels of nitrogen (N) and phosphorus (P) which can stimulate the growth of phytoplankton[56] that can contribute to harmful algae blooms.[57] When these outputs exceed the capacity of the local ecosystem to assimilate wastes, water quality deteriorates and can be toxic to aquatic biota.[58] These released nutrients can alter the chemistry of the surrounding ecosystem leading to low levels of DO, murky waters, mortality in fish, corals, and seagrasses, and dead-zones (regions with very low to no oxygen).[59,60] Eutrophication in general already affects half of U.S. estuary waters and, over the next two decades, is expected to degrade 70 percent of U.S. coastal waters.[61]

Sedimentation of outputs

The seafloor and aquatic inhabitants beneath aquaculture net pens may also be affected by these outputs. Feed and feces leaves net pens and settles on the ocean floor, with dispersal dependent on size and total output of the material, current velocity, and water depth.[62] This organic matter can alter the chemical and biological make up of the sediment.[63] High rates of sedimentation may disrupt the filtering mechanism of bivalve mollusks and can even bury animals.[64] In severe cases, this sedimentation can cause dead zones on the ocean floor. In areas of poor water flow, some dead zones have been found to extend 500 feet in diameter around net pens.[65]

The breakdown of organic materials in this sediment further contributes to aquaculture's extraction of oxygen from the environment.[66] Compared to control sites, oxygen consumption in the sediment below fish farms is up to 15 times higher, and organic carbon and nitrogen levels can be 10 times higher.[67]

Decomposing organic materials can also produce methane and hydrogen sulfide.[68] Methane bubbling from the sediment is reportedly common beneath Scottish aquaculture farms.[69] The presence of hydrogen sulfide, which is lethal to fish in small concentrations and can give water the odor of rotten eggs, indicates that the water quality is severely degraded.[70] Disturbing the sediment under fish farms can increase the concentration of hydrogen sulfide in the water from the sea floor to the surface, which researchers note may negatively affect the welfare of the cultured fish.[71] Considering the significant potential for negative impacts on animals and the environment, the use of open net pens does not satisfy the organic precept of minimizing pollution.

Biofouling

Biofouling, the growth of unwanted organisms such as algae, bacteria, and mussels on submerged structures, creates additional concerns for the welfare of farmed fish.[72,73] Biofouling is especially prevalent on net pens because of their heightened levels of nutrients and organic matter.[74] Though expensive to deal with, biofouling must be addressed since it can negatively affect fish health.[75] Biofouling begins quickly and, within a week or two of submerging the net, can be visibly evident. In one case it was reported to have reduced a net's open area within one week by 37 percent.[76]

The restriction of water flow through fouled nets can affect both waste materials flowing out and fresh oxygenated water flowing in,[77] potentially creating anoxic conditions in the pen.[78] This fouling effect was reportedly the cause of 4,500 fish deaths in one open aquaculture facility.[79]

Net penned fish face additional stress since the organisms fouling the nets can harbor diseases (netpen liver disease and amoebic gill disease) and parasites (nematodes and sea lice).[80] When nets are fouled with hard shelled organisms, fish who swim against the net can be injured, losing scales and increasing their risk of developing bacterial and viral infections.[81,82]

Biofouling remediation may have its own consequences. The most common anti-fouling paint contains copper due to its effectiveness at inhibiting the growth of fouling organisms.[83] Increasing use of such coatings is linked to heightened levels of copper in aquatic environments, however, which is worrisome given the potential toxicity of copper to marine organisms.[84] Cleaning and repairing fouled nets may also disturb and stress the fish, possibly increasing mortalities.[85]

Since net pens pose significant challenges in the form of poor water quality, biofouling, and increased pollution, they should be prohibited in organic systems for the welfare of cultured species, the health of affected wild species, and environmental integrity.

ESCAPES

Escapes of farmed fish from their pens cause "biological pollution," where a natural environment is infested with a non-native species, and can pose serious welfare and ecological concerns for both the cultured and wild species. Escapes occur through both chronic leakage and large escape events. Chronic leakage is slow, continuous escapement from small holes in the netting or from human error. Large escape events result from large-scale damage often caused by storms or predators.[86,87]

The growth of the salmon aquaculture industry has been identified as a contributing factor in the diminishing numbers of wild salmon.[88] Catches of wild salmon in the North Atlantic dropped by 80 percent between 1970 and 2000.[89] Risks to wild populations increase with increasing numbers of escapes and these risks are greatest when wild fish are outnumbered by escapees.[90,91] The National Marine Fisheries Service and U.S. Fish and Wildlife Service has cited the genetic and ecological risks of aquaculture salmon as a reason for listing the Gulf of Maine Distinct Population Segment of Atlantic salmon as endangered.[92] Their actions for recovery of the population include minimizing the effects of aquaculture escapes.[93]

In some rivers on North America's east coast, farmed salmon populations are ten times that of wild salmon and, in the North Atlantic, estimated salmon escapes are as high as two million per year.[94] Table 1 provides a brief list of documented escapes revealed by a cursory sampling of the recent literature.

Table 1

Year	Escape event
1987-1996	At least 250,000 salmon escapes on West Coast of North America[95]
1997	350,000 salmon[96]
2000	411,000 salmon in 21 events[97]
2000	100,000 salmon in Maine[98]
2000	63,000 trout from 6 events in Scotland[99]
2002	600,000 salmon from one event in the Faroe Islands[100]
2005	510,840 salmon in 19 escapes in Scotland[101]

In 2001, it was estimated that escapees of farmed salmon outnumbered wild catches by a factor of seven.[102] Due to their low numbers and sensitive subpopulations, wild salmon may suffer from escapees flooding their gene pool. Escapees may also suffer since they may not be prepared for life outside of a net pen.[103]

Farmed fish escaping into the wild may result in continuous competition for habitat, food, and mates. Interbreeding may result in both reduced biodiversity and impaired fitness of wild populations.[104,105,106] The full impact of escapes is uncertain until the invading species is established, however, at which point it may be difficult to reverse.[107]

These effects have been most thoroughly documented for salmon due to the industry's large scope and the distinct subpopulations unique to wild salmon.[108] Wild salmon are thought to form local subpopulations that are adapted to specific regional locations and express traits based on the environmental conditions found in those places.[109] Adaptation through natural selection for beneficial traits can improve reproductive success and survival in those environments.[110,111]

In contrast to wild salmon, which have evolved in their specific environment and are well suited to it, farmed salmon have been selectively bred to improve growth rates. Selection over just ten generations of salmon can increase their growth rates by 50 percent.[112] These breeding programs make the cultured fish distinct from their wild counterparts, tending to reduce their adaptability and survivability in natural conditions.[113]

Competition

Though escapees are generally less adapted to survival in the wild, they will still compete with wild fish for resources. Competition for food is common since the diets of cultured and wild fish overlap.[114] Wild fish will likely prevail over cultured fish of the same size for limited food and habitat. In the presence of abundant food supplies, however, cultured fish selected for growth may exhibit a size advantage, enabling them to dominate their wild counterparts.[115,116]

Salmon populations are territorial. The added aggressive and often larger farmed salmon escapees[117] can outcompete the wild salmon for space, displace them to poorer habitats, and increase mortalities.[118,119,120]

Reported in 2000, this type of competitive displacement depressed the productivity of a native River Imsa population in Norway by 30 percent.[121] The likely outcome from competition between farmed and wild fish is that both populations will be reduced.[122]

Genetic effects

Interbreeding between wild and escaped fish tends to result in hybrids less fit for life in their natural environments.[123] Breeding performance of farmed fish in general is inferior. A 2000 Norwegian study found their success equaled one-third that of native fish.[124] Since farmed salmon are selectively bred for production characteristics, they show less genetic variation and adaptation than wild populations. Thus, when interbreeding does occur, the genetic makeup of hybrids will be altered compared to wild populations.[125,126] This introgression—the incorporation of genetic material from escapees into the gene pool of an indigenous (native) population following interbreeding—is frequently negative and can result in fitness reduction from combinations of genes which are beneficial being broken up in succeeding generations.[127,128,129,130] These hybrids ultimately may reduce the adaptability of subpopulations to their ecological niches.[131,132] This reduced genetic variability and adaptability may lead to hybrids with impaired survivability compared with wild salmon.[133,134,135] One study found the lifetime success of different hybrid groups to be 27 to 89 percent, relative to their wild counterparts, with 70 percent of second generation embryos not surviving.[136,137]

Hybrids may display altered body forms, potentially impairing reproductive success and, thus, negatively affecting wild populations following interbreeding.[138] Additionally, since farmed fish are not selectively bred to display avoidance behavior as they are raised in an environment with few predators, they do not properly avoid predators, a trait which may also have negative implications for hybrids.[139,140,141] These hybrids may suffer higher mortalities for taking greater risks.[142]

These impacts necessitate an evaluation of the long term survival of some wild salmon populations.[143] In their paper on fitness reduction and extinction, McGinnity with Ireland's Aquaculture Catchment Management Services and co-authors summarized:[144]

> Irrespective of the exact extent of fitness reduction, the fact that farm escapes are repetitive, often resulting in annual intrusions in some rivers, means that such reductions in fitness are cumulative, which could potentially lead to an extinction vortex in endangered populations.

Eliminating escapes is the best way to decrease harmful interactions between escapees and their wild counterparts.[145] The only way to effectively eliminate escapes in organic systems is to disallow net pens.

SEA LICE

Sea lice infestations are a major problem plaguing marine aquaculture and impacting animal welfare. Sea lice, ectoparasites that are naturally found in the marine environment, feed on the mucus, skin, and scales of fish such as salmon.[146] Although sea lice normally exist outside of aquaculture, the unnaturally high host density created by cage aquaculture provides an environment for parasites such as sea lice that rely on spatial proximity between hosts for transmission to proliferate.[147].[148]

Generally, skin lesions are prone to infection and contribute to a fish's inability to osmoregulate. Chronic ectoparasitic infections can cause mucus accumulation and attract myxobacteria and other bacteria, fungi, and ectocommensal organisms which may all contribute to further disease.[149]

There is evidence that fish find lice infestation extremely aversive. Fish will behave in a manner indicating that lice infestation is stressful and, when given the chance to behaviorally respond in a manner that helps to alleviate their stress, they will tend to do so. Birkeland and Jakobsen showed that salmon lice (*Lepeophtheirus salmonis*) infestation may cause sea trout to return to freshwater prematurely. Infested sea trout in their field experiment suffered from osmoregulatory failure in sea water, which may be why infested fish return to brackish water and then eventually to freshwater earlier than usual.[150]

Karvonen et al. demonstrated that rainbow trout avoid *Diplostomum spathaceum* infestation by avoiding the infestation source, thereby decreasing the number of established parasites.[151] However, when fish with low levels of infestation were restricted to lake cages in natural waters, parasite load increased significantly. Not only does confinement limit parasite avoidance behavior, the cumulative environmental and social stresses[152] associated with intensive crowding may reduce the ability of fish to tolerate otherwise normal levels of infestation.[153,154]

A new concern has arisen that marine cage farming may increase the risk of disease outbreaks caused by opportunistic parasites.[155] Nowak found that, some free-living organisms, like *Neoparamoeba* spp. and *Uronema* spp. parasitize fish in culture, yet these organisms have never been reported in wild populations.[156] The reason for this is not yet fully understood, but Nowak suggested that the appearance of new parasites in sea water cage farming indicates that free-living organisms are evolving into new opportunistic parasite forms.

Damage caused by lice infestation

In a review of pathogens of farmed Atlantic salmon, Pike wrote that sea lice “cause nothing but tribulation to those who derive a livelihood from raising Atlantic salmon (*Salmo salar*) in sea cages.”[157] Norwegian salmon farms experienced disease outbreaks due to sea lice in the 1960s and Scottish fish farms suffered from similar problems in the 1970s.[158] In addition to animal welfare implications, sea lice impact the profitability of the industry because the parasites cause stress and decreased food intake, thereby reducing growth rates in their fish. The producer also incurs costs due to expensive treatments and additional labor used to manage the parasite problem.[159]

During more severe sea lice infestations, mortalities may result and surviving fish may be condemned to low market value.[160] In a Scottish study, Rae estimated that the cost of stress and infection on Atlantic salmon was approximately 5% per year, equivalent to a loss of ₤13 million per year.[161] Similarly, Carvajal et al. noted the serious economic threat posed by sea lice to Chilean aquaculture, a major producer of salmonids, costing farmers US$0.30/kg. This cost was mainly associated with delousing as well as the slower growth of fish due to the physiological stress response to infection.[162]

Farmed fish sea lice infestations may spill over into the surrounding environment. Noting that sea trout returning to rivers were lice-infested[163] and recognizing that salmon farms are a potential source of large quantities of sea lice, Penston et al. hypothesized that parasites on salmon farms were associated with infestations in wild sea trout. In their study, recorded sea lice levels in fish farms had reached a maximum during one of their study periods and, shortly thereafter, sea lice larvae peaked in open-water samples. They also found that nauplii (the free-swimming first stage of the lice larvae) numbers were higher just adjacent to the farm site than anywhere else. The authors concluded that there is a relationship between sea lice numbers on cage sites and larvae densities in surrounding open-waters.[164]

Sea lice have become such a serious issue where farmed and wild salmon share common marine habitat because it is believed that one way in which farmed salmon initially acquire lice is from wild adult salmon as they pass cages en route to fresh water spawning grounds. Under natural conditions, *Lepeophtheirus salmonis* would die off as soon as salmon enter freshwater. It now seems, however, that salmon farms offer an artificial medium for lice to overwinter and proliferate at elevated levels.[165]

High parasite loads from fish farms have been implicated in the collapse of pink salmon, sea trout, and Atlantic salmon populations in diverse regions of the world.[166] Krkosek et al. cite a large number of studies that have found a link between lice parasitizing wild salmonids and the presence of farms.[167] Krkosek and colleagues maintain that marine salmon farms which are situated along wild salmon migratory routes act as reservoirs of concentrated sea lice populations, thereby upsetting the otherwise natural host-parasite system[168]

Krkosek et al. demonstrated how a single farm could alter the natural dynamics of lice transmission. The authors monitored sea lice (*Lepeophtheirus salmonis* and *Caligus cleminsi*) infections on juvenile pink and chum salmon as they swam past a salmon farm during their seaward migration. The results suggested that the farm was able to impose an "infection pressure" four order of magnitude higher than ambient levels. In addition, sea lice levels exceeded ambient levels for another 30 km along the two wild salmon migration routes they were studying. The authors argued that young wild salmon are generally parasite-free as they leave their freshwater grounds and make their way toward their marine habitat. Transmission of sea lice from returning adult conspecifics does not begin until the two cohorts pass each other en route at a later time. Fish farms along the migration route may therefore provide a significant source of parasites much earlier in the young salmons' life cycles than would normally occur.[169] Morton reached similar conclusions when her study found that the highest infections rates by early stage lice occurred at, and immediately adjacent to, net pens containing adult Atlantic salmon.[170]

Morton et al. found additional evidence of a direct relationship between salmon farms and sea lice on adjacent, wild, juvenile counterparts.[171] In their 10-week study in nearshore areas of British Columbia, they found sea lice were 8.8 times more abundant on wild fish near farms rearing adult salmon and 5 times more abundant on farms holding smolts compared to areas distant from salmon farms. They reported that 90 percent of juvenile pink and chum salmon were infected with a level of lice that they propose is the lethal limit. This was in contrast to a reported zero level of sea lice in all areas not containing salmon farms.[172]

Lice treatment

Recognizing the gravity of sea lice infection, scientists and producers have tried to combat the problem with the development of lice treatments. This generally involves finding active ingredients that kill lice without negatively affecting fish; however, some drugs used to manage severe infections may cause side effects that create new welfare issues.[173] It is also important that treatments are delivered to fish in a stress-free manner.[174]

Treatments range from bath treatments (e.g., dichlorvos,[175] hydrogen peroxide[176]) to the more recent development of in-feed drugs (e.g., SLICE[177]). Unfortunately, lice may quickly reappear after what may seem to have been a successful first round of treatment with compounds such as dichlorvos, an organophosphorus pesticide, which fail to kill juvenile stages of sea lice. Another concern is the possibility of the target parasite developing resistance if one medication is used over a prolonged period of time.[178] Due to the difficulties of treating and managing parasite infestations, scientists are currently trying to develop a vaccine against sea lice.[179,180]

Until there is unequivocal evidence of a parasite bath treatment whose impact on surrounding aquatic flora and fauna is non-threatening there will be continuing concern.[181] Although the application of in-feed drugs would have less impact on the environment, some drugs would still be released through uneaten food particles and fish feces.[182]

Non-chemical methods of lice control have been experimented with. There has been some success using wrasse as cleaner fish for salmon, however, there have been problems with the welfare of the wrasse as they themselves endure predation from other fish and low survival during the winter months.[183,184] Since sea lice are positively phototactic, the use of light lures has also been tested as a non-chemical means of treatment. While lice were attracted to the light under controlled experimental conditions, trials in real fish farms proved to be more problematic and the light lure method was eventually deemed ineffective.[185]

Other non-chemical means of controlling, though not eradicating, parasite outbreaks include rotational farming and fallowing (reviewed by Rae[186]). In one experiment, Chambers and Ernst studied the dispersal of skin flukes, *B. seriolae*, by tidal currents and their implications for sea-cage farming of kingfish in Australia.[187] The authors intended to demonstrate that strategically positioning farms may prove a valuable technique in controlling parasitic spread. In their study, infection rates were lower at cage sites across tidal currents, rather than inline with them. Their results also showed, however, that the dispersal of *B. seriolae* was still considerable and required distances of over 8 km between independent management units[*] for effective parasite management. This raises the question of whether such distances between management units are economically feasible and, thus, likely to be adopted.

Sea lice may also serve as a vector for lethal diseases including infectious salmon anemia (ISA) which has recently started affecting both farmed and wild fish in the United States, resulting in calls for enhanced control measures.[188,189] To protect the endangered population of Maine salmon, the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) include the development and implementation of a comprehensive disease management plan as one action plan for recovery, specifically citing the need to minimize outbreaks of ISA.[190] If these agencies are indeed considering mandatory control measures to stop the spread of ISA and these chemical control measures would be forbidden in organic production, then a conflict between standards for organic salmon aquaculture and rules promulgated by the NMFS and FWS may ensue.

Data regarding the numbers of sea lice on wild fish versus farmed fish in many regions are sparse. Although taking samples of fish from net pens is relatively easy, this is much more difficult with free-ranging wild specimens. In addition, this type of data may only be available from farms themselves or in confidential records. Nevertheless, in comparisons of ambient levels and farm sites, a great deal of evidence shows that parasite loads are higher closer to farm sites.[191,192]

Until a vaccine is readily available for commercial use, it seems unlikely that there can be a truly non-chemical organic method of treating parasites effectively. Withholding treatment and allowing fish to suffer parasitization may have unacceptable health and welfare consequences. Thus, open net pen aquaculture is currently incompatible with organic standards.

PREDATORS

Predators are another issue of concern with open aquaculture systems. The high concentration of fish confined in these systems attracts many predators.[193] The main predators of net penned fish are sea birds (e.g., herons, gulls, cormorants, and shags) and aquatic mammals (e.g., mink, otters, seals, and sea lions). Studies have shown that predation is a significant problem with most, if not all, open system cage farms. Although there are vast differences amongst farms in various parts of the world, marine farms tend to attract a greater range of predator species than closed land-based systems or freshwater systems.[194]

Predation on fish farms has been reported to cause significant economic damage to the industry in many parts of the world. For example, a Chilean study described a loss of 400 tons of fish to sea lions across 23

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[*] Independent management unit (IMU): a cage or group of cages whose parasite population are independent from another cage or group of cages or the distance at which parasite dispersal is negligible for parasite management purposes.

farms in 1997, resulting in an estimated economic loss of US$6.3-8.3 million.[195] Similarly, a study performed in the Czech Republic found carp losses from otters alone to amount to approximately US$1.3 million.[196] in 1996, salmon losses in Canada totaled an estimated CDN$10 million.[197]

Predator management

Scottish researchers conducted a survey of Scottish fish farms to see if they suffered from predators and, if so, what types of anti-predator controls were used.[198] Managers reported 12 types of predators, with seals being the most prevalent. A total of 19 different types of anti-predator controls were used, including physical barriers such as diverse types of netting, acoustic harassment/deterrent devices, and shooting. The survey suggested that the degree of protection afforded by different anti-predator methods differed considerably depending on farm site and the method used.

Underwater netting provides some defense against seals and is similar to using top nets against birds. Seals, considered by many farm managers to be the most problematic predator, are considerably stronger than birds, however, and can manipulate cages and nets in ways that birds cannot.[199] Also, since seal attacks are generally performed underwater, many fish may be lost before the problem is even noticed.[200]

The effective deployment of underwater netting depends on the physical characteristics of the local aquatic environment and must account for tidal, current, and weather conditions.[201] Pemberton and Shaughnessy counted a total of 235 seal attacks on salmon and trout net pen farms in Tasmania during a four-month period.[202] The Australian fur seals would usually attack pens at night, making it difficult for farmers to see them damaging both pens and fish and, in some instances, causing fish escapes.[203][204]

Because seals were entering fish farms at night and, furthermore, displayed no fear of shooters,Pemberton and Shaughnessy noted that shooting was an ineffective method of predator control. The use of underwater acoustic seal scarers also proved ineffective because the pinnipeds ignored the acoustic deterrent and continued hunting. Pursuit with boats, lights, seal crackers, and emetics did help to reduce the number of attacks but the study demonstrated that the only way to completely prevent seals from attacking fish farms was to physically exclude them from fish pens with barriers.[205]

A study of the interaction between South American sea lions and salmon farms in Chile found acoustic harassment devices and other deterrents, such as fiberglass models of killer whales, to be ineffective.[206] Acoustic harassment devices transmit sounds under water that are intended to irritate or frighten predators, leading them to avoid fish pens. According to farm employees, while these acoustic devices initially worked well, they lost their effectiveness after a few months. Sea lions are able to avoid the sound by surfacing.[207] In some instances, if the sound is not sufficiently aversive, it may become associated with the presence of food and ultimately act as an attractant rather than a deterrent.[208]

Of all devices, a properly deployed anti-predator net achieves the greatest reduction in sea lion attacks but proper deployment may be impeded if water currents change their physical setting or if nets are not adequately maintained.[209,210] Seals may also learn to manipulate nets in order to reach the fish inside by, for example, pushing the anti-predator net against the fish pen to access prey swimming along the sides of the enclosure or by pushing against netting to pin fish against walls where they can be bitten.[211,212] Sea lions have often been reported attacking salmon by biting the fish through the hanging net.[213] Nash et al. note that the continual presence of these predators circling pens and attacking the salmon is an important source of stress to the captive fish, which has been reported to result in lowered growth rates and compromised immune responses.[214]

One interesting finding in a Chilean study was the lack of a significant relationship between the distances between farm sites and sea lion colonies. The researchers attributed this result to the fact that sea lions have been known to travel over 200 km on foraging trips.[215] Sepùlveda and Oliva therefore maintain that any farm, irrespective of its distance from a colony, could be vulnerable to sea lion attacks.[216] Similar results of sea mammal predation on fish farms have been reported in North America.[217]

The impact and nature of predation on fish stocks and the effectiveness of various anti-predator devices have been studied by many, under both wild circumstances and in closed systems. A common finding is the enormous amount of fish predators can consume if afforded easy access to their prey.[218,219] In an attempt to understand the dynamics of predation on commercial and recreational fishing, Dieperink investigated the foraging area of a large cormorant colony in a Danish fjord.[220] A large net pen was stocked with hatchery-reared rainbow trout. When cormorant predation was precluded with a top cover net, the background mortality was approximately 15 percent per day. However, once the top net cover was removed, the mortality increased to 98 percent per day. The researcher wrote "direct observation revealed that a flock of cormorants emptied the pound net in about 30 min, consuming 110 fish weighing a total of approximately 50 kg."[221] Iintensive open net pen systems create an environment that may therefore be conducive to high mortality, stress, and injury.

Danger to predators

The welfare of predators themselves also deserves attention. Proper deployment of top nets is important, for example, since without correct tensioning to prevent sagging birds risk entanglement.[222] Canada permits the killing of problematic seals that cannot be deterred any other way[223] and electric fences that exclude animals like otters and mink.[224]

Another anti-predator tactic is the relocation of pinnipeds away from the vicinity of fish farms to which they are a nuisance. However, not only do the animals experience being trapped and displaced, but relocation programs have not achieved success either because the numbers of pinnipeds are too large to realistically relocate or because seals and sea lions return to the same farm sites in a matter of weeks, reportedly traveling distances of 500 km to reach them.[225] Although these options may provide some relief to the aquaculture industry, practices such as trapping, poisoning, electrically shocking, and shooting, as well as accidental net entanglement have negative welfare implications for predator species.

Conclusion

Due to the stress, suffering, and decreased welfare imposed on both farmed fish and the surrounding wildlife from poor water quality, escapes, parasitic infestations, and predation, open cage net pen systems are not compatible with organic principles. Since the associated welfare problems in these systems run contrary to the precepts of organic production, open systems should not be permitted.

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