J Agric Environ Ethics (2009) 22:437–461
DOI 10.1007/s10806-009-9169-2

ARTICLES

Animal Welfare and Organic Aquaculture in Open Systems

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Accepted: 14 April 2009 / Published online: 30 April 2009

Abstract The principles of organic farming espouse a holistic approach to agriculture that promotes sustainable and harmonious relationships amongst the natural environment, plants, and animals, as well as regard for animals' physiological and behavioral needs. However, open aquaculture systems—both organic and conventional—present unresolved and significant challenges to the welfare of farmed and wild fish, as well as other wildlife, and to environmental integrity, due to water quality issues, escapes, parasites, predator control, and feed-source sustainability. Without addressing these issues, it is unlikely that open net-pen aquaculture production can be compatible with the principles inherent to organic farming.

Keywords Animal welfare · Aquaculture · Fish escapes · Open net-pen farming · Organic · Predators · Sea lice

Introduction

If maintained at their current yields, fisheries face uncertain futures, with predictions of global collapse by 2048 of all currently fished species (Worm et al. 2006). "The wild harvest of seafood, man's last major hunting and gathering activity, is at a critical point," wrote a researcher with the US Department of Agriculture (USDA). "Technology has enabled harvesting to outpace the speed at which species can reproduce" (Harvey 2004).

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From 2001 to 2003, the average global per-capita consumption of fish and shellfish was 16.4 kg (36.2 lb) (National Marine Fisheries Service Office of Science and Technology, Fisheries Statistics Division 2007) and is predicted to increase to 22.5 kg (49.6 lb) by 2030 (Food and Agriculture Organization of the United Nations 2002). The estimated human population is expected to rise from 6.09 to 8.2 billion between 2000 and 2030 (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat 2007). Given that fisheries' catches have essentially plateaued over the last decade (Food and Agriculture Organization of the United Nations 2008) and that consumption has outpaced the growth of the world's human population since the 1960s (World Health Organization 2007), the world's fisheries are unlikely to satisfy the marketplace. "In response," continued the USDA researcher, "the seafood industry is beginning to shift from wild harvest to aquaculture, the production of aquatic plants and animals under grower-controlled conditions" (Harvey 2004).

Though finfish are raised for various purposes, including restocking programs and sale or use as ornamental or bait fish, these fish are primarily farmed for human consumption. Today, fish production, like conventional chicken or pig production, for example, has increasingly become intensified, moving towards purpose-built agricultural systems designed for high stocking densities (Shepherd and Bromage 1988).

Absent the additional demands placed on fish populations by the increasing human population, the Food and Agriculture Organization (FAO) of the United Nations predicted in 2006 that worldwide aquaculture production must nearly double in the next 25 years to satisfy current global consumptive patterns for fish. Since the mid-1980s, when 9% of the fish consumed by humans were farmed in aquaculture systems, the fish farming industry has expanded approximately 8% per year. In 2006, 43% of all fish consumed worldwide were cultured in a production system rather than caught from wild sources (Food and Agriculture Organization of the United Nations 2006). An address to the World Organization for Animal Health (OIE) Global Conference on Animal Welfare in 2004 reported that aquaculture has "developed to become the fastest growing food production sector in the world and it will continue to grow in the years to come" (Håstein 2004). It is inevitable that the numbers of aquacultured fish will soon surpass those who are wild-caught from the world's fisheries.

Aquaculture systems can be open or closed, classified by the ways in which the production method interacts with the environment. An open aquaculture system is a production facility confining farmed fish in net-pens—submerged enclosures with mesh walls. A single facility may be comprised of many net-pens in close proximity. Typically sited in large, natural bodies of water, open systems do not have solid barriers separating them from the aquatic environment. As such, water is exchanged freely between the net-pen and the surrounding water. These production facilities rely on this exchange, via water currents, to replenish oxygen and remove wastes from the net-pens. In contrast, closed, land-based aquaculture systems are not in direct contact with natural bodies of water, so the aqueous environment can be environmentally controlled and waste water captured before being filtered or recycled (Caffey and Kazmierczak 1994).

Organic Agriculture

Broadly, organic production encourages the dramatic reduction of external inputs by prohibiting use of synthetic chemicals, fertilizers, pesticides, pharmaceuticals, and feed additives, while encouraging reliance on internal farm resources, using natural ecological processes to sustain agricultural yields and disease resistance, and emphasizing preventative measures over treatments of problems (Hermansen 2003; International Federation of Organic Movements 2006). For example, to control unwanted or pest populations, many organic facilities have adopted a farm rotation system (Biao et al. 2003) rather than employing more conventionally used treatments. Indeed, proponents contend that organic farming should benefit the environment through protecting the air, wildlife, and their habitats; conserving surrounding landscape; reducing environmental pollution; and protecting clean surface and underground water from becoming polluted (reviewed in Biao et al. 2003).

However, despite growing interest in organic foodstuffs (United States Department of Agriculture 2002), generally, and organic aquaculture (Pelletier and Tyedmers 2007), specifically, the term “organic” lacks a universally accepted definition (Guthman 1998). Different concepts have been presented as an important focus, such as animal welfare (The Center for Food Safety 2005) and environmental protection (Graig Farm 2006; Pelletier 2003), and many require the use of organic feeds (Pelletier and Tyedmers 2007).

For example, the International Federation of Organic Agriculture Movements (IFOAM) defines organic agriculture as “a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved” (International Federation of Organic Movements 2008b). While IFOAM does not specifically identify animal welfare as a component to its definition of organic agriculture, the Soil Association explicitly states that its organic certification ensures that production and processing adhered “to strict animal welfare and environmental standards” (Soil Association 2008).

Bridging these two concepts of organic production is the USDA’s National Organic Standards Board’s (NOSB’s) definition, which states that organic farming is an “ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems.” According to the NOSB, “[t]he 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,” and amongst several key requirements to achieve this goal, NOSB lists “promoting animal health and welfare while minimizing stress” (National Organic Standards Board 2007).

Organic Aquaculture

Organic aquaculture is still relatively new in concept and development (Pelletier 2003). The USDA, for example, is presently considering aquaculture standards that, if adopted, will allow for fish and other aquatic animals to be labeled as USDA certified Organic.

There is intense debate within the organic and fish farming sectors as to how, or even if, organic standards for aquaculture can be developed. Extrapolating practices and standards originally developed for terrestrial species for aquatic species remains a major challenge. For example, although principles such as the banning of antibiotic and hormone use may be equally applicable to both land and aquatic animal production, the standard of feeding organically raised animals with organic feed poses a particular challenge for the production of piscivorous species of fish, as it is still questioned whether wild-caught fish and fish by-products can be used as organic feed (Boehmer et al. 2005). Hence, standards defining organic aquaculture systems may change as principles incorporating environmental, food safety, social, and animal welfare objectives for aquaculture are refined. As such, those involved in developing organic aquaculture standards must allow for continuous review and adaptation to encompass advances in science and technology (Pelletier 2003).

Additionally, standard-setting should not only be a reflection of best practice and sound science, but should also address other relevant factors, such as consumer preference. In fact, due to increasing consumer concern about the sustainability, public health, and animal welfare issues associated with conventional farming (Biao et al. 2003; Lien and Anthony 2007), it has been suggested that animal agriculture industries are in need of ethical guidance (Apotheker 2000).

Consumers expect organic producers to follow higher animal welfare standards (Hermansen 2003). Since welfare is an integral part of organics, intensive open net-pen fish farming is currently incompatible with the principles of organic production. This paper will address many areas where organic ideals and open systems are in disharmony.

Water Quality

Degraded water quality in and around net-pens may negatively impact the health and welfare of both cultured fish and wildlife. Although the relationships amongst the environment, animal welfare, and disease are complex, the problems fish face due to acute and chronic stress from poor water quality is relatively well-understood (Håstein 2004).

Effects of Poor Water Quality on Fish Health

Water quality is often considered one of the most important factors affecting fish health (Conte 1993). The large surface area of gills that enables fish to efficiently extract oxygen also make them highly sensitive to pollution and poor water quality (Fisheries Society of the British Isles 2002). Optimal water conditions for health and welfare should mirror the characteristics of their natural surroundings, including temperature, dissolved oxygen (DO), pH, salinity, levels of organic and inorganic substances, and light (Håstein et al. 2005). Conditions that merely set limits on toxicity should not be the defining characteristics, though those limits may be easier to assess (Conte 1993; Wedemeyer 1997).

Optimal water conditions can vary depending on the species, age, and size of the farmed animals, as well as their history of pollutant exposure (Wedemeyer 1997). 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 (Conte 1993; Håstein et al. 2005). Intensive systems, which often fail to provide optimal environments, may lead to decreased health and increased stress and mortality (Håstein et al. 2005).

Respiration and waste production can also deteriorate water quality. Respiration decreases the DO content and increases carbon dioxide (CO_2), and farmed fish's wastes increase levels of ammonia, nitrate, nitrite, and suspended solids (Conte 1993; Pickering 1998). Hypoxia and low levels of DO may trigger the stress response in fish (Pickering 1998). Accumulation of nitrite in the water can alter respiration by decreasing blood oxygen transport capacity (Conte 2004). Altered levels of other chemicals, including CO_2 and ammonia, can disturb fish physiology, causing impaired gill and kidney function, and may increase respiration, which can potentially exacerbate exposure by increasing the amount of water passed over the gills (Conte 1993; Pickering 1998; Wall 1999; Wedemeyer 1997).

Poor water quality can also lead to injuries in the gills, increasing susceptibility to bacterial infection, and bacterial growth may hinder gas exchange to the point of death. Physiologically 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(Wedemeyer 1997).

Because the body temperature of fish is typically within a few degrees of the surrounding water, any temperature increase in the environment will increase their metabolic rate and demand for oxygen (Wall 1999). When water temperatures increase, oxygen levels must be carefully managed, as DO capacity of the water is inversely proportional to temperature (Pickering 1998). As a result, water temperature conditions for farmed fish must be closely monitored (Conte 1993) to reduce hypoxia-associated stress at higher temperatures (Pickering 1998). At the other extreme, stress induced by lower temperatures can suppress the immune system and reduce feeding, which are both potentially harmful to fish welfare (Lemly 1996; Pickering 1998).

While analysis and adjustment of water quality in general can improve the welfare of farmed fish in controlled, land-locked, closed systems, adequate adjustment of water quality is often not practical or even possible in open aquaculture systems. Because net-pens are typically large cages submerged in vast bodies of water such as lakes or oceans, there are no solid barriers separating the enclosures from the aquatic environment in which they are sited. As such, water is freely exchanged between net-pens and the surrounding body of water. Given that, the weather, natural water currents, and surrounding aquatic environment primarily determine water parameters of the net-pen facility.

Impacts of Water Flow

The flow of water through and around net-pens can influence the welfare of the fish confined inside the enclosures, as well as any adjacent wild species. In net-pens, water quality is adjusted by water flow through the net from the surrounding environment via currents, tides, and cage movement (Conte 2004; Johansson et al. 2007). This exchange must be sufficient both to remove metabolites, food, and feces, and to replenish sufficient levels of DO (Conte 2004). Restrictions in flow can prevent DO from being replenished in and around the net-pen, and can reduce the amount of waste products that are removed by the receiving waters (Iwama 1991).

Many factors can hinder water exchange with surroundings, including net fouling (detailed below), the mesh size of the net, shape of the local body of water's floor, configuration of pens, and stratified density layers in the water. Reduced water exchange and circulation have been linked to oxygen depletion (Johansson et al. 2007), reduced and heterogeneous growth, negative changes in the kidneys and gills, and suppressed disease resistance (Håstein 2004; Toften et al. 2006). The water emanating from trout farms has been found to have DO levels up to 30-percent lower than the surrounding water (Korzeniewski and Salata 1982). It is apparent that the complex relationship between reduced flow through cages and the exchange of oxygen and waste with the environment requires further study (Johansson et al. 2007).

Pollution

Pollution from open systems can negatively affect wild fish and the surrounding ecosystem. Few attempts are made to reclaim, capture, or process the pollutants that flow from the enclosures into the environment (Goldburg and Naylor 2005). The main outputs from net-pens are suspended solids of fecal material and uneaten feed (Iwama 1991).

To illuminate the scope of the problem, researchers have estimated the number of humans needed to produce the quantity of waste created by fish farms. One study found that a 200,000-fish salmon farm releases enough nitrogen to equal the untreated sewage of 19,800 people, phosphorus for 26,667 people, and fecal matter for 62,505 people (Hardy 2000). The equivalent total organic load from trout farms in Denmark has been compared to the raw sewage of 500,000 people (Warrer-Hansen 1982). The entire Scottish salmon aquaculture industry produces enough nitrogen and phosphorous to equal the sewage of 3.2 and 9.4 million people, respectively (MacGarvin 2000).

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 (Iwama 1991).

Eutrophication (nutrient enrichment or hypernutrification) can occur as a result of these pollutants. Fecal matter and feed have high levels of nitrogen and phosphorus, which can stimulate the growth of phytoplankton (Iwama 1991) that can contribute to harmful algae blooms (Goldburg et al. 2001). When these outputs exceed the capacity of the local ecosystem to assimilate wastes, water quality deteriorates and can be toxic to aquatic biota (Hargreaves 1998). 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). Eutrophication already affects half of all US estuary waters and, over the next two decades, is expected to degrade 70% of US coastal waters (Goldburg et al. 2001). The dead zone resulting from eutrophication in the Gulf of Mexico is caused primarily by agricultural runoff, particularly farm fertilizers and terrestrial farm animal manure (Roach 2005).

Sedimentation of Outputs

Fish farming may also adversely affect the floor of the body of water and the aquatic inhabitants beneath aquaculture net-pens. Uneaten feed and feces leave net-pens and settle on the floor, with dispersal dependent on size and total output of the material, current velocity, and water depth (Iwama 1991). The amount of waste in the form of particulate organic matter has been estimated to equal 10–25% of the dry weight of feed that fish consume; as a result, depending on the size of the facility, the waste can be many thousands of kilograms per day (Kutti et al. 2007b).

This organic matter can alter the chemical and biological makeup of the sediment (Goldburg et al. 2001). A case study of the sediment quality in and around fish cage farms found a significant difference between the sediment below aquaculture pens and that from non-fish farmed areas. Below cage farms, the sediment was found to be acidic, sulfidic, and extremely reducing (Pawar et al. 2001). The accumulation of solid waste from feces and uneaten food has potentially significant effects on the quality of marine habitat available for benthic (bottom-dwelling) animals and wildlife dependent on the benthos. Reduction of the availability of key benthic habitat due to accumulation of solid waste from feces and uneaten food from open net-pen fish farming can, in turn, adversely affect a wide variety of wildlife. High rates of sedimentation, for example, may disrupt the filtering mechanism of bivalve mollusks and can even bury animals (Pearson and Rosenberg 1978). One study found significant regional loss of diversity of benthic species as well as a significant increase in harmful nutrient pollution in the Bay of Fundy near areas of higher concentrations of aquaculture facilities (Pohle et al. 2001).

A study on the impacts of a trout farm on the water quality of a freshwater creek revealed similar results when investigators found fish farm effluents seriously deteriorating the ecological quality of creeks and streams due to particle sedimentation, interstice clogging, decrease of benthic macrofauna, and stimulation of microphytobenthos growth. Significant ammonium, nitrite, and particulate phosphorus concentrations were detectable 500 m (1,640 ft) downstream of the fish farm (Bartoli et al. 2007). Even on a deepwater farm where the decomposition capacity of the seabed is suitably adequate to prevent sedimentary overloading, traces of pollutants can generally be found some distance away from the fish farms (Kutti et al. 2007a).

Decomposing sediment from aquaculture systems further contributes to extraction of oxygen from the environment and can produce methane and hydrogen sulfide (Kutti et al. 2007b; Samuelsen et al. 1988). Compared to control sites, oxygen consumption in the sediment below fish farms is up to 15-times higher (Iwama 1991). In severe cases, dead zones can develop on the floor beneath net-pens, surrounded by an area of low biodiversity (Pearson and Rosenberg 1978). In regions with poor water flow, these areas of very low or no oxygen have been found to extend 150 m (492 ft) from the net-pens (Beveridge 1996). Methane bubbling from the sediment is reportedly common beneath Scottish aquaculture farms (Gowen and Bradbury 1987). The presence of hydrogen sulfide, which is lethal to fish in small concentrations, indicates that the water quality is severely degraded. Disturbing the sediment under fish farms can increase the concentration of hydrogen sulfide in the water from the sea floor to the surface, which may negatively affect the welfare of the farmed fish (Samuelsen et al. 1988). 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, is especially prevalent on net-pens due to their elevated levels of nutrients and organic matter, and presents challenges to fish health and welfare (Braithwaite and McEvoy 2005).

Biofouling begins quickly. Braithwaite and McEvoy (2005) report a case in which biofouling reduced a net's open area by 37% within 1 week. The restriction of water flow through fouled nets can affect both waste materials flowing out and fresh oxygenated water flowing in, potentially creating anoxic conditions in the pen. This fouling effect was reportedly the cause of 4,500 fish deaths in one open aquaculture facility.

Net fouling organisms can also harbor diseases, such as net-pen liver disease and amoebic gill disease, as well as parasites, such as nematodes and sea lice. 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 (Braithwaite and McEvoy 2005).

Biofouling remediation may have its own consequences. The most common antifouling paint contains copper due to its effectiveness at inhibiting the growth of fouling organisms. Increasing use of such coatings, however, is linked to elevated levels of copper in aquatic environments, which is potentially toxic to marine organisms. Cleaning and repairing fouled nets may also disturb and stress the fish, possibly increasing mortalities (Braithwaite and McEvoy 2005).

Since net-pens pose significant challenges in the form of poor water quality, increased pollution, and biofouling, their use should be strongly questioned in organic systems for the health and welfare of both cultured and wild species, and environmental integrity.

Fish Escapes

Escapes of farmed fish from their pens cause "biological pollution" and can pose serious welfare and ecological concerns for both cultured and wild species. Aquaculture has been reported as the second-greatest cause after shipping of non-native species introduced to an ecosystem (Molnar et al. 2008). Escapes occur through chronic leakage, slow, continuous escapement from small holes in the netting or from human error, as well as through large escape events resulting from significant damage often caused by storms or predators (Bridger and Garber 2002; Goldburg et al. 2001).

Fish Escapes in the Salmon Industry

The effects of fish escapes have been most thoroughly documented for salmon due to the industry's large scale and the uniqueness of wild salmon subpopulations (Naylor and Burke 2005). Wild salmon are thought to form local, distinct subpopulations adapted to specific areas and expressing traits based on the regional environmental conditions (Bridger and Garber 2002). Adaptation through natural selection for beneficial traits can improve reproductive success and survival in those environments (Bridger and Garber 2002; Taylor 1991).

The growth of the salmon aquaculture industry has been identified as a contributing factor in the diminishing numbers of wild salmon (Ford and Myers 2008). Catches of wild salmon in the North Atlantic dropped by 80% between 1970 and 2000 (Esmark et al. 2005). Risks to wild populations are amplified with increasing numbers of escapes and are greatest when wild fish are outnumbered (Naylor et al. 2005). 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 2 million animals per year (McGinnity et al. 2003). The National Marine Fisheries Service (NMFS) and US Fish and Wildlife Service (FWS) have cited the genetic and ecological risks of aquacultured salmon as a reason for listing as endangered the Gulf of Maine Distinct Population Segment of Atlantic salmon. Their actions for recovery of the population include minimizing the effects of aquacultured animal escapes (National Marine Fisheries Service US Fish and Wildlife Service 2005).

Escapees themselves may suffer since they may not be adept at surviving outside of a net-pen (Goldburg et al. 2001), and, due to their low numbers and sensitive subpopulations, wild salmon may suffer from escapees flooding their gene pool. Interbreeding may result in both reduced biodiversity and impaired fitness of wild populations (Goldburg et al. 2001; McKinnell and Thomson 1997; Naylor and Burke 2005). The full impact of escapes is uncertain until the invading species is established; however, at that point, it may be difficult to reverse the harms caused by the escaped farmed fish (Naylor and Burke 2005).

Competition

Farmed fish escaping into the wild may result in continuous competition for habitat, food, and mates. 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 (Fleming et al. 2000), though 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 (Bridger and Garber 2002; Naylor et al. 2005).

Salmon can be territorial. The often larger farmed salmon escapees, who may be more aggressive (Einum and Fleming 1997), can outcompete the wild salmon for space, displace them to poorer habitats, and increase mortalities (Fleming et al. 2000; McGinnity et al. 2003; Naylor et al. 2005). Reported in 2000, this type of competitive displacement depressed the productivity of a native River Imsa population in Norway by 30% (Fleming et al. 2000). The likely outcome from competition between farmed and wild fish is that both populations will be reduced (McGinnity et al. 2003).

Genetic Effects

In contrast to wild salmon, who have evolved to suit their specific environment, farmed salmon have been selectively bred for faster growth rates. Selection over just ten generations of salmon, for example, can increase their growth rates by 50% (Hershberger et al. 1990). Such breeding programs make cultured fish distinct from their wild counterparts, tending to reduce their adaptability and survivability in natural conditions (Naylor et al. 2005).

Interbreeding between wild and escaped fish tends to result in hybrids less fit for life in natural environments. Since farmed salmon are selectively bred for production characteristics, they show less genetic variation and adaptation than wild populations. Thus, when interbreeding occurs, the genetic makeup of hybrids is altered compared to wild populations (Goldburg et al. 2001; McGinnity et al. 2003). This introgression—the incorporation of genetic material from escapees into the gene pool of a native population following interbreeding—is frequently negative and can result in fitness reduction from combinations of beneficial genes being broken up in succeeding generations (Bridger and Garber 2002; Fleming et al. 2000; Goldburg et al. 2001; Naylor et al. 2005). Hybrids ultimately may reduce the adaptability of subpopulations to their ecological niches (McGinnity et al. 2003; Naylor et al. 2005), leading to animals with impaired survivability compared with wild salmon (Bridger and Garber 2002; Einum and Fleming 1997; McGinnity et al. 2003). One study found the lifetime success of different hybrid groups to be 27–89% that of their wild counterparts, with 70% of second-generation embryos not surviving (McGinnity et al. 2003).

Breeding performance of farmed fish in general is inferior. Hybrids may display altered body forms that may impair reproductive success and, thus, negatively affect wild populations following interbreeding (Bridger and Garber 2002). A Norwegian study found hybrid reproductive success only one-third that of native fish (Fleming et al. 2000).

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 that may also have negative implications for hybrids (Bridger and Garber 2002; Johnsson and Abrahams 1991; Jonsson 1997). These hybrids may suffer higher mortalities for taking greater risks (Jonsson 1997).

These impacts necessitate an evaluation of the long-term survival of some wild salmon populations (Fleming et al. 2000). In their paper on fitness reduction and extinction, McGinnity et al. (2003) summarized:

> 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 (Bridger and Garber 2002). The only way to effectively eliminate escapes in organic systems, however, is to prohibit use of net-pens.

Sea Lice

Sea lice infestations are a major problem plaguing open system aquaculture and negatively impacting animal welfare. Sea lice feed on the mucus, skin, and scales of fish such as salmon (Rae 2002), causing skin lesions prone to infection and affecting the host's ability to osmoregulate. Chronic ectoparasitic infections can cause mucus accumulation and attract myxobacteria and other bacteria, fungi, and ectocommensal organisms, all of which may contribute to further disease (Sommerville 1998). Although sea lice normally exist outside of aquaculture, the unnaturally high host density created by cage fish farming provides a favorable environment for parasites such as sea lice that rely on spatial proximity between hosts for transmission to proliferate (Barber 2007).

Welfare Implications

Evidence exists 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 (1997) 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.

Karvonen et al. (2004) demonstrated that rainbow trout avoid *Diplostomum spathaceum* infestation by avoiding the infestation source, thereby decreasing the number of established parasites. 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 (Barton et al. 1986) associated with intensive crowding may reduce the ability of fish to tolerate otherwise normal infestation levels (Barber 2007; Urawa 1995).

Economic Implications

In a review of pathogens of farmed Atlantic salmon, Pike (1989) indicated that in the past, sea lice have caused problems for fish farmers raising salmon in net-pens, and it is not clear that the situation has been much improved with time. Norwegian salmon farms experienced disease outbreaks due to sea lice in the 1960s, and Scottish fish farms suffered similarly in the 1970s (Pike 1989). In addition to their negative impacts on farmed fish welfare, sea lice impact the profitability of the industry because the parasites cause stress and decreased food intake, thereby reducing growth rates in farmed fish. Producers also incur costs due to expensive treatments and additional labor used to manage the parasite problem (Rae 2002).

During more severe sea lice infestations, mortalities may result and surviving fish may be condemned to low market value. In a Scottish study, Rae (2002) estimated that the cost of stress and infection on Atlantic salmon was approximately 5% per year, equivalent to a loss of £13 million annually. Similarly, Carvajal et al. (1998) noted the serious economic threat posed by sea lice to Chilean aquaculture, a major producer of salmonids, costing farmers $0.30 USD per kilogram, primarily associated with delousing as well as the slower growth of fish due to the physiological stress response to infection.

Ecological Implications

Sea lice infestations of fish farms may also affect the surrounding environment. Noting that sea trout returning to rivers were lice-infested and recognizing that salmon farms are a potential source of large quantities of sea lice, Penston et al. (2004) hypothesized that parasites on salmon farms were associated with infestations in wild sea trout. According to their findings, 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. Numbers of nauplii (the free-swimming first stage of the lice larvae) were also found to be higher immediately adjacent to the farm site than elsewhere. The researchers concluded that there is a relationship between sea lice numbers in cage sites and larvae densities in surrounding open-waters.

One way in which farmed salmon initially acquire lice is from wild adult salmon as they pass cages en route to freshwater spawning grounds. Under natural conditions, *L. salmonis* die off as soon as salmon enter fresh water. However, it now appears that salmon farms offer a medium for lice to overwinter and proliferate at elevated levels (Morton 2002).

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. Krkošek et al. (2005) cite a large number of studies that have found a link between lice parasitizing wild salmonids and the presence of farms, and maintain that marine salmon farms situated along wild salmon migratory routes act as reservoirs of concentrated sea lice populations, thereby upsetting the otherwise natural host-parasite system.

Krkošek et al. (2005) demonstrated how a single farm could alter the natural dynamics of lice transmission. The researchers monitored sea lice (*L. 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 orders of magnitude higher than ambient levels. In addition, sea lice levels exceeded ambient levels for another 30 km (18.6 mi) along the two wild salmon migration routes they were studying. Krkošek et al. argued that as young wild salmon are generally parasite-free as they leave their freshwater grounds and make their way toward their marine habitat, and 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 salmon's life cycles than would normally occur. Morton (2002) reached similar conclusions when her study found that the highest infections rates by early stage lice occurred in and immediately adjacent to net-pens confining adult Atlantic salmon.

Morton et al. (2004) found additional evidence of a direct relationship between salmon farms and sea lice on adjacent, wild, juvenile counterparts. 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% 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.

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 (Costelloe et al. 1998a, b).

In addition to sea lice, Nowak (2007) found that some free-living opportunistic parasitic organisms, like *Neoparamoeba* spp. and *Uronema* spp., parasitize fish in culture, yet these organisms have never been reported in wild populations. The reason for this is not yet fully understood, but Nowak suggested that the appearance of new parasites in cage fish farming indicates that free-living organisms are evolving into new opportunistic parasite forms.

Lice Treatment

Sea lice treatments, which should be delivered to fish in a stress-free manner (Rae 2002), range from bath treatments (e.g., hydrogen peroxide (Speare et al. 1999)) to the more recent development of in-feed drugs (e.g., SLICE (Health Canada 2007)), but their effectiveness is questionable. Lice may quickly reappear after a purported successful first round of treatment with compounds such as dichlorvos (Rae 2002), an organophosphorus pesticide, which fail to kill juvenile stages of sea lice, for example. Also, the development of resistance to treatment by the target parasite is a concern if one medication is used over a prolonged period of time (Rae 2002). Some drugs used to manage severe infections may also cause side effects that create new welfare issues (Toovey et al. 1999).

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 regarding the effects of chemicals on non-target plant and animal species. 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 (Pike 1989). Indeed, due to the difficulties of treating and managing parasite infestations, scientists are currently working to develop a vaccine against sea lice (Fisheries and Oceans Canada 2007; Fisheries Research Services 2007).

Non-chemical methods of lice control have also been examined. Some success has been achieved using wrasse as cleaner fish for salmon, for example; however, the welfare of the wrasse themselves has been jeopardized, as they endure predation from other fish and suffer low survival during the winter months (Bjelland et al. 1996; Sayer et al. 1996). 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 (Rae 2002).

Other non-chemical means of controlling, though not eradicating, parasite outbreaks include rotational farming and fallowing (reviewed by Rae (2002)). In one experiment, Chambers and Ernst (2005) studied the dispersal of skin flukes, *Benedenia seriolae*, by tidal currents and their implications for sea-cage farming of kingfish in Australia. The researchers 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. However, their results also showed that the dispersal of *B. seriolae* was still considerable and effective parasite management required distances greater than 8 km (5 mi) between independent management units.[1] This raises the question

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[1] 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.

of whether such distances between management units are economically feasible and, thus, likely to be adopted.

In addition to the animal welfare and environmental impacts of sea lice, the parasites may also serve as a vector for lethal diseases including infectious salmon anemia (ISA), which has recently begun affecting both farmed and wild fish in the United States, resulting in calls for enhanced control measures (Goldburg et al. 2001; National Marine Fisheries Service US Fish and Wildlife Service 2005). To protect the endangered population of Maine salmon, the NMFS and 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 (National Marine Fisheries Service US Fish and Wildlife Service 2005). 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.

Presently, an effective, responsible, non-chemical, organic method of treating parasites is not available. As withholding treatment and allowing fish to suffer parasitization have unacceptable health and welfare consequences, open net-pen aquaculture is in this way currently incompatible with organic standards.

Predators

The high concentration of fish confined in open aquaculture systems attracts predators (Sepùlveda and Oliva 2005), primarily sea birds (e.g., herons, gulls, and cormorants) 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. In general, these fish farms tend to attract a greater range of predator species than closed, land-based systems or freshwater systems (Beveridge 1996). Predation on fish farms results in death and injury to fish, and reported economic damage to the industry in many parts of the world can be substantial (Adámek et al. 2003; Nash et al. 2000; Sepùlveda and Oliva 2005).

The impact and nature of predation on farmed fish, and the effectiveness of various anti-predator devices have been well studied, under both wild circumstances and in closed systems. A common finding is the significant number of farmed fish that predators can consume if afforded easy access to their prey (Adámek et al. 2003; Yurk and Trites 2000). In an attempt to understand the dynamics of predation on commercial and recreational fishing, Dieperink (1995) investigated the foraging area of a large cormorant colony in a Danish fjord. 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% per day. However, once the top net cover was removed, the mortality increased to 98% per day. The researcher wrote that “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” (Dieperink 1995). Intensive open net-pen systems create an environment that may therefore be conducive to high mortality, stress, and injury.

Predator Management

In a survey of Scottish fish farms, 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 firearms. The survey suggested that the degree of protection afforded by different anti-predator methods differed considerably depending on farm site and method used (Quick et al. 2004).

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. Underwater netting provides some defense against seals and is analogous to using top nets against birds. Seals, considered by many farm managers to be the most problematic predator, are considerably stronger than birds and can manipulate cages and nets in ways that birds cannot. Since seal attacks are generally performed underwater, many fish may be lost before predation problems are noticed (Quick et al. 2004). Pemberton and Shaughnessy (1993) counted a total of 235 seal attacks on salmon and trout net-pen farms in Tasmania over a 4-month period. The Australian fur seals typically attacked pens at night, making it difficult for producers to see them damaging pens, and, in some instances, caused fish escapes (Pemberton and Shaughnessy 1993; Sepùlveda and Oliva 2005).

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 (Quick et al. 2004; Sepùlveda and Oliva 2005). Seals may also learn to manipulate nets in order to reach the fish inside by 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 (Nash et al. 2000; Sepùlveda and Oliva 2005), for example. Sea lions have often been reported attacking salmon by biting the fish through the hanging net (Sepùlveda and Oliva 2005). Nash et al. (2000) 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.

Pemberton and Shaughnessy (1993) noted in their study that seals displayed no fear of people discharging gunshots, leading them to note that shooting was an ineffective method of predator control. The use of underwater acoustic deterrents also proved ineffective. Acoustic harassment devices transmit sounds under water that are intended to irritate or frighten predators, yet seals continued hunting despite their use. Although pursuit with boats, lights, seal crackers, and emetics did help to reduce the number of attacks, the study demonstrated that the only way to effectively prevent seals from attacking fish farms was to physically exclude them from fish pens with barriers. Other studies have generally confirmed the utility of properly tensioned anti-predator nets (Nelson et al. 2006).

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 (Sepùlveda and Oliva 2005). 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 (Jefferson and Curry 1996). In some instances, if the sound is not sufficiently aversive, it may become associated with the presence of food and ultimately attract rather than a deter predators (Quick et al. 2004). Studies have also found that loud, highly aversive acoustic deterrents directed at seals and sea lions may also drive other marine mammals such as harbor porpoise, dolphins and orcas from their normal foraging areas (Morton 2000; Morton and Symonds 2002; Olesiuk et al. 1995). In some cases, the habitat exclusion effect was seen over many miles.

The absence of a significant relationship between the distances between farm sites and sea lion colonies was determined in a Chilean study. The researchers attributed this to the fact that sea lions have been known to travel more than 200 km (124 mi) on foraging trips (Campagna et al. 2001). Sepùlveda and Oliva (2005) therefore maintain that any farm, irrespective of its distance from a colony, could be vulnerable to sea lion attacks. Contrarily, research on harbor seal predation in North America has indicated that predation is reduced if a farm is situated distant from seal haul outs (Nelson et al. 2006).

Danger to Predators

The welfare of predators themselves also deserves attention. Proper deployment of top nets is important, for example, since birds risk entanglement without correct tensioning to prevent sagging (Quick et al. 2004). Similarly, in both shellfish and finfish aquaculture, fatal entanglement of marine mammals, including endangered dolphins attracted to blue fin tuna aquaculture sites, has been documented (Kemper et al. 2003). As noted above, highly aversive acoustic harassment devices intended to deter pinniped predation also displace a variety of other species of marine mammals from the area, effectively excluding them from key habitats. Canada permits the killing of problematic seals who cannot be deterred any other way (Nash et al. 2000) and the use of electric fences that exclude such animals as otters and mink (Rueggeberg and Booth 1989).

Another anti-predator tactic is the relocation of pinnipeds away from the vicinity of fish farms to which they are a nuisance. Such programs have not achieved success, however, because the numbers of pinnipeds are too great to realistically relocate the animals or because seals and sea lions return to the same farm sites in a matter of weeks, reportedly traveling distances of 500 km (311 mi) to reach them (Nash et al. 2000).

Although predator management methods may be viewed as providing some relief to the aquaculture industry, practices such as trapping, poisoning, electrically shocking, and shooting, as well as accidental net entanglement, in most cases have extraordinarily negative welfare implications for predator species.

Fish Feed and Sustainability

In addition to impacts of open aquaculture systems on water quality and the benthic environment, and potential interactions with wild salmon via escapes or disease vectoring, finfish aquaculture requires the provision of food at a significant cost to the marine ecosystem. Food for farmed fish is derived from the capture of wild forage fish, including such species as sardines, menhaden, capelin, anchovy, and herring or other small schooling fish. These animals are an important part of marine food webs and are key prey for wild fish, marine mammals, and marine birds (Alder et al. 2008).

High trophic level fish species are typically raised in open aquaculture systems, which has been a particular point of contention in the development of national organic standards for farmed fish in the United States (The Fish Site 2008a, b). Some who oppose allowing the "organic" label on such species argue that fish intended for organic certification should not be fed fishmeal and fish oils derived from wild, non-certified organic sources. Confusion surrounds the issue of how this feed could fulfill the 100-percent organic feed rule for farmed animals such that the farmed fish can themselves be certified as organic (International Federation of Organic Movements 2007). Nevertheless, in November 2008, the NOSB recommended to the National Organic Program of the USDA that up to 25% of feed can be comprised of non-organic wild fish (National Organic Standards Board 2008).

There is also dissonance in the idea that organic systems be managed sustainably considering the fact that for carnivorous fish species, the input of wild-caught fish can exceed the output of farmed fish. Between 2.5–5 kg (5.5–11 lb) of wild-caught fish are needed to feed and produce 1 kg (2.2 lb) of farmed salmon (Naylor et al. 2000). Because of the dependency on wild-caught fish to manufacture farmed fish feed, it has been argued that instead of alleviating pressures on wild fish populations, salmon farming exacerbates the problem, thereby making this an unsustainable farming system (Allsopp et al. 2008).

Demand for wild-caught fish to feed farmed fish will increase with the growth of the aquaculture industry, perhaps limiting the biomass of schooling fish available as forage for wild fish populations, marine mammals, and seabirds (Alder et al. 2008). As a result, the farming of carnivorous fish, such as salmon who are reared in open net-pen systems, is incompatible with organic principles.

Discussion

Organic farming regulations are aimed at satisfying the IFOAM's goals (Cabaret 2003). Although the Federation's definition of "organic" does not explicitly include animal welfare, IFOAM's organic animal farming principle does promote the advancement of animal welfare (International Federation of Organic Movements 2008a). However, research has shown an incompatibility may exist between producers' and consumers' understanding of, or expectations from, organic agriculture as it relates to the farmed animals themselves. For example, whereas some producers may equate good welfare with good health, consumers may believe good animal welfare is represented in part by natural rearing conditions (Frewer et al. 2005). Farmers may be less familiar with and less sympathetic to alternative methods of farming that put an emphasis on animal welfare (Frewer et al. 2005); however, this attitude may need to change as consumers are increasingly placing more emphasis on higher-welfare products (Bennett 1998). Traditionally, product quality has been judged by consumers by the physical properties of the food, such as color, texture, taste, and shelf-life. Increasingly, however, consumers are concerned with production methods (Matthews 1996). For example, in November 2008, by a margin of nearly 2–1, Californians voted to ban battery cages for egg-laying hens, gestation stalls for pregnant sows, and crates for calves raised for veal (California Secretary of State Debra Bowen 2008). In a consumer survey regarding perceptions about eating farmed versus wild-caught fish, sustainability and ethical issues were found to be of importance to consumers and influenced which type of fish they purchased and consumed (Verbeke et al. 2007).

Research has shown that there exists public distrust in regulatory institutions and current production systems (Frewer et al. 2005). As ethical and moral factors are now recognized as capable of influencing societal acceptability of certain production processes (Frewer et al. 2005), animal care and husbandry practices that do not meet consumers' approval may not fully succeed commercially. There is clear evidence that consumers' perceptions of animal welfare associated with animal production systems can influence their purchase choices (Frewer et al. 2005). This may be especially true in the organic community. It may be difficult for consumers to be comfortable accepting an "organic" label on fish raised in a system laden with many significant animal welfare challenges. Indeed, this challenge was recently illuminated during the debate over defining and setting organic aquaculture standards in the United States, and can be seen in the NOSB's recent recommendation to allow for the organic labeling of carnivorous fish raised in open net-pen aquaculture systems. Despite years of deliberation and discussion, there is still much dissatisfaction with the NOSB recommendation within several sectors, including environmental, consumer, and even some producer groups.

Conclusion

There are diverse definitions outlining organic production, and the challenge of developing a universally accepted definition is exacerbated by the ethical and societal demands consumers place on determining acceptable levels of animal welfare (Alrøe et al. 2001). Nevertheless, it is difficult to envisage how open system fish farming could confer environmental benefits, decrease pollution, avoid the use of pesticides, and increase animal welfare relative to conventional aquaculture in the ways required to fulfill organic principles.

There is an urgent need to discuss and develop a stronger and more unified philosophy of organic animal agriculture, especially with regards to animal welfare (Lund et al. 2004). This is particularly critical considering the implications of inappropriate husbandry and agriculture practices on the farmed animals themselves and their surrounding environment, including wildlife, as well as growing concern for animal welfare by consumers.

Presently, separating these problems of welfare and sustainability from open system aquaculture is challenging if not impossible. Considering organic systems claim these two ideas as tenets, it is imperative that organic programs address these issues.

Indeed, welfare potential can be compromised in organic open aquaculture systems. Deteriorated or otherwise uncontrolled water quality poses particular challenges to farmed fish and their surroundings. Outputs from these systems can further harm local wildlife and the ecosystem. Possibilities for escapes and parasitic infestations further threaten both farmed fish and surrounding wildlife in open systems. Additionally, predation harms cultured fish and potentially those species who are preying on these floating farms.

Until welfare challenges to farmed fish and wildlife, negative effects on the surrounding ecosystem, and unsustainable feeding practices are fully corrected, open net-pen systems remain incompatible with organic principles.

Acknowledgments We wish to thank Miyun Park, Michael Greger, and Sharon Young for their insightful comments and suggestions. An earlier draft of this paper was presented at the National Organic Standards Board's 2007 Organic Aquaculture Symposium.

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