ASSESSMENT OF THE CHILEAN SALMON INDUSTRY CAPABILITY TOWARDS ORGANIC PRODUCTION: ANALYSIS OF REGULATIONS, ENVIRONMENTAL KNOWLEDGE AND BIOREMEDIATION SYSTEMS

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Abstract

In 2006 marine aquaculture production in Chile reached 800 thousand tons, over 75% of which came from salmonids grown in open cage net pens. There is evidence from Chile, and much more from elsewhere, that salmonid aquaculture is associated with a range of unfavorable environmental impacts. In contrast to a rapidly expanding, well-financed and technologically advanced industry, existing environmental regulations in Chile are outdated, poorly enforced, and lack scientific and political transparency. We call for government and industry to support research leading to the development and enforcement of a transparent, independent, ecosystem-based regulatory framework that promotes integrated multi-trophic aquaculture (IMTA). Monitoring programs and licensing procedures must consider the impacts of individual sites and the cumulative impacts from multiple (types of) sites across a wide range of spatial scales. Before such changes are realized, the environmental threats and human health risks will remain unacceptably high and salmon farming in Chile will not meet any reasonable set of organic aquaculture standards.

Introduction

Chilean marine aquaculture production of fish, shellfish and seaweeds reached over 800 thousand tons in 2006, making Chile the leading mariculture producer in the western world. Farmed salmonids account for over 75% of production, making this export-focused industry the second largest contributor to the Chilean economy. Net pen aquaculture began in the 1980's and developed rapidly enough that Chile is now the second largest farmed salmon producer in the world after Norway. Fish are grown to marketable size exclusively in open cage net pen facilities in the protected inner seas of southern Chile. The industry is considered consolidated, and is now expanding to the pristine coastal areas of southern Patagonia (Buschmann et al., 2006a). Rapid growth and weak government oversight have prevented the adoption of sustainable management practices and given the industry little incentive to modify a successful financial model. Following the trend in northern countries, concerns about the ecological impacts of open net pen aquaculture started to be raised in Chile during the mid 1990´s (Buschmann et al., 1996a).

This paper considers open cage net pen salmonid aquaculture in Chile in the context of organic aquaculture standards. We begin by briefly describing the regulatory environment within which the salmon aquaculture industry operates. We then review documented and potential impacts of open cage aquaculture on marine and freshwater ecosystems. We conclude that substantial changes are required before open cage net pen aquaculture in Chile can meet any reasonable set of organic standards. We call for a transparent, independent and ecosystem-based regulatory framework and highlight the potential use of bioremediation systems to reduce environmental impacts.

Aquaculture development, regulations and industry performance

Fish, shellfish and seaweed aquaculture production is increasing exponentially in Chile (Fig. 1). The density of licensed sites is often high, with different types of facilities (e.g. salmon and shellfish) located adjacent to one another (Fig. 2). This situation makes it difficult, if not impossible, to evaluate the impacts associated with a single salmonid aquaculture facility. At the same time, these licensing practices require a regulatory framework and monitoring standards capable of detecting across a range a spatial scales not only the cumulative impacts of multiple sites, but potential interactive effects of multiple types of sites.

Although environmental and sanitary regulations for salmonid aquaculture exist in Chile (reviewed in Buschmann et al., 2006b), at least three factors limit their effectiveness. 1) Licensing and monitoring regulations were developed during the mid-1990s, when the number and density of salmon faming sites were a fraction of their present levels. These regulations were designed to monitor the impacts of individual sites, which is not possible in the present high density situation. 2) A site's environmental impact is determined solely by monitoring the benthic sediment directly below fish net pens without including the water column by assuming high dilution. The assessment of this 'impact' is made by measuring dissolved oxygen levels in the sediment, by determining an anoxic (zero oxygen concentration) condition. 3) The entrance of imported eggs and application of different therapeutic products is officially controlled, but enforcement is inadequate and controversy surrounds the illegal use of banned products and the poorly controlled application of others.

More generally, government regulatory, monitoring and enforcement efforts in Chile are compromised by limited financial and technical resources, and a lack scientific transparency. There is an urgent need for the government and industry to collectively support the establishment of independent, open and binding environmental assessments. The striking lack of research from Chile on the environmental impacts of salmon aquaculture highlights the need to expand basic research capacity through an independent granting agency jointly funded by government and industry. A search of 'salmon environmental impact' in the ISI web of knowledge database reveals only 13 of 265 papers published between 1988 and

1997 were related to Chile. The Chilean Parliament publicly recognized this deficiency in 2006, but to date no change in either regulatory policy or financial support has been observed. To fill this void, the private sector has created different forms of self-regulation. These efforts appear to be modifying the behavior of the salmon producers, but will require an open and multidisciplinary science-based assessment of their ability to control the environmental and social impacts of the industry.

Environmental impacts of salmon aquaculture in Chile

Figure 3 summarizes research to date on the environmental impacts of salmon net pen aquaculture in the inland seas of southern Chile. It is well established that organic waste from salmon farms changes the physico-chemical properties and reduces biodiversity of benthic sediments (Buschmann, 2001; Soto & Norambuena, 2004; Buschmann & Fortt, 2005; Mulsow et al., 2006). Organic waste also enhances the growth of macroalgae, leading to algal blooms with as yet unknown bottom up effects (Vergara 2001, Buschmann et al., 2006a). These studies are consistent with those from the northern hemisphere suggesting that inputs of organic material from salmon farms disrupt benthic ecosystems. Recent improvements in feeding technology have reduced the amount of food waste introduced to benthic environments, but waste from excrement cannot be eliminated because the assimilation capacity of salmon may be high, but has a limit.

Salmonid aquaculture delivers chemical and drug contaminants to the environment through various pathways with potentially long lasting ecological and evolutionary impacts. Precipitation of copper in sediments, presumably from antifouling paints, has been associated with benthic biodiversity loss (Buschmann & Fortt, 2005). Antibiotic use appears to be higher in Chile than other countries and has recently been strongly criticized by consumer and environmental interest groups. Tetracycline and quinolones have been found in native fishes near net pens (Fortt, et al., 2007; Fig. 3) and antibiotic laden organic waste may modify the resistance of benthic bacteria (Cabello, 2004; 2006). The indiscriminate use in Chile of drugs designed to prevent sea lice outbreaks (Pike and Wadsworth, 2000) appears to have increased the resistance of lice. Green malachite is presently prohibited in Chile. However, chemical and drug contaminants are entering the environment more freely in Chile than in other salmon farming jurisdictions. We suggest this issue requires stronger regulatory and scientific attention.

Salmon farms can disrupt marine food webs by attracting carnivorous birds and mammals (Buschmann et al., 2006a). Though Chilean regulations recognize the potential threat to such organisms, the direct and indirect effects of this chemically-laden prey subsidy on these species and those associated through interspecific interactions remain unknown. Farmed salmon escape from marine net pens through persistent low-level leakage (1-5%) and by the millions when extreme weather (Soto et al. 2001) destroys entire facilities. Farmed salmon have lower survival rates than wild salmon (McGinnity et al., 2003), but in the marine environment escapes display similar body condition and feed on the same prey items as wild salmon (Jacobson & Hansen, 2001). Data collected following a catastrophic escape event in Chile suggest farm raised salmon negatively affected native marine species through competition and/or predation (Soto et al., 2001). Evidence from the northern hemisphere leaves little doubt that escaped salmon will enter and successfully reproduce in Chilean rivers (Sægrov, 1997; Volpe et al., 2000). Though the negative effects of escape reproduction on con- and heterospecific salmonid populations have been documented (Fleming et al., 2000; Volpe et al., 2001; McGinnity et al., 2003), we have only recently begun investigating how aquaculture escapes and their offspring affect the native freshwater fish communities of southern Chile.

Environmental strategies for a sustainable development

The recycling of organic material by filter feeders and seaweeds (extracting species) may help mitigate some of the impacts associated with salmonid (fed) aquaculture

(Chopin et al., 2001; Troell et al., 2003, Neori et al., 2007). This multi-trophic approach was first explored in Chile during the late 1980´s when rainbow trout (*Oncorhynchus mykiss*) were grown at a stocking biomass of 35 kg m^{-3} in land-based tanks using pumped seawater. The fouled water was then used to cultivate oysters (*Crassostrea gigas*) and the agar producing alga *Gracilaria* (Buschmann et al., 1994). The results showed that tank cultivation of trout was technically feasible, a high nitrogen removal capacity (above 80%; Buschmann et al., 1996b) and economically viable if high densities fish could be farmed at a large enough scale to pay for the investment (Buschmann et al., 2001; Chopin et al., 2001). In addition, the oysters and the algae significantly reduced nitrogen and phosphorus levels in the waste water (Buschmann et al., 2000).

Similar integrated multi-trophic aquaculture (IMTA) approaches have been proposed for mitigating the negative impacts of rearing smolts in lakes (Soto & Mena, 1999). Even more promising is the possibility of moving the freshwater phase to completely closed land-based facilities. Technological advances have made producing smolts in closed-freshwater systems an economically viable alternative to open net pen rearing in lakes and some companies in Chile are already investing in such facilities (León-Muñoz et al., 2007). In marine coastal systems extractive organisms (seaweeds and shellfish species) have also demonstrated high bioremediation capabilities (Troell et al., 1997, Buschmann et al., 2000; Halling et al., 2005). There are, however, economic challenges to establishing IMTA for producing multiple products consumed in Chile. Like oriental countries, Chile has a long tradition of shellfish and seaweed consumption. However, the domestic price for these goods is too low to attract investment for their production. The ability of the emerging abalone cultivation industry to secure export markets may foretell the success of IMTA in Chile. If seen as economically viable, IMTA will be an important driver for the development of kelp farming (see Figure 4) and mussel (see Fig. 5) aquaculture. If profitable, there is real promise that in the coming years IMTA will help bring together these new cultivation approaches and reduce the amount of waste produced by salmonid aquaculture.

Clearly, IMTA cannot remove all the organic and inorganic waste from salmon farms and monitoring strategies must be flexible enough to accommodate a wide range of scenarios. The accumulation of chemicals and drugs in extracting species poses a challenge as well if IMTA approaches are to provide multiple consumable resources. Despite these challenges, IMTA should play a central role in the development of ecological sustainable net pen aquaculture in Chile and elsewhere.

Conclusion

The environmental impacts of salmon aquaculture in Chile are largely unstudied. Nevertheless, there are clearly numerous benthic and pelagic impacts, which could be reduced by the creation and enforcement of science-based regulations. These regulations will need to explicitly consider and monitor impacts resulting from cumulative effects at spatial scales ranging from the single site to the entire region. Logically, the new regulatory framework must also encourage and accommodate emerging IMTA technologies. The establishment of well-financed and politically independent agencies to fund research and enforce regulations is essential. Until these challenges have been met, open net pen salmon aquaculture in Chile cannot be certified under any reasonable set of organic aquaculture standards.

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FIGURE CAPTIONS

Figure 1. Gross produduction (tonnes) of fish, shellfish and seaweed aquaculture in Chile.

Figure 2. Salmon farming around Chiloé Island in southern Chile. Each arrow points to a salmon farm. At this salmon farm density, interactive effects between them are expected, restricting the development of organic farming.

Figure 3. Summary of environmental impacts on the benthic and pelagic systems of Chilean salmon aquaculture.

Figure 4. Kelp (*Macrocystis pyrifera*) production in suspended lines near salmon cages in the south of Chile: A) juvenile plants and B) adult plant to be harvested.

Figure 5. Mussel (*Mytilus chilensis*) farms in the south of Chile: A) General view in Reloncaví estuary and B) close up near Puerto Montt.

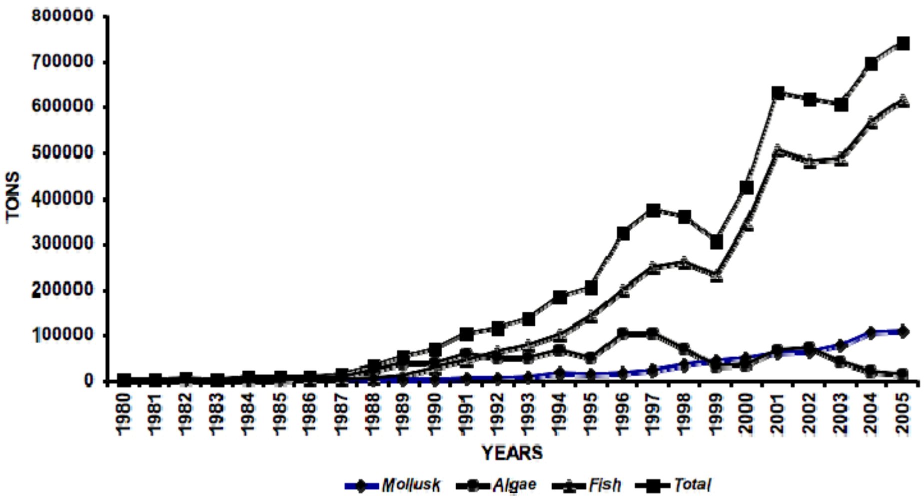
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Figure 1

FIGURE 2

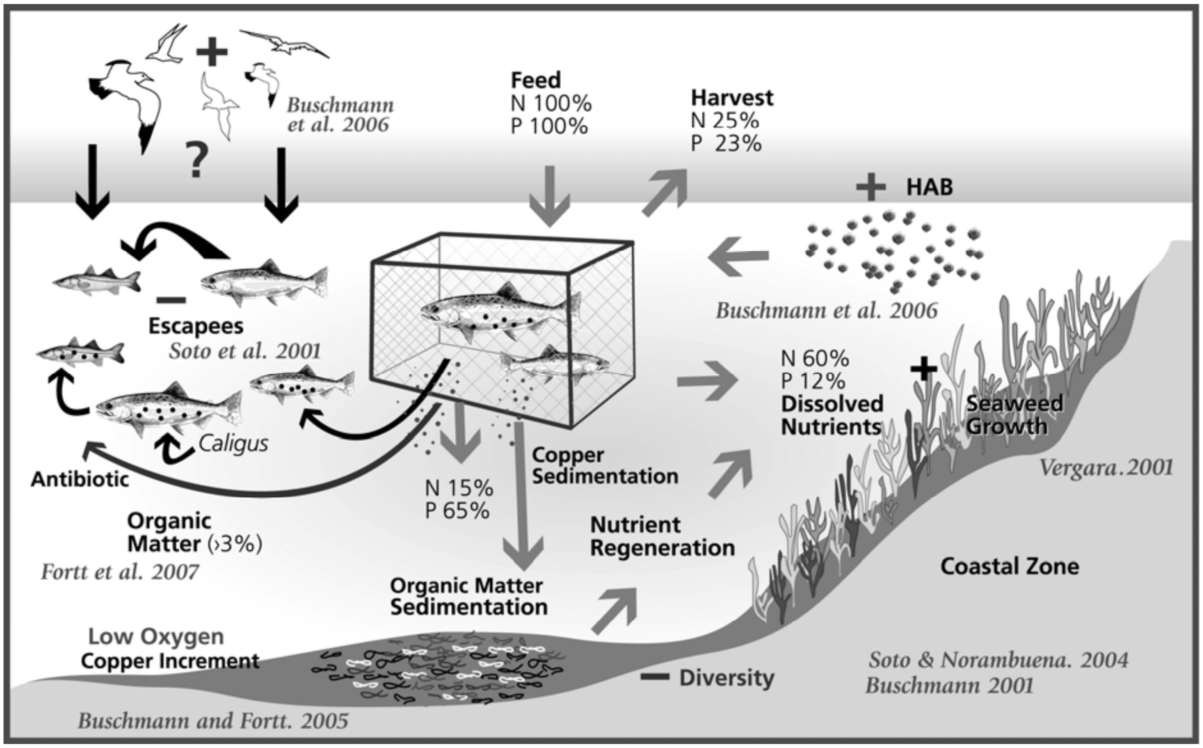
+
?
Buschmann et al. 2006
Feed
N 100%
P 100%
Harvest
N 25%
P 23%
+ HAB
Buschmann et al. 2006
Escapees
Soto et al. 2001
N 60%
P 12%
Dissolved Nutrients
+
Seaweed Growth
Caligus
Copper Sedimentation
Antibiotic
N 15%
P 65%
Vergara.2001
Organic Matter (›3%)
Nutrient Regeneration
Fortt et al. 2007
Coastal Zone
Organic Matter Sedimentation
Low Oxygen
Copper Increment
Diversity
Soto & Norambuena. 2004
Buschmann 2001
Buschmann and Fortt. 2005

Figure 3

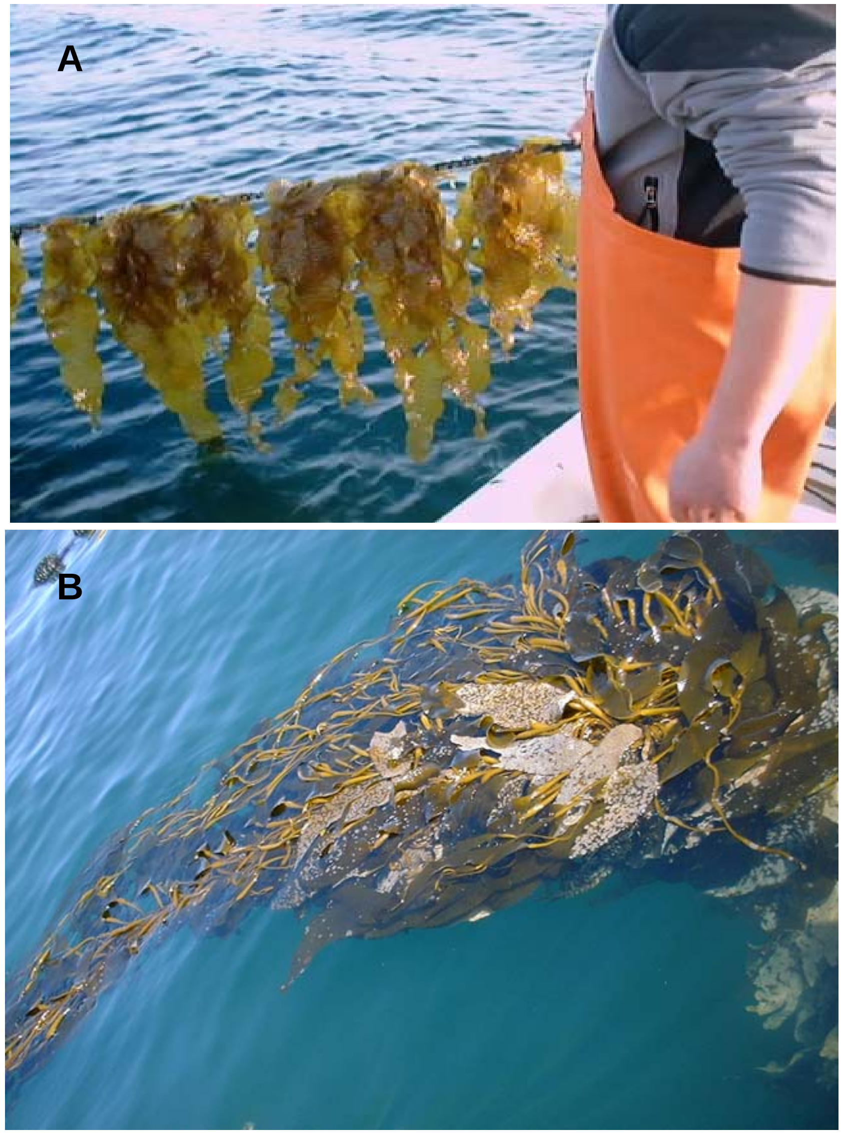

Figure 4

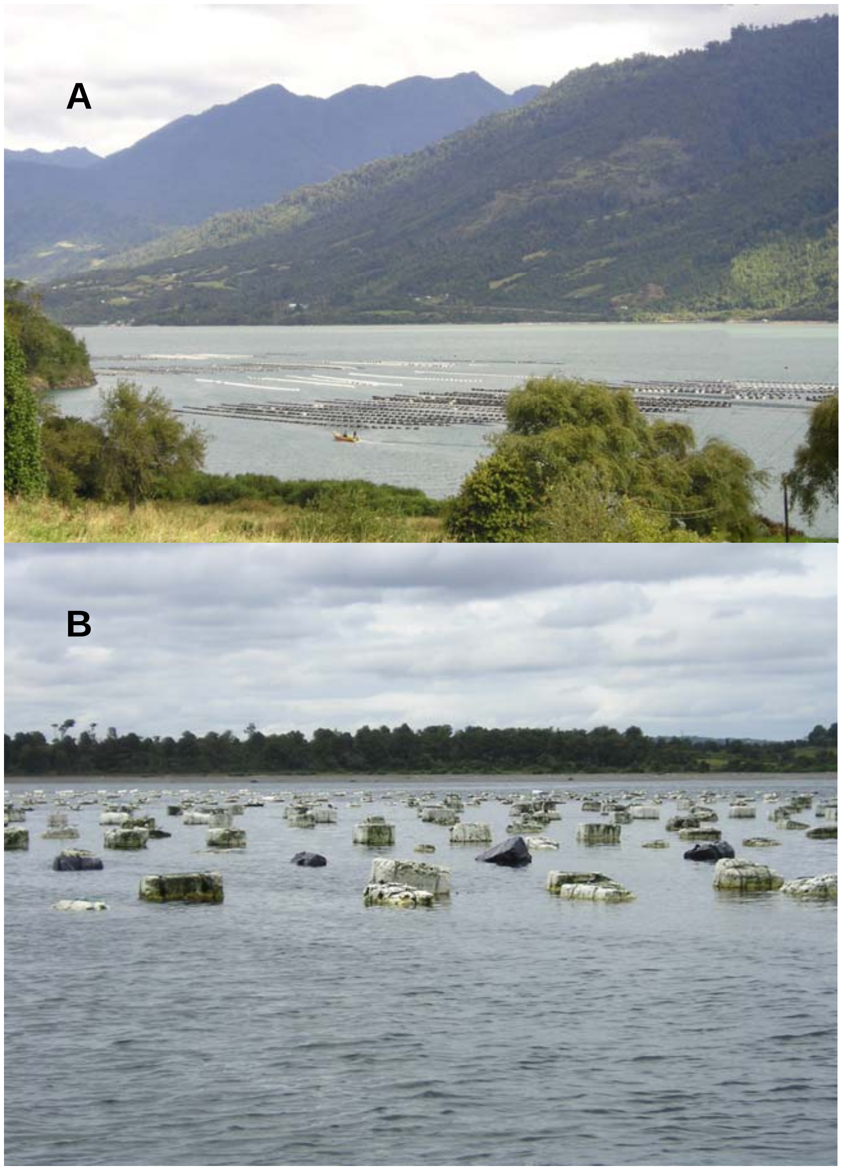

Figure 5