

Ecosystem approach and interactions of aquaculture activities in southern Chile

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Abstract

The main objective of this paper is to understand key, practical and important problems, in relation to carrying capacity of seaweed, caged-salmon and mussel-farm production, respectively, located within the Inland Sea of the Xth region (ISEX), the Republic of Chile. Several interactions between different aquaculture activities in the ISEX have been studied, with particular emphasis in the water column and Harmful Algal Bloom. From an ecological point of view the aquaculture production in the ISEX is composed of 2 major components; photoautotrophic (Seaweeds) and heterotrophic (Mussels and Salmonids). One problem that we have observed is a low mussel yield possibly explained by the lower than normal phytoplankton abundance during 2009 in the ISEX compared with the last decade.

It is important to carry out a marine survey and models to evaluate fate, proportions and balance of the primary nutrients. Only once this is complete can we more accurately estimate the environmental carrying capacity of areas and nutrients that are limiting resource for phytoplankton, and hence for mussels yield. An aquaculture and ecosystem model is required to forecast and verify the different photo-autotrophic and heterotrophic biomass level and the magnitude and fate of nutrients. Assuming that bio-ethanol and marine bio-fuel projects will be successful, in the long term (10 – 15 years), we could observe nutrients depletion in ISEX during summer period, due to large production areas (> 25 000 hectares) of seaweed.

Introduction

This case study is based on an ecosystem approach and the interactions between several marine aquaculture activities in the south of the Republic of Chile. The main **objective** of this study is to understand several key, practical and important problems, in relation with the environmental carrying capacity of caged-salmon and mussel-raft aquaculture sites, both systems located within the same Inland Sea of the Xth region (ISEX) of the Republic of Chile. This case study illustrates the interactions between different aquaculture activities in the coastal zone and inland sea of the South of the Republic of Chile, with particular emphasis in those ecological aspects observed basically during the last decade (Soto and Jara, 2007; Buschmann *et al.*, 2009; Clément *et al.*, 2010).

Aquaculture in South America

Aquaculture in South America and Latin America is quite a diverse activity in terms of species, geography, and technologies among others; however it may be outlined as follows:

During recent years Peru is becoming an important trout producer in fresh waters, and this country has the advantage of being one of the largest fish meal and oil producer in the world. The Peruvian aquaculture industry is, little by little, turning into an important industry and is attracting significant investment. Although it is in an incipient stage, it is steadily growing. In 2007 their production was 39 000 tonnes and by 2009 it grew to 49000 tonnes. In 2010 it is expected to exceed 52 000 tonnes (www.aqua.cl). The Argentine Republic particularly in the south has few fresh waters salmonids aquaculture facilities including cage systems in reservoirs. Ecuador has a well established large shrimp production occupying a significant amount of the surface areas of the coastal zone, but these data will not be analyzed in this case study. Since 2003, the Paraguayan Tilapia industry has grown annually approximately 200 percent and it has more than 2 600 producers and an annual production of approximately 1 000 tonnes (www.aqua.cl).

Arzul *et al.*, 2002 studied the interaction of ecological aspects of several activities in South American countries, with emphasis on noxious phytoplankton. My colleague Dr. Philip Scott will present his results of these aquaculture activities from inland waters of the Federative Republic of Brazil during the workshop.

Regional and national factors relevant to site selection for aquaculture

- National New Regulations. Ley de Pesca y Acuicultura; Aquaculture Environmental Regulation (RAMA), Aquaculture Sanitary Regulation (RESA), Aquatic Pest Regulation (REPLA).
- Environmental Impact Assessment. New institutions; Ministry of the Environment.
- At a Regional level the Integrated Coastal Zone Management has implies new policy in sites selections.
- Historical decisions and concessions policy.

Identifying issues locally specific to species, cultures, and geographies

At present, the salmon farming industry faces a major challenge after the ISA virus outbreaks initiated in the ISEX and region XI during 2007, areas that have been used for salmon-cage farming during the last decades. Note also that ISA virus disease was detected in salmon farms in some sites of XII region.

The precise estimation of the carrying capacity of the fjord systems (for aquaculture activities) and the possible impacts of changes in the carrying capacity of ecosystems poses a major scientific challenge in this pristine region (Iriarte, González and Nahuelhual, 2010; Tapia and Giglio, 2010).

The basic schematic ecosystem model in the ISEX is described in Figure 1 and illustrates the 3 major contributors and their interactions;

1. Seaweeds (*Macrocystis pyrifera* and *Gracilaria*);
2. Mussels farms (*Mytilus chilensis*); and
3. Salmonids (*Salmo salar*, *Oncorhynchus kisutch* and *O. mykiss*).

This basic model, i.e. considering the estuarine circulation, the atmospheric inputs, land pollution effects, and other activities such as salmon, mussel and seaweed farms illustrate a holistic and integrated ecosystem (Soto, 2009). Using this basic model we can estimate the Nitrogen and Phosphorus loading in the ISEX of the Republic of Chile. Also it is relevant to study the Chaitén volcano ash fluxes, the local meteorological and light temporal variability, and the nutrient fluxes between phytoplankton, mussels, seaweed and salmonids; gelatinous zooplankton assemblages' predations/consumption effects; land-sea interactions, particularly pollution problems from waste water.

In: Brooks and Mahnken, 2003 inform that 20.5 – 30.0 g of nitrogen and 6.7 g of phosphorus are released per kilogram of Atlantic salmon produced when fed modern high-energy diets containing 30 percent lipid. Therefore we can estimate the N and P loading, however, we do not know the total budget, fluxes and removals.

Seaweed culture

During the last 20 years seaweed culture has been dominated basically by *Gracilaria*, but recent new aquaculture projects related with the use of brown-algae biomass and bio-ethanol could change the scenario. These projects are led by BAL Chile S.A and they are culturing the brown alga *Macrocystis pyrifera* in the ISEX. This project has great potential if the cost of production is feasible. It will imply a relevant increase of autotrophic biomass, nutrients and CO₂ uptake or removal and O₂ production. However, this activity will compete with mussel farms for marine space. In addition, from a biological and ecological point of view, nutrient competition (nitrogen and phosphorus) of seaweed culture and phytoplankton assemblages could be observed in the midterm and the environmental carrying capacity for extensive culture – seaweed and mussels – could be observed.

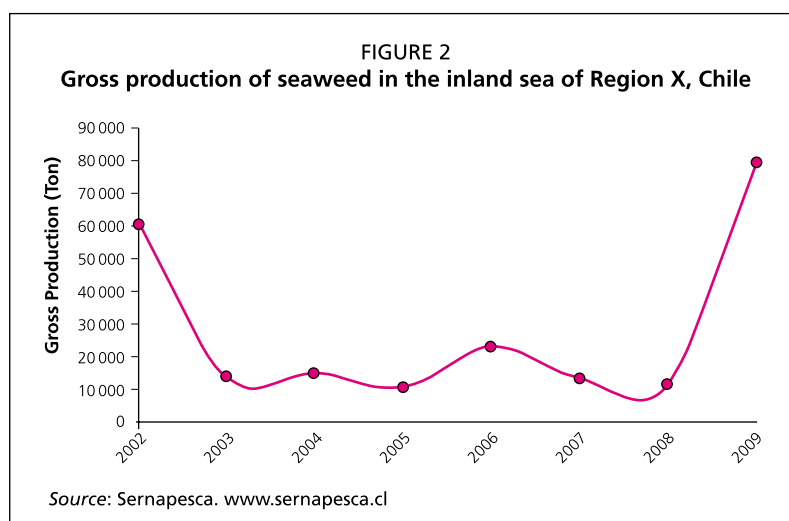
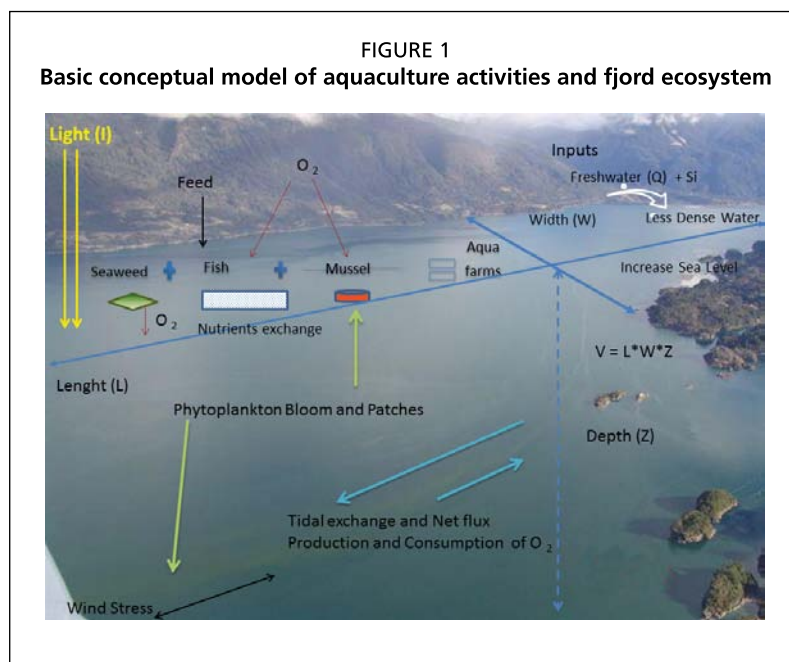
A model is required to forecast and verify the different photo-autotrophic and heterotrophic biomass level and the magnitude and fate of nutrients, in order to establish which nutrients may be a limiting resource. The enclosed graph shows the total seaweed production (Figure 2).

Salmonid culture

The salmonid aquaculture industry in the Republic of Chile has been an import economical activity with positive growth rate until 2006. However, after 2006 we observed the most severe crisis due to ISA virus outbreak and the global financial problem at the same time, with losses in fish biomass and an economical impact over US\$1 600 000 000.

The main questions that arise are:

Was the Environmental Carrying Capacity (ECC) of the Marine Inland Sea exceeded? However, we do not know the real and potential ECC in the ISEX.



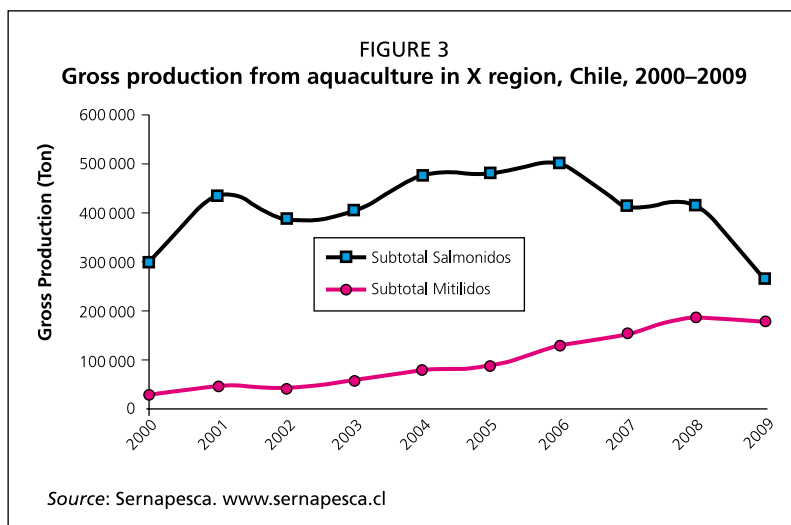
Was this disease outbreak only a sanitary problem and independent from environmental or oceanographic conditions?

Some key issues that contribute to the crisis were:

- a) Many farm sites in small areas or volume of water. The aquaculture and environmental regulations and/or the licenses system authorize the location of sites to close each other.
- b) Bad quality of smolts and imported eggs with new diseases.
- c) A large biomass production system per site (> 5000 tonnes).
- d) A lack of a specific regulation for waste water treatment from salmon processing plant located in the coastal zone.
- e) Unusual proportion (*for fish*) of terrestrial vegetable protein and other feed stuffs instead of fish meal and oils in commercial feeds.
- f) A not well coordinate logistics and marine transportation issues.
- g) Others.

Mollusc culture

Mussel farms and biomass were increased exponentially during the last 6 years; however after 2008 there was decrease in the growth rate (Figure 3). We do not know if the biomass decrease was due to the financial global crisis or an environmental carrying capacity problem or both. During 2008 the total loading of mussels from ISEX aquaculture was around 200 000 tonnes in an area no larger than 8 750 km².



In 2009, mussel farmers observed a very low yield (ratio = soft tissue/total weight) of mussels in raft system in many culture sites in the ISEX of the Republic of Chile.

To investigate this, a time series (www.plancton.cl/pal) analysis of inter-annual and spatial phytoplankton abundance was conducted from which it may be concluded that in 2009 there was very low cell abundance in the water column at many culture sites of ISEX.

In addition, a different source of information and a complete 14th -month temporal-spatial phytoplankton monitoring at 3 sites, with replicates showed the same trend (Clément *et al.*, 2010). Therefore, the low mussel yield is possibly explained due to the lower than normal phytoplankton abundance during 2009 in the ISEX compared with the last decade. The 2009 phytoplankton abundance was the lowest in almost a decade and the 2010 spring data shows the same trend.

Why is there a correlation between the low culture mussel yield and strong decrease of phytoplankton abundance during 2009? The hypotheses are:

- An eventual overloading of the carrying capacity of the mussels biomass and culture.
- After June 2007 there was a dramatic decrease in the number of salmon farms in the ISEX area, which resulted in a reduction in organic and nutrient inputs to the water column.
- In May 2008 there was a large eruption of Chaitén Volcano, producing an enormous amount of ash, some of which was deposited in the ISEX (Figure 4).

- Meteorological time's series data indicates that 2009 was a colder year than normal.
- And we speculated the ISEX ecosystem after 2008 had less phytoplankton nutrients due to a combination of oceanographic conditions.
- We believe that is a combination of interactions between the above-mentioned factors, not one factor exclusively.
- While we do not intend to solve the problem here, we believe this is an interesting case of ecological interactions between mussel and salmon farms and biological water column conditions. We will discuss the issue in the workshop.

Use of models and Decision Support tools.

DEPOMOD

This model has been used commercially in the Republic of Chile by several consulting companies (Gargiulo, 2007) and also has been evaluated and compared with field data and others models by academic scientist (Salamanca, *personal communication*), Tironi, Marin and Campuzano (2010). DEPOMOD is a Scottish initiative (Cromey *et al.*, 2002a and b) and has been a useful tool for fish- farm environmental assessment. Locally it was compare with other models, and showed the same patterns, but different dispersal surface area under the cages (Tironi, Marin and Campuzano, 2010).

COPAS (*Centro de Investigación Oceanográfica en el Pacífico Sur-Oriental*)

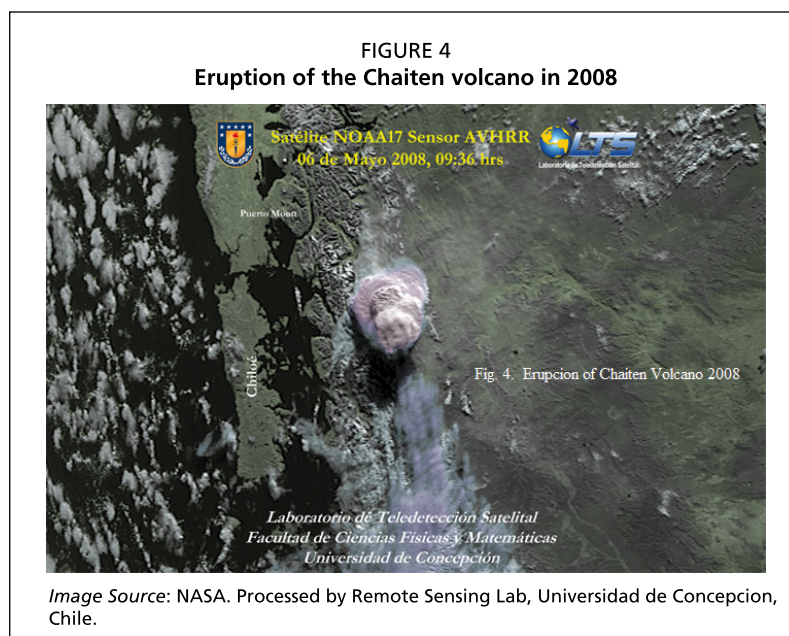
One of the goals of COPAS is to contribute to the knowledge of circulation, water masses and large-scale processes off southern Chile, and the effects of their variability on present and past biological productivity and biogeochemical cycling in the Eastern South Pacific, including the fjords system (www.copas.cl).

The scientists of COPAS have been conducting a large-scale multidisciplinary research project with contributions from several aspects of marine ecology, oceanography and modelling to estimate the carrying capacity of fjords (Iriarte, González and Nahuelhual, 2010; González *et al.*, 2010).

The ECOManage Project: (www.ecomanage.info)

Ecologists and social scientists are presently merging their skills for developing integrated tools to help decision-makers in the difficult task of integrated coastal zone management. EcoManage is a project that aims to push the capacity of assisting managers to merge knowledge from ecological and socio-economic disciplines to better understand:

- (1) The variables driving the health of the coastal zone such as local pressures from people, and pressures originating from the drainage basin, transported mostly by rivers and by groundwater;
- (2) The socio-economic activities that are important and their impacts on the ecosystem including feedback loops on socio-economics; and



(3) The physical characteristics of the ecosystem that together with the loads determine its ecological state.

Three coastal zones showing conflicting interests between urban, industrial and agricultural pressures and environmental maintenance have been selected for this study. These areas are: Aisén Fjord in the Republic of Chile, Bahía Blanca estuary in the Argentine Republic and Santos estuary in the Federative Republic of Brazil.

Participatory methods will be applied for interaction with stakeholders in order to establishing study scenarios and indexes for social-economic and ecosystem analyses and to measure environmental impacts of management decisions. Field data will be analyzed using a Spatial Decision Support System (SDSS). The models created will help simplify the assessment of the impact of management scenarios and evaluate their performance. The project will improve normative rules for the functioning of the systems, and in this way to improve environmental management for the estuaries towards sustainable development [<http://antar.uchile.cl/>].

MOHID

Laboratorio de Modelación Ecológica (2012) presents the MOHID modelling system as an excellent framework to develop management tools for particulate waste assessment in coastal marine systems, according to the needs, capacities and requirements of local decision-makers. This system has the ability to synthesize data from numerous salmon farms and their cumulative effects, with relatively low fund requirements, a continuously updated open-source modelling software system and a growing online support community (www.mohid.com), making it an excellent choice to assess environmental impacts of coastal system, especially for developing countries.

In order to improve the usability and acceptance of MOHID's lagrangian module as a solid waste dispersal model for aquaculture, this system requires field validation and it needs to be compared with other models such as DEPOMOD and MOHID in similar scenarios.

Other local Models

A model of the spatial distribution and loading of organic fish-farm waste to the sea bed was used and refined in Dalcahue channel (ISEX). The 90 percent isoline of the sedimentation model marks the boundary of ecologically influenced sediment compared to *in situ* data, considering

- I. Carbon content
- II. Macrobenthos
- III. Redox potential
- IV. Metabolic solutes

This indicates a maximum loading capacity of $5 \text{ g C m}^{-2} \text{ d}^{-1}$ for the benthos in the investigated area before an influence on benthos and biochemistry is visible or measurable, respectively. The sedimentation model is a powerful tool to predict organic carbon sedimentation and its distribution over the sea floor, thereby assisting in managing site specific limits. The sedimentation of organic carbon can be spatially correlated to the impact on the benthos; however, it is a conservative measure and is negligible when considering the overall carbon cycle in a fish farm area (Hevia, Rosenthal and Gowen, 1997).

Main gaps and improvement needs according to the EAA

We require a nutrient budget and assessment, particularly for silica, nitrogen and phosphorus, in the ISEX. Once this has been done it will be possible to estimate the relative amounts and inputs of "new production" from aquaculture with those natural fluxes in the sea.

Integration of current approaches with regulation and governance: examples of current practice and problems

Immediately after the ISA virus crisis, new aquaculture and fisheries laws were discussed for more than a year in Congress. These laws have been approved and have had many implications from a financial, sanitary and environmental point of view (Ley General de Pesca y Acuicultura. Última Modificación Ley N° 20.451 F.D.O. 31/07/2010 www.subpesca.cl). One of major changes is a different production system based in a **group of concessions** (*barrios* Clément, 2008) (Figure 5). The system is operating based on organized and coordinate actions; groups of salmon producers have to stock their smolts within a period and area (group of concessions), and they have to harvest the biomass before 24 month of production. After this production system and period the groups of concessions have to fallow for 3 months. The method is commonly called 24+3.

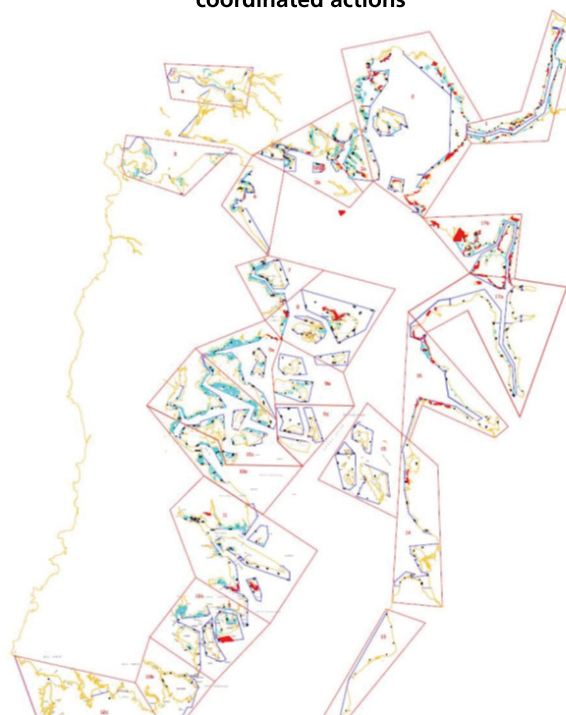
Identifying current and future issues and bottlenecks

- There will be (in the short term 5–8 years) several conflicts due to marine space utilization of the aquaculture activities in the ISEX.
- Assuming that bio-ethanol and marine bio-fuel projects will be successful, in the long term (10 – 15 years), we could observe nutrients depletion in ISEX during spring and summer period, due to large production areas (> 25000 hectares) of seaweed.
- Fresh and marine water quality deterioration.
- Habitat disturbances due to intense use of waterbodies and the coastal zone.

Recommendations

It is important to carry out a marine survey and models to evaluate fate, proportions and balance of the primary nutrients involved in aquaculture activities including photo-autotrophic production. Only once this is complete can we accurately estimate the environmental carrying capacity of areas and nutrients that are limiting resource for phytoplankton, and hence for mussels yield and also for photo-autotrophic production in aquaculture.

FIGURE 5
Concessions group of farms in Southern Chile based upon coordinated actions



Source: Sernapesca. www.sernapesca.cl

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