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Salmon farming vulnerability to climate change in southern Chile: understanding the biophysical, socioeconomic and governance links

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Abstract

Here, we describe an assessment of climate-change vulnerability for the salmon farming sector in southern Chile using a model that combines semi-quantitative measures of Exposure (risks), Sensitivity (economic and social dependence) and Adaptation Capacity (measures that prevent and mitigate impacts). The evaluation was carried out in eight pilot communes representative of salmon production (marine grow-out). Exposure was estimated with a semi-quantitative risk assessment tool based on oceanographic, meteorological and hydrological information, mortality-by-cause databases, and through extended consultation with experts and relevant stakeholders. Threats included relevant changes in water temperature and salinity, declines in dissolved oxygen, occurrence of HABs, and diseases that could be associated with climate change. Based on our analysis of the data, we divided the farming regions into four sub-regions with distinctive oceanographic properties and superimposed the sea surface warming trend and a spatial pattern of mortality by respective cause. Reduction of precipitation and the increase of air and sea surface temperature are the most relevant foreseen climate change drivers, especially for regions X and XI. The resulting vulnerability matrix indicated that communes with higher production concentrations were more exposed, which in some cases coincided with higher sensitivity and lower adaptation capacity. Our models of four management scenarios allowed us to explore the changes in vulnerability associated with a southward movement of salmon production towards the Magallanes region. By identifying new protocols to increase adaptation and reduce vulnerability in a spatially explicit fashion, we provide policy recommendations aimed at increasing climate change adaptation and the long-term sustainability of the sector.

Key words: Chilean Patagonia, climate change, salmon-farming employment, vulnerability.

Introduction

Aquaculture, the fastest growing global food sector, must face climatic variability and climate change (De Silva & Soto 2009)-related risks. Several authors have described potential impacts of climate change on aquaculture and some of the relevant factors, summarized in the last IPCC science report (Handisyde *et al.* 2017), including an increase in sea surface and inland water temperatures, a change in precipitation patterns, a change in salinity, oxygen depletion, sea-level rise, and an increase in storminess and extreme weather events. Furthermore, increased concentration of CO_2 in the oceans is leading to ocean acidification. These factors could affect aquaculture performance by reducing growth of farmed individuals, enhance pests and diseases exacerbating their impact and increasing their distribution, damage infrastructure, limit access to resources etc. (Bueno & Soto 2017; Dabbadie *et al.* 2018). Model-based climate projections under scenarios with increasing concentrations of greenhouse gases consistently predict long-term changes similar to those observed in the last decades (IPCC 2014).

Aquaculture science and technology can respond to long-term climate-related changes with improved and more adapted species, strains, and production technologies. On the other hand, abrupt environmental disruptions, whose frequency is expected to increase under climate change scenarios (Mitchell *et al.* 2006), are most often related to natural climate variability and impose major challenges for adaptive responses.

Chile is the second largest global producer of farmed salmon with a production of over 700 thousand tons and an export value around US$4 billion in 2016. The salmon farming grow-out stage takes place in floating cage farms distributed throughout the Chilean Patagonia inner seas and fjords in the national political regions X, XI and XII (Fig. 1). Aquaculture activity has created a value chain through direct and indirect employment, demand for services, taxes contribution, etc. Thus, some coastal cities (e.g. Puerto Montt, Castro and Quellón) and communities are strongly dependent on the salmon farming sector. The farming system also produces negative externalities such as environmental impacts (Niklitschek *et al.* 2013; Urbina 2016; Yatabe *et al.* 2011; Quiñones *et al.* this volume) and complex interactions with coastal communities (including artisanal fisheries) mostly due to conflicting demands for the use of coastal space and potential effects on marine resources.

Atlantic salmon's optimal temperature range is between 13 to 17°C (De Silva & Soto 2009) and increasing sea temperatures could affect performance under farming conditions. Salmon farming as an industry with high technological integration could react to mid-and long term changes but may not be prepared to face sudden or temporary changes in parameters such as surface temperature, salinity or near-surface stratification. The latter, for example, may trigger harmful algal blooms (HAB) or enhance hypoxia events that cause direct mortality or produce conditions that deteriorate performance and health in farmed fish.

The level of social and ecological vulnerability to climate anomalies in this region became evident in the late austral summer of 2016, when the worst ever recorded HAB took place in northern Patagonia (León-Muñoz *et al.* 2018). As a result, the salmon industry lost about 40 thousand tons due to direct mortality and poor growth of fish (Apablaza *et al.* 2017). Salmon production in 2016 dropped by about 24% relative to 2014 and some communes lost most of their production (Clément *et al.* 2016). The unusual HAB was apparently related to a climate anomaly characterized by a marked decrease in freshwater input to Patagonian coastal waters, increased solar radiation and altered hydrobiological setting (León-Muñoz *et al.* 2018). The regional drought was, in turn, caused by the superposition of a strong El Niño event (natural variability) with the effects of anthropogenic climate change (Garreaud 2018).

Losses in salmon production, employment and local livelihoods revealed that this industry and the associated socioeconomic system are vulnerable to climatic variability and climate change (Bueno & Soto 2017).

Climate-related anomalies may not only trigger devastating HAB events but also could produce environmental conditions conducive to the proliferation of parasites and diseases (Bueno & Soto 2017), which are a main concern and cause of economic losses for the salmon industry (Ibieta *et al.* 2011). One of the main parasites affecting farmed salmon, the sea lice (*Caligus rogercresseyi*), performs better in waters with higher temperature and salinity (Amundrud & Murray 2009). Similar evidence has been found for the amoeba that causes gill damage to fish and facilitates the onset of disease and coinfections (Oldham *et al.* 2016).

Considering the high salmon farming losses in Chile due to HABs and diseases that may be influenced by environmental conditions, it is necessary to understand the vulnerability of this sector under climate change scenarios.

Objectives

The main objective of this contribution is to describe a climate-related vulnerability assessment for the salmon farming sector in southern Chile using a dynamic tool and an approach that identifies key elements that will increase adaptation and reduce vulnerability. As noted before, climate anomalies (e.g. droughts) are relevant since they can lead to environmental disruptions conducive for HABs and parasite/diseases proliferation. Significant climate anomalies most often result from the superposition of natural variability with long-term trends of anthropogenic origin.

Approach

We adapted the IPCC Vulnerability model (Brugère & De Young 2015; Handisyde *et al.* 2017) to develop a climate change socioecological vulnerability matrix for the salmon farming sector as a participatory, simple, flexible and dynamic tool. The model involves three components: *exposure* (E) to climate-related threats leading to loss of farmed biomass; *sensitivity* (S) which mainly represents the employment and livelihoods dependency and *adaptation capacity* (AC) which entails relevant measures and