Aquaculture and global changes

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Aquaculture is a booming sector, currently supplying more than half of the fish and shellfish on world markets. Climate change will affect some aquaculture activities; however, the scale of these impacts cannot yet be quantified, given the uncertainty of global models. Adaptation of production systems is potentially feasible through actions by all stakeholders involved. Direct impacts will be related to changes in production conditions in freshwater, brackish water and marine environments. The main indirect impact is likely to be related to the dependence on an exogenous food supply for the cultivated organisms. However, the negative (inland water eutrophication, ocean acidification, etc.) and positive impacts (aquaculture activities in colder areas, better growth of farmed organisms, etc.) could balance out. Finally, impacts will vary depending on region and type of production.

Aquaculture – an ancient activity, close to agriculture, consisting of animal or plant production in aquatic environment – is currently booming. It has been growing exponentially since the 1980s and now supplies more than half of the fish and shellfish for the global market, while global fishing statistics remain stationary.

Scientists expect aquaculture to be severely impacted by climate change. Various publications on this issue[1] state that the forecast global environmental conditions will affect the aquaculture sector. It is important to note, however, that all the predicted impacts will not necessarily be negative.

In fact, climate change is likely to create development opportunities in countries or regions where current production is low.

In aquaculture, unlike fisheries, human intervention occurs throughout the life cycle, with some exceptions[2]. This therefore allows stakeholders to take action to adapt[3] to climate change. The success of the adjustments made will depend upon the severity of environmental conditions, the costs and the adaptability of the relevant actors, as well as upon national and international decision-makers.

DIRECT RISKS OF GLOBAL CHANGE FOR AQUACULTURE

In 2017, global aquaculture production reached a record level of 111.0 million tonnes (fresh weight equivalent; valued at 242.8 billion US dollars), including 79.2 million tonnes of consumables (231.0 billion US dollars) and 31.8 million tonnes of aquatic plants (mainly algae; valued at 11.8 billion US dollars). Climate change will jeopardize some aquaculture activities, but the extent of these impacts cannot yet be quantified in the absence of global models that take into account all direct and indirect effects of global changes.

1 See recommended references.
2 In particular, aquaculture activities based on individual catches from natural environments.
3 In the case of production, adaptation means finding a technical solution to sustain the activity despite constraints.

In any case, there will be consequences on production, which in turn will affect humans. The global demand for fishery and aquaculture products is increasing. Moreover, aquaculture products are an important source of nutritious food for developed and developing countries (viz. a contribution to food security), and represent a source of income for all communities, regardless of their standard of living. Among the impacts of climate change affecting aquaculture, direct consequences are expected to be mainly related to changes in production conditions. Average production will thus be affected, not only in the marine environment (Table 1), but also in inland areas (fresh and brackish waters), where the majority of global production is concentrated. These inland production areas are more sensitive to changes; in fact, global warming and the resulting temperature rise in global surface waters are expected to have a much greater impact on aquaculture in inland areas than in the marine environment (due to the modification of the optimal temperature range of the organisms currently cultivated).

Table 1. Summary of climate change impacts on oceans and coastal areas affecting aquaculture (from Allison *et al.*, 2011).

- Change in temperature
- Change in ocean salinity, density and
- stratification
- Change in ocean circulation and coastal upwellings
- Rising sea levels
- Land-ocean interactions
- Changes in natural climate variations (ENSO)
- Increasing frequency and severity of extreme weather events
- Ocean acidification and changes in seawater chemistry
- Timing and success of physiological processes, spawning and recruitment
- Primary production
- Changes in marine life distribution
- Changes in marine life abundance
- Phenomenological changes (*i.e.* life cycle stage duration)
- Species invasion and diseases
- Changes in climate regime and extreme events

Nevertheless, the negative and positive impacts could balance out. Among the positive impacts of climate change, scientific models predict an expansion of aquaculture activities towards cooler parts of the world, which are likely to have longer thawing periods, better growth rates of farmed organisms, and an improved food conversion capacity for the latter. However, these positive effects will be concurrent with negative impacts (*e.g.* increased eutrophication in inland waters and ocean acidification). In both cases (negative or positive effects), production methods need be adapted.

DIVERSE VULNERABILITIES AND DIFFERENT TYPES OF PRODUCTION

Aquaculture is not carried out uniformly throughout the world. This heterogeneity must be taken into account to establish a meaningful assessment of the potential impacts of climate change. Climate change is likely to occur with differing intensities depending on the geographical area, thus resulting in different impacts. It is therefore necessary to keep in mind that aquaculture exists mainly in three climate regimes[4] (tropical, subtropical and temperate), in three types of environment (seawater, freshwater and brackish water), and covers a wide range of taxa.

In Asia, impacts related solely to global warming are likely to be essentially beneficial, resulting in better growth rates of farmed stocks. However, this should not conceal the impacts of climate change on water availability, worsening weather conditions, such as extreme rainfall, increasing eutrophication and stratification of stagnant water.

The concentration of aquaculture in certain areas (namely Asia and the tropics) makes it possible to focus on developing adaptation strategies to locally

4 Aquaculture is predominant in tropical and subtropical regions and is mainly located in Asia.

mitigate the impacts of climate change, especially if the expected gap between supply and demand for aquatic products for consumption is to be filled by aquaculture.

Among the various global changes predicted, one in particular is regularly highlighted, as shellfish production on the west coast of the United States is already experiencing its impacts: ocean acidification. The associated adverse effects are well documented for two key product groups in aquaculture: bivalves and crustaceans.

The increased concentration of dissolved CO_2 in seawater can impact marine life at three levels: (1) the limitation of available carbonates, mainly affecting calcifying organisms; (2) the increase in H^+ ions in the water resulting in decreasing pH – *i.e.* acidification of surrounding environment; and (3) an increase in CO_2 partial pressure in organisms, causing hypercapnia.

The socio-economic impact will be significant, particularly on shellfish production. In 2017, although farmed shellfish only accounted for a volume of 7% (8.4 million tonnes) of the total aquaculture production for human consumption, it represented a value of 25% (61.1 billion U.S. dollars). In contrast, mollusk production (17.4 million tonnes), although more than twice that of crustaceans only represented half of their economic value. There have been attempts to adapt to the impacts of climate change on different production systems, including the use of cages or closed systems.

Example: What will the impacts of climate change be on the Chinese aquaculture industry?

In terms of risks, the latest IPCC forecasts for East Asia are:

- Average annual temperature: +3.3°C by 2100;
- A possible increase in total annual precipitation;
- Increased climate variability.

According to several authors, the negative impacts related to fish production will be: heat stress, increased oxygen demand, increased pollutant toxicity and a higher incidence of fish diseases. More generally, production systems are likely to undergo a decrease in oxygen solubility in a warmed ocean, eutrophication, stratification, uncertain water supply, and saltwater incursion inland due to rising sea levels.

INDIRECT RISKS OF GLOBAL CHANGE FOR AQUACULTURE

The impacts of climate change are not just limited to the surrounding environment of the production site. The predicted conditions will foster, in particular, the remobilization of contaminants that are currently not bioavailable, the emergence of diseases, increased toxic algal blooms, the disappearance of key species (*e.g.*, phytoplankton for filter feeders) or conversely, the occurrence of harmful species in the culture medium.

However, the main indirect impact of climate change on aquaculture is likely to be linked to its dependence on external food supplies. Indeed, 70% of the world's aquaculture production depends on the supply and production of raw materials from agriculture and industrial fisheries. These external inputs will be affected by climate change and will therefore have an indirect impact on the aquaculture industry.

The negative impacts are likely to be experienced most sharply in the temperate regions, where fish farming is entirely based on carnivorous species. However, other areas are also expected to be affected, as the vast majority of countries involved in aquaculture production use fishmeal.

Recent changes in the distribution and productivity of a number of fish species can be linked with a degree of certainty to regional climate variability, such as the El Nino-Southern Oscillation. There is a strong relationship between fishing and climate trends. Moreover, the increased frequency and intensity of extreme weather events are likely to have a major impact on fisheries production, and therefore indirectly on aquaculture.

As the indirect impacts on aquaculture activities and/or productivity are subtle, complex and difficult to identify, it is challenging to develop measures to adapt to climate change. A close and interdependent relationship exists between fisheries and aquaculture. This relationship is illustrated by the contribution of some inputs derived from the fisheries industry and used in aquaculture, including fishmeal, fish oils and, to a lesser extent, juvenile organisms. The impacts of climate change on fisheries worldwide will therefore have consequences on the aquaculture industry.

CONCLUSION AND RECOMMENDATIONS

There are, or will be, solutions to help aquaculture adapt to climate change. The resilience of aquaculture sensus *lato to* unexpected shocks has already been proven. In particular, this can be illustrated by the short time it took for most Asian countries to replace shrimp species when one species had been severely affected by a virus (with a regionally significant dispersion) or by the speed at which some countries affected by devastating weather events resumed normal production.

Despite these advantages, the aquaculture sector must prepare itself. Advances in the development of predictive models must be made, taking into account the multiple stress factors that will result from climate change. Moreover, progress in the selection of species better adapted to cope with the predicted conditions (multiple stressors) is needed, along with a conceptualization of adaptation solutions for cultivation practices.

Additionally, it is important that the changes in aquaculture practices be as environmentally friendly as possible, including the efficient use of resources such as water, land, energy and nutrients in agricultural systems. Feed formulation improvements are in progress and will have to be made, and should ideally include ingredients derived from alternative marine resources (such as by-products from fish filleting factories). More environmentally friendly aquaculture could also benefit from the implementation of certification programs. Even though these programs do exist, the concept of sustainable aquaculture is still the subject of debate.

However, the current situation is not as bad as what is reported in the media. Even though the current production practices are far from perfect, they are generally more efficient, in terms of both energy and product produced per unit of food input than other land-based animal production systems. Furthermore, aquaculture is relatively less environmentally damaging than most agricultural counterparts.

These conclusions are almost always based on high-value aquaculture products, such as shrimps and carnivorous fish like salmon, hence leading to false ideas among the general public, planners, developers and investors. In reality, the vast majority of aquaculture still depends on fish and shellfish situated at the bottom of the food chain. Moreover, macroalgae are also produced and can potentially act as carbon sinks, thus contributing to carbon sequestration.

Finally, although many uncertainties remain concerning the magnitude of climate change impacts on aquaculture and the sector's adaptability, aquaculture will undoubtedly be affected. Action must therefore be preventively taken to allow the continuation of this activity upon which the world's population is becoming increasingly dependent.

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