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Synthesis of current knowledge, adaptation and mitigation options

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Chapter 22: Climate change and aquaculture: interactions with fisheries and agriculture

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KEY MESSAGES

- Interactions of aquaculture with other sectors may either exacerbate existing climate change impacts or help to create solutions to impacts of climate change on other industries.
- With the expected increase in extreme weather events, the number of escapes from aquaculture is anticipated to rise. Minimizing impacts of escapes can be achieved by regulating the movement of non-native aquatic germplasm, certification of cage equipment, modifying pond systems, capacity development of farmers and implementation of management measures.
- Reduced availability and quality of freshwater may lead to increased competition among water users. Water consumption by aquaculture can be reduced by a series of technological or managerial innovations but ultimately, the involvement of stakeholders in the development of coherent policy, legal and regulatory frameworks is essential for effective decision-making on future food-water scenarios and water allocation decisions.
- Even though important sources of fishmeal and fish oil are vulnerable to climate change, increased use of fish processing wastes and rapid developments in novel feedstuffs is likely to mean that the issue is only of importance for aquaculture in the short- to medium-term.
- Aquaculture also offers solutions to some impacts of climate change. Culture-based fisheries, for example, can be used to address climate change aggravated issues of recruitment in wild stock, requiring minimal feed use or other types of care.

22.1 INTRODUCTION

This chapter addresses the question of how climate change influences the interactions of aquaculture with fisheries and agriculture.

Although aquaculture has been dependent in varying degrees upon fisheries as a source of seed and feed, this dependence is steadily reducing. Reliance on wild seed carries high risks from a disease perspective and in some cases has inhibited development of productive farmed strains. Few fish farming operations today rely on wild seed or broodstock. Shrimp farming is also increasingly dependent on hatchery reared stock, while fears that climate change may reduce natural spatfall - upon which much oyster and mussel farming has been dependent - has attracted greater investment in hatcheries.

Much seaweed culture is reliant upon clones, liberating it from dependence on wild material. Of greater significance in the context of climate change is the potential for culture-based fisheries to compensate for shortfalls in wild recruitment. A concern here, however, is the impact of the deliberate release of hatchery reared stock, perhaps of alien species, into the natural environment and the accidental release of farm stock from aquaculture operations as a result of flooding and extreme weather events.

Climate change is likely to change the supply of ecosystem services derived from aquatic environments qualitatively and quantitatively, forcing changes in the types and distribution of fisheries, agriculture, aquaculture and other economic activities. With increasing frequencies and intensities of storms, for example, a greater premium may be placed on sheltered coastal areas, not only for fishing but also for aquaculture sites and for marinas and tourist facilities. In areas increasingly subjected to droughts, especially where population increases are great, competition for freshwater will likely increase, promoting the use of water saving recirculating aquaculture system (RAS) technologies.

With the rapid growth of aquaculture and intensification of production practices has come an increased use of feeds for finfish and crustacean aquaculture (Tacon, Hasan and Metian, 2011). Among the feedstuffs used are fishmeal and fish oil derived from fisheries vulnerable to climate change, raising concerns about the resilience of aquaculture to climate change.

This chapter does not address issues related to greenhouse gas emissions and mitigation, which are discussed in Chapter 27.

22.2 ESCAPES AND IMPACTS ON BIODIVERSITY AND SOCIAL AND ECONOMIC CAPITAL

The expected increase in extreme weather events resulting from climate change raises the likelihood of an increase in escapees from aquaculture farms and the prospect of adverse impacts on biodiversity. Freshwater and coastal ponds account for most farmed fish production, an estimated 85 percent to 90 percent, with the rest, especially in the marine environment, being primarily produced in floating cages. Most crustaceans are farmed in coastal ponds, while mussel rafts and intertidal trestle systems account for most oyster and mussel production. Seaweeds are largely farmed using off-bottom lines in shallow water or suspended long lines in deeper water. Losses of farmed aquatic organisms occur through floods (ponds), extreme weather events (cages, long-lines and trestles) and, occasionally, marked changes in currents (off-bottom and floating long lines and cages). Earthen ponds are susceptible to stock losses, especially in areas prone to flooding. The aquaculture systems most prone to escapes, however, are net cages (Beveridge, 2004).

Much aquaculture depends on the farming of non-native aquatic germplasm (De Silva *et al*., 2009; De Silva, 2012; FAO, forthcoming). Moreover, when aquatic plants and animals are transferred from the wild into a farm environment they undergo both inadvertent and targeted domestication: the former is caused by the culture environment (e.g. unusually high stocking densities, changed water quality and exposure to pathogens) and the latter by breeding programmes selecting for such traits as faster growth and improved disease resistance (De Silva, 2012; Lorenzen, Beveridge and Mangel, 2012). Over time, the domesticated strain diverges genotypically and phenotypically from the wild fish populations from which it originated.

The genetic diversity of wild populations is essential in adapting to changing environmental conditions. While farmed organisms tend to be less fit than their wild conspecifics when released into natural environments, they nevertheless may be released in sufficient numbers and survive sufficiently well to impact on wild fish populations. Feral farmed-fish can damage ecosystems (e.g. carps in the USA), displace wild fish through ecological interactions (e.g. competition for space or food; predation), reduce fitness and genetic diversity of populations if they interbreed with wild conspecifics, and change the dynamics of infectious diseases (Beveridge, Ross and

Kelly, 1994; Naylor *et al*., 2005; Singh and Lakra, 2011). Such changes also create social and economic impacts and adversely affect public perceptions of aquaculture (Jackson *et al*., 2015). Negative interactions are most likely where wild populations are small, and/or highly adapted to local conditions, and/or declining. However, long-term outcomes of the interactions between cultured and wild fish are highly variable and difficult to predict because outcomes are influenced by complex, linked ecological and genetic processes that are highly sensitive to domestication effects in cultured fish and wild population characteristics (Lorenzen, Beveridge and Mangel, 2012).

While there has long been concern about the impacts of aquaculture on biodiversity (Beveridge, Ross and Kelly, 1994) evidence for adverse impacts of non-native aquatic germplasm on indigenous species and strains is, with a few notable exceptions, scant (Canonico *et al*., 2005; De Silva, 2012). In a review of Atlantic salmon escapes Thorstad *et al*. (2008) highlight the risks to wild populations posed by feral native aquatic species, questioning the received wisdom that farming indigenous species is preferable to that of alien species. Evidence for impacts of feral seaweed and shellfish on biodiversity is even more scant (Briggs *et al*., 2004). Moreover, few studies have examined the impacts of feral non-native aquatic germplasm on social and economic capital. Arthur *et al*. (2010) found that non-native tilapias and carps were established in many Southeast Asian aquatic ecosystems with little discernible adverse environmental impact whereas their positive impact on livelihoods and incomes was considerable.

It is nonetheless in the interest of farmers, the state and other stakeholders reliant on aquatic ecosystems to minimize the incidence of escapes into the environment. The Convention on Biological Diversity[1] seeks to regulate the movement of non-native aquatic germplasm to protect biological diversity and minimize the transfer of pathogens. Movement of non-native aquatic germplasm is addressed in various codes of conduct and technical guidelines (e.g. FAO, 2008) and is also prohibited by law in many countries.

Article 9.31. of the FAO Code of Conduct for Responsible Fisheries, which deals with aquaculture, states that countries

> *"… should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks into waters under the jurisdiction of other states, as well as waters under the jurisdiction of the state of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stock." (FAO, 2008).*

In Norway, Scotland (United Kingdom) and Chile reporting of aquaculture escapes and their underlying causes is mandatory and reports are made public[2]. In a pan-European (Ireland, Scotland, Norway, Spain, Greece and Malta) survey of the extent and causes of escapes from marine fish farms over a three year period (2007 to 2009) more than 20 causes - structural, biological, operational, external and unknown - were identified (Jackson *et al*., 2015). While only 10 percent of loss incidences were directly attributed to storm damage, Jackson *et al*. (2015) concluded that adverse weather was a likely contributing factor to losses from other categories. The relationship between number of incidences and stock losses, however, is weak, with some types of incidence, including storms, accounting for a disproportionate amount of catastrophic losses. For example, Jackson *et al*. (2015) found that over 5 million fish, equivalent to 56 percent of all escapes in their study, were caused by just two incidences, neither of

[1] http://www.cbd.int/

[2] see http://aquaculture.scotland.gov.uk/data/fish_escapes_record.aspx?escape_id=2000460, for example.

which was because of storm damage. Insurance claims provide further insights. In the European Commission funded Sixth Framework Programme Ecosystem Approach for Sustainable Aquaculture project[3] (2001 to 2006) 76 claims were made by Greek fish farmers for stock losses resulting from storm damage, accounting for 36 percent of the total value of all claims, while a further 19 percent of the total loss value was from equipment damage, also caused by storms (Jackson *et al*., 2015).

Jensen *et al*. (2010) found that differences in the numbers of fish farm escapes within Europe are in part a result of the higher equipment standards and better management practices in Northern Europe compared to the Mediterranean. A number of countries have begun to tackle the issue, primarily because of public concerns over impacts on wild fish populations. The Government of Scotland (United Kingdom), for example, is working with stakeholders to develop technical standards for fish farm equipment (Marine Scotland, 2015) and implement statutory industry training[4]. By 2020 all finfish farms in Scotland must have appropriate equipment and procedures in place to minimize escapes. Similar measures have been implemented in Chile.

No such measures have yet been taken with regard to ponds or other systems. Careful zoning and site selection to avoid flooding and modification of designs to minimize escapes during floods (e.g. Handisyde *et al*., 2014) will help reduce stock losses. While the efficacy of such measures has yet to be clearly demonstrated, evidence is mounting that they are helping drive down numbers of escapes. The methodologies being implemented in Northern Europe for cage aquaculture, involving the development and application of technical standards and implementation of good management practices, could be extended worldwide as well as to other types of aquaculture system. The combination of regulation and financial self-interest provides strong incentives. A framework for the development and management of aquatic genetic resources, which addresses many of the issues relating to use of non-native aquatic germplasm, is currently under development by FAO in consultation with *inter alia*, WorldFish and the Southern African Development Community member countries (D. Bartley, personal communication, 2018).

The optimum preventative measures to minimize escapes will vary according to the risks, costs and methods of production in different localities but implementation of suitable measures is a necessary adaptation to the consequences of climate change, particularly the expected increase in frequency and intensity of extreme events.

22.3 LAND AND WATER AND COMPETING SECTORS

According to the Intergovernmental Panel on Climate Change Fifth Assessment Report (Jimenez Cisneros *et al*., 2014) climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions, impacting on freshwater ecosystems by changing surface and groundwater flows and water quality. This is expected to intensify competition among various types of agriculture (crop, livestock, etc.), as well as between agriculture and other demands for example, potable water supplies for urban settlements, water for industry and for energy production, potentially impacting on regional water and energy supplies as well as food security. Agriculture is one of the main users of freshwater and global adaptation to climate change must consider food production systems that are more efficient in using such resources.

Aquaculture is a relatively water-efficient way of producing animal protein (Verdegem, Bosma and Verreth, 2006). Water consumption by aquaculture can be divided into direct (i.e. net water harvesting, derived from the water content of harvested fish) and indirect use (i.e. water required to produce aquaculture feeds and to

[3] http://www.ecasa.org.uk.
[4] see http://thecodeofgoodpractice.co.uk/chapters/.

maintain pond water levels, compensating for water losses from evaporation, seepage and intentional discharge). The former is negligible: each tonne of fish harvested results in the removal of around 760 litres of water (Beveridge and Brummett, 2016). Indirect losses may be several orders of magnitude greater. Evaporative losses increase with pond surface area and with temperature, modified by wind movement and topography, and can be as high as 6.3 mm per day (Verdegem, Bosma and Verreth, 2006), equivalent to a daily loss of 63 cubic metres per hectare. Water loss by seepage is primarily determined by soil characteristics, clay soils providing much better water retention than silt and sand soils. Although more extensive forms of pond aquaculture have limited water exchange, low stocking densities typically result in high water use per unit of production.

Water for freshwater pond fish farming may come from rainwater harvesting (i.e. the interception and storage of water before it reaches the aquifer) or from diversion or abstraction of water from rivers or canals. Groundwater resources are costly to develop and often have water quality problems (e.g. high iron, sulphur and CO_2 and low dissolved oxygen concentrations). The withdrawal of water from river channels or diversion to fish ponds can affect the flow regimes (the environmental flows) needed to sustain fish and the fisheries upon which they depend (Brummett, Beveridge and Cowx, 2013).

Cage aquaculture derives aquatic ecosystem services from the lake or reservoir in which cages are sited. The issue of water use in lakes is thus largely limited to water used to produce feeds and to disperse and assimilate wastes (see below), while in reservoirs the requirements to maintain sufficient water depths for cage aquaculture may compromise water drawdown plans for power and irrigation (Lorenzen *et al*., 2007). Dense development of cages in irrigation canals also reduces water flows, compromising supplies of water for irrigation (Beveridge, 2004).

Increased temperatures will increase respiratory demands by farmed aquatic animals and evaporative water losses from ponds, thereby increasing water use per unit of aquaculture production. Decisions on water allocation must be guided by policy and regulation and involve stakeholders (FAO, 2016a, 2016b). However, there remains a lack of key data on water use and no methodology that facilitates comparisons of freshwater use in aquaculture with other food production sectors. This inhibits analysis of synergies and trade-offs between farmed aquatic products and terrestrial foods in terms of water use and consumption, and formulation of future food-water scenarios, thereby hindering informed decision-making and policy considerations (Gephart *et al*., 2017).

Direct water consumption by aquaculture can be reduced through site selection. Hills and trees reduce solar and wind induced losses (although trees also increase evapotranspiration) and in areas with clay soils, evaporative losses per unit of fish production can be limited by deepening ponds, reducing the surface water to volume ratio. Use of concrete or butyl pond liners reduces water seepage losses, but they are expensive (Boyd and Chainark, 2009). Increasing on-farm productivity through higher stocking densities, greater reliance on external inputs and aeration can reduce on-farm water consumption. However, crop-based feedstuffs, which increasingly predominate in commercial pelleted diets, require water, increasing the water consumed per unit of farmed aquatic food production (Troell *et al*., 2014a, 2014b). If crop-based feedstuffs for aquaculture are imported as, for example, they are in water-stressed Egypt, the issue of water use can be outsourced to areas where freshwater is more plentiful, albeit at greater transport costs (and greenhouse gas emissions). Better water management too is important and can be encouraged through charging for water use or through regulation of abstraction aimed at protecting ecological flows (Brummett, Beveridge and Cowx, 2013). Similarly, reducing aquaculture wastes through use of more digestible feeds and improved feed management reduces demand on aquatic ecosystem services.

Aquaculture can also be incorporated into multiple water use basin-level initiatives, further reducing water use and consumption per unit of aquaculture production, and improving resilience to climate change (Nagabhatla *et al*., 2012). Other aquaculture technologies that result in less direct water use include RAS and aquaponics (see Chapter 21).

While marine finfish culture is an efficient means of producing animal protein, the great majority of farmed marine finfish presently relies on feedstuffs that require freshwater (Troell *et al*., 2014a, 2014b). In the near future, however, feeds are expected to come from alternative sources, including food processing wastes, microalgae and seaweed. Bivalves and seaweeds, of course, require no additional foods. Well implemented mariculture could thus prove to be a sound adaptation strategy to climate change induced shortages of freshwater, accompanied by initiatives to try to change consumer interest towards non-fed species (Duarte *et al*., 2009).

22.4 CAPTURE-BASED AQUACULTURE

Capture-based aquaculture – the farming and fattening of individuals that have been captured in the wild – is still relevant in aquaculture, especially with species that are difficult to breed in captivity. These include, for example, the great majority of farmed mussels, some farmed shrimp in Asia (especially *Penaeus monodon* and, in Bangladesh, freshwater prawns), the farming of tuna worldwide and other high-value marine finfish species in Asia. Climate change, along with the disturbance of breeding grounds, may exacerbate pressure on wild populations of these species, reducing their ability to maintain viable populations. Climate change may reduce their availability and therefore affect coastal fisheries for and farming of these resources. There is thus a need to make hatchery seed more available and affordable to farmers and to identify alternatives for fishers whose livelihoods rely on the collection of seed.

22.5 CULTURE-BASED FISHERIES

Culture-based fisheries (CBF) are defined here as fisheries dependent on regular stocking of hatchery reared progeny or broodstock, either to support fisheries (discussed in Chapter 18) or as an integral part of the rehabilitation of ecosystems such as corals damaged by climate change (see De Silva and Soto, 2009). A number of issues associated with stocking open waters with fish of farm origin are covered in Section 19.2 above.

CBF are highlighted as a climate smart fish production system because, other than at the hatchery stages, they do not require feed or other care (FAO, 2013). The practice is already widespread as a response to recruitment-limited water bodies, such as man-made reservoirs (De Silva, 2016), but may have future potential in systems where natural recruitment has become constrained or no longer viable because of water scarcity, seasonal temperature fluctuations and other impacts. On the other hand, fishers engaged in CBF in non-perennial water bodies subject to changes in rainfall pattern may have to change their stocking and harvesting calendar to better fit with the altered pattern of monsoonal rains (Wijenayake *et al*., 2010).

CBF in reservoirs and in some lakes in Central America provide an important protein source for coastal communities, especially when their usual food sources are affected by external forcing factors such as climate change.

The provision of hatchery-produced seed may help address climate change impacts on coastal CBF, for example, when benthic populations that support fisheries (e.g. clams, oysters) have been damaged by storms. Additionally, hatchery produced seed may be more resistant to lower pH or higher temperatures. Fisheries of benthic organisms in many places around the world depend on the availability of seeds and their settlement in natural beds (e.g. clams and sea urchin fisheries in Southern Chile, scallop fisheries in Peru). Settlement may be vulnerable to climatic variability and climate change, on top of heavy overfishing. Indeed, the future of many coastal fisheries will probably depend on hatchery-produced seed that are adapted to climate change. It is important to ensure that CBF do not have undesirable impacts on the genetic diversity of wild populations, as discussed in Section 19.2.

22.6 AQUACULTURE DEPENDENCE ON FISHMEAL AND FISH OIL

The proportion of finfish and crustacean aquaculture production reliant on feeds, often including fishery derived fishmeal (FM) and fish oil (FO), is high and increasing (Tacon, Hasan and Metian, 2011). However, this trend must be seen against a background of improved feeds and feeding practices (as indicated by improved food conversion ratios), reductions in fishmeal and fish oil dietary inclusion rates and the increasing use of alternative FM and FO sources (Little, Newton and Beveridge, 2016; Ye *et al*., 2017). The proportion of fish from capture fisheries that is being reduced to FM and FO has been declining (Ye *et al*., 2017) and high prices are forcing feed manufacturers to reduce FM and FO inclusion rates in favour of oilseeds such as soy and to seek cheaper, alternative sources, such as fish processing wastes (Little, Newton and Beveridge, 2016). FAO estimates that FM produced from fish processing wastes will represent 38 percent of world FM production by 2025, compared to 29 percent for 2013 to 2015 (Ye *et al*., 2017). Moreover, such estimates do not take account of the rapid development and commercialization of alternative protein and lipid sources. Many commercial feed manufacturers[5] have embarked on the development of commercially viable FM- and FO-free diets, substituting those products with novel feedstuffs, such as insect protein meal and microalgae. Thus, while the single largest fishmeal and fish oil reduction fishery, located in Peru, is vulnerable to adverse effects of climate change (Chapter 15), the implications of this for aquaculture diets is assessed as being of only minor concern in the medium to long term.

22.7 DISCUSSION

Climate change will likely increase interactions between aquaculture, fisheries and agriculture in a range of ways and as climate change progresses, aquaculture will have to set out its comparative advantages in meeting countries' economic, environmental and social objectives *vis-à-vis* these other sectors. Competition between aquaculture and other users for freshwater will intensify as resources become scarcer. Increasing use of surface and groundwater for irrigated agriculture to compensate for dwindling or unreliable precipitation, for example, may affect the availability of freshwater for aquaculture. Water allocation decisions will require consideration of the role that countries wish aquaculture to play in meeting their economic, social and environmental goals. An equitable allocation of water resources among users will require the involvement of stakeholders in the development of coherent policy, legal and regulatory frameworks. In turn, this will need an appropriate water use and consumption framework and reliable data, which ideally should be generated through initiatives that involve the cooperation of otherwise competing economic sectors.

Much can also be done to reduce the vulnerability of aquaculture to climate change. With the expected increase in extreme weather events, the numbers of escapes from aquaculture is also anticipated to rise, but this can be minimized by certification of equipment fit for purpose (i.e. able to withstand likely extreme weather events where it is being used), regulating the movement of non-native aquatic germplasm and enforcing the monitoring of escapes. Domestication, improved hatchery technology, and implementation of policies that encourage investment by farmers in seed production and distribution will further reduce use of wild aquatic resources for seed. Dependence on FM and FO can be reduced by incentivising commercialization of

[5] https://www.skretting.com/siteassets/au-temp-files/nexus-and-reports-and-brochures/nexus_issue_22_web.pdf

alternative sources of feedstuffs, such as fish processing wastes, black soldier fly larvae, microalgae and seaweeds.

Aquaculture also has the potential to reduce the impact of climate change on other sectors. One such example is through the development of culture-based fisheries, which can contribute to sustaining food security, resilience and the livelihoods of fishing communities.

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