A CASE STUDY FOR REGENERATIVE AND RESTORATIVE AQUACULTURE

Marine Finfish Farming

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The Nature Conservancy

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Juvenile Kanpachi, *Seriolia rivoliana*, in a marine net pen.

INDUSTRY OVERVIEW

In 2020, total global production of aquatic animals from marine and inland environments was an estimated 178 million tonnes (FAO, 2022a). Of this production, 63% (112 million tonnes) was harvested in marine and coastal areas, split 70/30 between fisheries and aquaculture (FAO, 2022a). For more than 60 years consumption of fish globally has been increasing at a rate greater than that of population growth, and it is possible that global demand for fish could double by mid-century (Naylor, Kishore, *et al.*, 2021). If this trend is to continue, the growing demand for aquatic foods will need to be satisfied by an increased contribution from sustainable marine farming. The Food and Agriculture Organization of the United Nations (FAO) is encouraging at least 35% growth in sustainable aquaculture globally by 2030 (FAO, 2022b).

Fifteen species currently make up 77% of marine finfish production via aquaculture. Atlantic salmon (*Salmo salar*) makes up 33% of this volume, followed by milkfish (*Chanos chanos*) at 14%, with 13 other species each contributing 3.5% or less. Yet, 72 million square kilometers of ocean could be environmentally suitable for the cultivation of one of the 102 most farmed marine species, finfish and others (Oyinlola *et al.,* 2018), illustrating it will be possible to markedly expand production of finfish farming in some regions.

To achieve sustainable expansion, marine finfish farming faces constraints, especially resource gaps through limitations to the availability of sustainable sources of feed, the need to continue overcoming the negative impacts of waste from intensive farming, and social acceptance of farmed products and systems (Costello *et al.*, 2020). Whether or not marine finfish aquaculture can be regenerative and restorative – providing direct benefits to the surrounding environment (The Nature Conservancy, 2021) – remains to be tested. The dependence of this sector on feeding and its greater concentration of waste means that, in comparison to seaweed and unfed mollusc species, there will also be some fundamental differences that likely negate the capacity for some environmental benefits to be provided, such as improvements to water quality. However, ongoing improvements in the capacity to control and mitigate practices that have negative environmental impacts provides the opportunity to critically examine whether there are practices that could be used to enhance or create positive effects. This case study provides an initial exploration of several prospects for offshore marine finfish farms to employ regenerative farming practices to generate benefits to biodiversity and the broader environment.

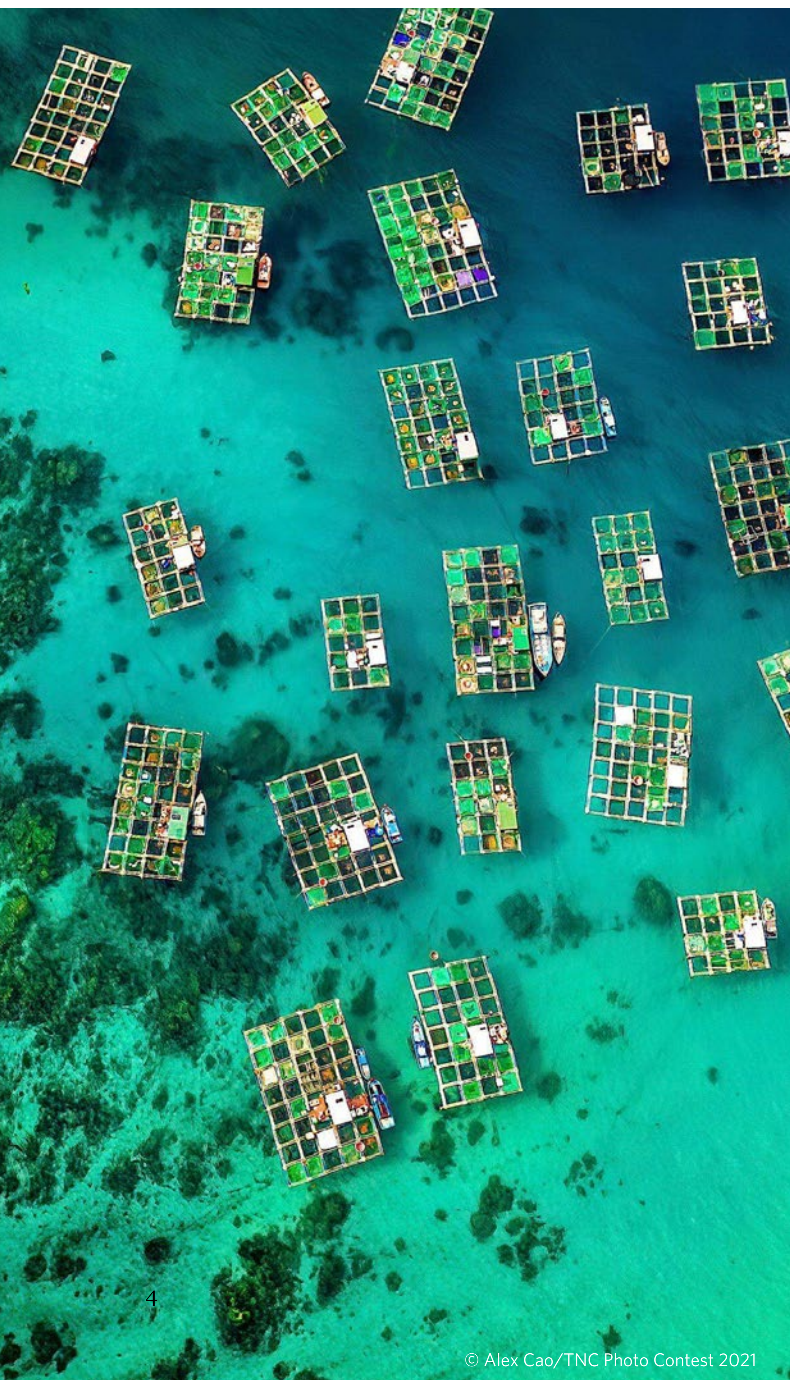
ENVIRONMENTAL CONTEXT

Farming of finfish in marine and coastal areas can have a range of well-known negative environmental impacts, including increased occurrence of pathogens, parasites, and pests; impacts on wild populations from escapes, waste and other pollutants; and the use of unsustainably farmed or fished ingredients in aquafeeds (Froehlich *et al.*, 2018; Naylor, Hardy, *et al.*, 2021). However, because these impacts are well known, they are increasingly considered and managed through strict regulation, risk assessment and mitigation, investments into advancing best practices, and monitoring (Fletcher *et al.*, 2004; Lauer *et al.*, 2015). For example, good progress has been made in recent decades on improving the efficiency of feed use and fish health and nutrition, which has lowered the food conversion ratio for many fed species (Naylor, Hardy, *et al.*, 2021). Also, capabilities to model site and area suitability and to set effective biomass and aquaculture zone criteria (e.g. Middleton and Doubell, 2014; Middleton, Luick and James, 2014) are expanding.

Offshore marine finfish farming net pen supported by a feed barge and maintenance vessel.

To mitigate negative impacts, the selection of a growing site that aligns with the characteristics and sensitivities of the natural environment can make a big difference. When situated in unsuitable locations that may stress sensitive habitats, such as rocky bottom, coral reefs, and seagrass, or within important areas for fishing or tourism, aquaculture can have negative effects on the environment and create conflicts with other ocean users. The FAO and United States National Oceanic and Atmospheric Administration (NOAA) have developed foundational technical resources that strongly encourage the development of comprehensive spatial plans for aquaculture to ensure long-term economic, social, and environmental sustainability, particularly in light of potential climate change impacts (Aguilar-Manjarrez, Soto and Brummett, 2017). These foundational principles can be built upon through the use of local environmental, operational, and geospatial data to generate high resolution aquaculture suitability analyses and support decision-making (Longdill, Healy and Black, 2008; Yin *et al.*, 2018). Studies of ecological carrying capacity can also be used to calculate the appropriate quantity of organic materials that can be added to an ecosystem. This approach is most effective in nearshore environments and can be difficult to employ in open ocean areas due to technical and modelling uncertainties in accounting for waste quantities and dispersal, which can then present a challenge to setting regulatory requirements. This approach is also highly site specific; the dispersal or deposition of dissolved and suspended solids is dependent on the farm site and variables such as local currents, water temperatures, erosional thresholds, the rugosity of the seafloor, and the composition of the benthic community.

To reduce the point source and cumulative effects of finfish farming in coastal areas, offshore marine finfish farming is also being developed. Offshore environments have distinct advantages that reduce both the likelihood and extent of negative impacts from fish and feed waste, namely the greater depth and often stronger currents in these environments, which naturally assist the dilution and dispersal of farm wastes. Yet moving farms offshore can influence the extent and efficacy of maintenance and associated resources. Where maintenance is intensified, (i.e. through more resource-intensive infrastructure or greater distances from port for vessels to travel to maintain sites) the reduced environmental impacts from waste could be "traded off" against increases in other impacts, such as increased greenhouse emissions from transport to service the farm infrastructure (Fujita *et al.*, 2023). Ensuring offshore facilities are operated autonomously using renewable energy can overcome this challenge and is becoming an important opportunity for expansion of aquaculture activities to meet the demand-supply gap (Cai and Leung, 2017). With automation, there will also be less pressure to consolidate feeding into a smaller area to suit manual handling and the on-site operation of workers, which can concentrate feed waste. Infrastructure can, instead, be spaced to best align with the carrying capacity of the local environment.



Aquaculture sites, Ly Son Island,
Quang Ngãi Province, Vietnam.

POTENTIAL PATHWAYS FOR ENVIRONMENTAL BENEFITS

Aggregation of a range of fauna, in particular fish, crustaceans, and echinoderms, at net pens for finfish farming is a common occurrence. A range of species are attracted for food, shelter, or merely orientating toward the built structures. These populations can be more abundant and larger than fish at reference sites; however, farm-associated fish can also have also higher levels of parasitic infection (Barrett, Swearer and Dempster, 2019), if disease is not mitigated through effective fish health management (e.g., approved veterinary medicine treatment). Where the occurrence of ecological traps, such as poorer population health due to transfer of parasites and pathogens or behavioural changes that result in higher rates of predation, can be mitigated, net pens could provide viable additional habitat for a range of life cycle requirements (Dempster *et al.*, 2004; Sudirman *et al.*, 2009). Primary production can also be enhanced by finfish farming. It has been suggested that in sites where the addition of waste-related nutrients is moderate, carrying capacity is not exceeded, and nutrient limitation exists, there may be a positive effect on primary production. (Rensel and Forster, 2007; Price *et al.*, 2015). These effects require greater attention and research to better understand the ecological and farming characteristics that determine whether an environmental benefit might occur. For example, mild anthropogenic nutrient sources in nutrient-poor areas may enhance seagrass growth, but excess anthropogenic nutrients are also a major driver of negative impacts to seagrass meadows (Vieira *et al.,* 2022). Therefore, understanding the general principles by which dissolved nutrients can be a benefit to these systems is important.

Disease prevention, including good farm biosecurity and a 'one health' approach, which acknowledges the interdependency of animal health and the health of the environment (Stentiford *et al.*, 2020), is critical to reducing the need for treatment of farmed finfish stock with chemicals, therapeutants, and antibiotics to reduce parasites and pathogens. Therapeutic veterinary medicines are an important tool to maintain aquatic animal health and welfare, but they should be used in association with other disease management and biosecurity measures (Roberts *et al.,* 2021). These treatments can be extensive and persistent (Miranda, Godoy and Lee, 2018), and if not appropriately regulated, ongoing use can exacerbate antimicrobial resistance (Reverter *et al.*, 2020). Net pens that can be sited in deeper waters and submerged can be positioned at a depth that improves fish survival and reduces the potential for disease amplification and retransmission (including to wild populations). This will decrease the need for chemical treatment, thereby creating more favourable conditions with less stress on the surrounding ecosystem as well as the farmed stock (O'Shea *et al.,* 2019). The strategic advantage of positioning net pens at an optimal depth within the water column also has the indirect benefit to waste treatment through reduction of marine ecotoxicity and can lead to more efficient fish production, increasing profitability and creating a business incentive (Box 1).

Box 1. **Offshore finfish farming of *Seriola rivoliana* – Charco Azul, Panama**

FOREVER OCEANS

Forever Oceans raises *Seriola rivoliana* in net pens in the open ocean off the Pacific coast of Panama. The farmer is using a unique design that employs a single-point mooring, rather than a grid of moorings, such that net pens can be raised and lowered in the water column in waters of 75 to 100 meters deep. Feeding is fully automated and monitored remotely rather than by personnel on a feed barge at the offshore site. Ocean modelling of carrying capacity has established that this approach is highly unlikely to generate impacts to the benthic environment (i.e., from fish and feed waste), which is confirmed through monthly sampling. The greater depth has also proven helpful for reducing parasite loads, which allows the company to run operations with only hydrogen peroxide treatment to reduce flukes instead of the environmentally harmful chemicals commonly used in parts of the industry. Forever Oceans has already reduced Scope 1 and 2 carbon emissions largely due to automation and has a strong interest in reaching carbon neutrality. In 2022, they conducted an Environmental Footprint Assessment to estimate their environmental impacts, including greenhouse gas emissions and a suite of mitigation strategies.

Due to the company's interest in regenerative practices throughout the lifecycle, this assessment also explores the likely effects of operations within the context of the current health of the local environment – the *reference situation* – and the opportunity for Forever Oceans to implement sustainability strategies that could have a positive effect on biodiversity – *the target reference situation* (Vrasdonk, Palme and Lennartsson, 2019). This approach enabled practices specific to fed finfish aquaculture and their effect on biodiversity to be recognized, and then the size of the positive effect that could be achieved through certain mitigating measures to be qualitatively estimated. Six strategies were identified as having the potential to generate both a negative impact to biodiversity, and a positive impact if specific, identifiable strategies were put in place (Figure 1).

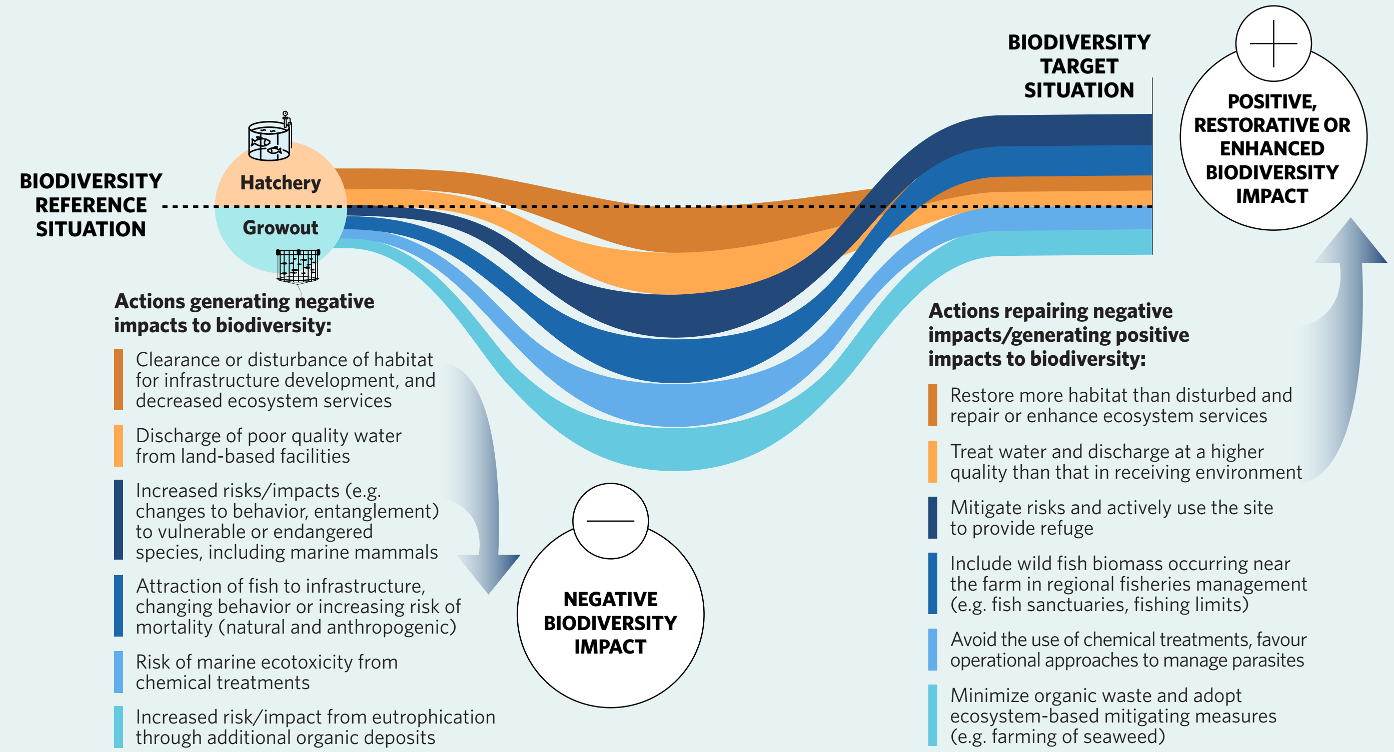
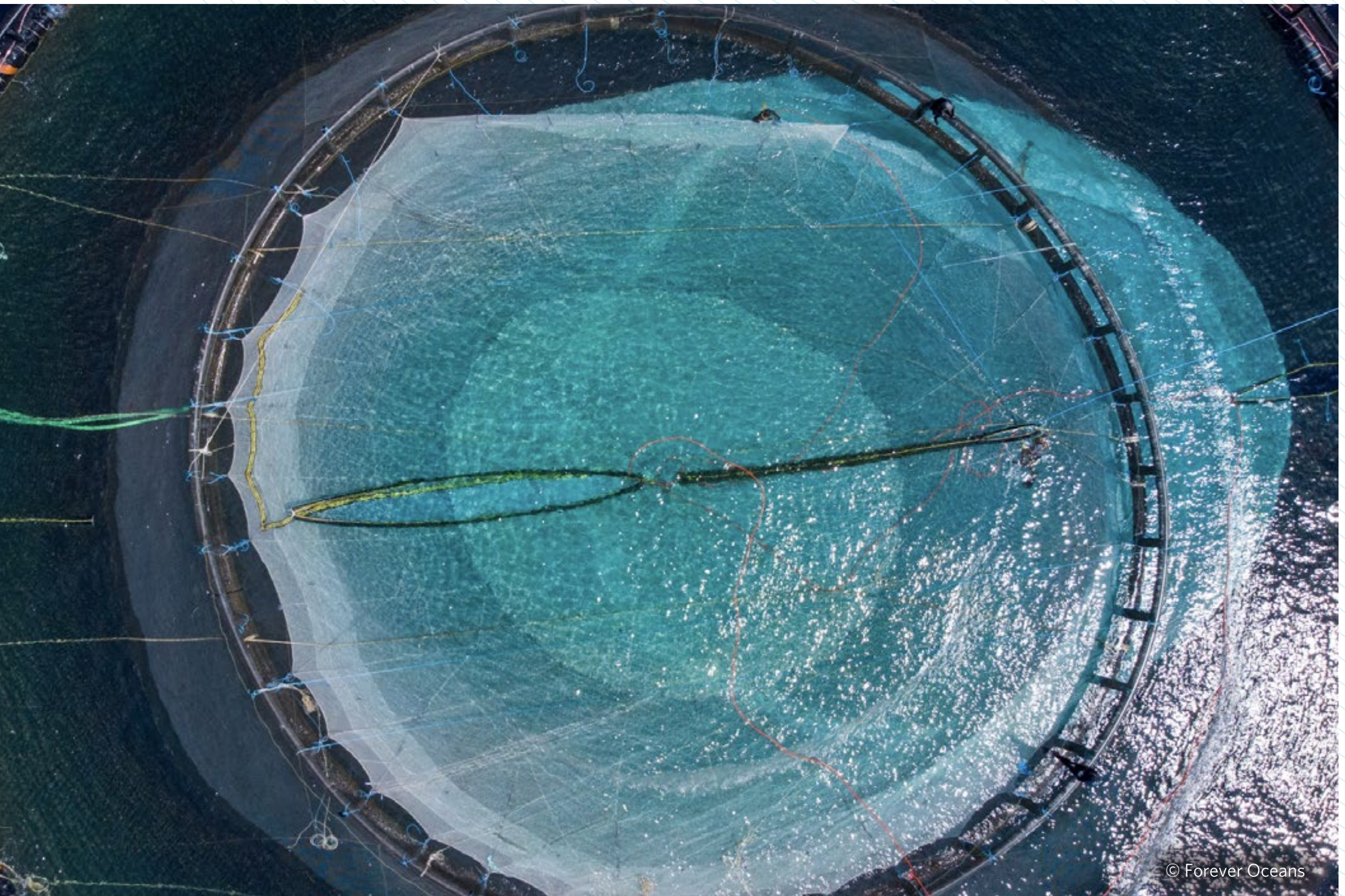


Figure 1. **Conceptual model of biodiversity interactions associated with fed finfish aquaculture that could generate either a positive or negative impact, depending on the practices implemented.**

In addition to the net pen design deployed, Forever Oceans is unique in the total area of concession for which it is a steward, having a total 46,000 hectares within its single Panama concession, the smallest of its concessions globally. The farmer intends to develop a maximum of 10% of this concession, raising an important question about how large offshore concessions could be proactively used for other environmental gains. Where risks to fauna (e.g., fish, marine mammals, seabirds), such as entanglement, changed behaviour and migratory patterns, can be mitigated, these ocean areas could provide critical refuge from other disturbances, such as mining and destructive or illegal fishing practices. In early 2023, Forever Oceans sponsored the start of a Fisheries Improvement Program for an area exceeding their concession in partnership with the local fishing association and international consultants. This management scheme may further offer a positive shift in environmental outcomes.

Yellowtail Kingfish (*Seriola lalandi*).



Offshore marine finfish farming net pen.

Where farms can be designed, sited, and operated to not negatively affect wild populations or exceed natural carrying capacity, an operator could choose to protect the waters between growing sites and zones to provide more area for marine protection or conservation. Marine resource rights currently issued by most governments are not often of long enough time frame (many permits for finfish farming are provided for several years or up to a couple of decades) to justify inclusion under most environmental protection schemes, such as Marine Protected Areas. But alternative models to achieve global targets, such as protecting 30% of ocean area by 2030, are needed. To build a bigger toolkit for conservation, (Gurney *et al.*, 2021) examining the value of marine finfish farm areas as other effective area-based conservation measures (OECMs) is warranted, particularly where aquaculture could also be used as a pathway to equity or to bring to the fore other positive impacts for nature and people, such as empowerment, increased responsibility and action, and improvements in governance (Alves-Pinto *et al.*, 2021). According to the Convention on Biological Diversity,

"An OECM is a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in-situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio–economic, and other locally relevant values."

Testing operating circumstances for marine finfish aquaculture farm areas as OECMs may see the benefits of a model whereby for-profit aquaculture production funds long-term marine protection.

To better understand the potential for offshore marine finfish farms to employ regenerative and restorative aquaculture practices, and to generate environmental benefits, rigorous sampling and monitoring will be needed. Real-time observation and adaptive response and management systems will be most appropriate. Machine learning approaches that can iteratively improve and guide feed application, management, and maintenance practices, so that they are appropriate to local environmental conditions and variability in environmental conditions should be applied. Underwater video monitoring and automated detection of critical events such as stock escapes (e.g., through net pen damage), mortalities, and increasing parasite loads, will be highly beneficial.

Offshore marine finfish farming net pen supported by a feed barge tethered to the main net pen.

POTENTIAL BENEFITS OF FINFISH FARMING

Habitat and biodiversity

Fish are commonly attracted to net pens and can be more abundant and larger around aquaculture sites, using these areas for range of life cycle needs, including recruitment. This can have a positive effect on wild fish populations. However, it can also create an ecological trap (reducing the fitness of the population through predation, disease, parasitism, or fishing) that must be avoided.

Marine finfish farm areas (permitted areas, lease areas, concessions) are often large, and regulatory requirements for mitigation of negative environmental impacts means net pens can be required (by law or best practice) to occupy only a small portion of this area. This provides an opportunity for the area to be actively managed for positive environmental or community outcomes, potentially reflecting OECMs that could enhance or expand protection areas for local biodiversity.

Water quality and climate change adaptation

Marine finfish species are unlikely to directly provide ecosystem services associated with waste treatment, biological control, or climate adaptation. But these services could be indirectly associated with coupling marine finfish farms with species that do, e.g., co-culture of seaweeds or bivalves, using the same area and supporting infrastructure, and co-location of other industry activities and infrastructure, such as energy facilities or artificial reefs. In the absence of having physical space and supporting infrastructure these services might not otherwise be made available.

Sustainable food, resources, and livelihood

When farmed efficiently, with the inclusion of renewable sources of fuel and energy and distributed to market without using greenhouse gas emissions-intensive transport (such as air freight), marine finfish can be a source of high-quality protein and nutrition produced with lower emissions and other environmental impacts than terrestrial food sources.

Downstream handling and processing of finfish are important sources of employment and livelihood in seafood industries, including for women in certain segments of the supply chain (The World Bank, 2012). Perpetuated inequality and a lack of effective policy, however, can lead to women in this sector being poorly paid or predominantly used in unstable or lower quality work conditions (FAO, 2022b). Attention to the availability but also quality of employment for women in processing and increasing their participation in farm-side activities could be a valuable ecosystem service.

Aquaculture activities provide a pathway for existing fisheries or other maritime sectors to engage in new or diversified economic opportunities and employment. Comparable equipment can be required between these sectors and activities that is compatible with other economic activities, such as seasonal fisheries.

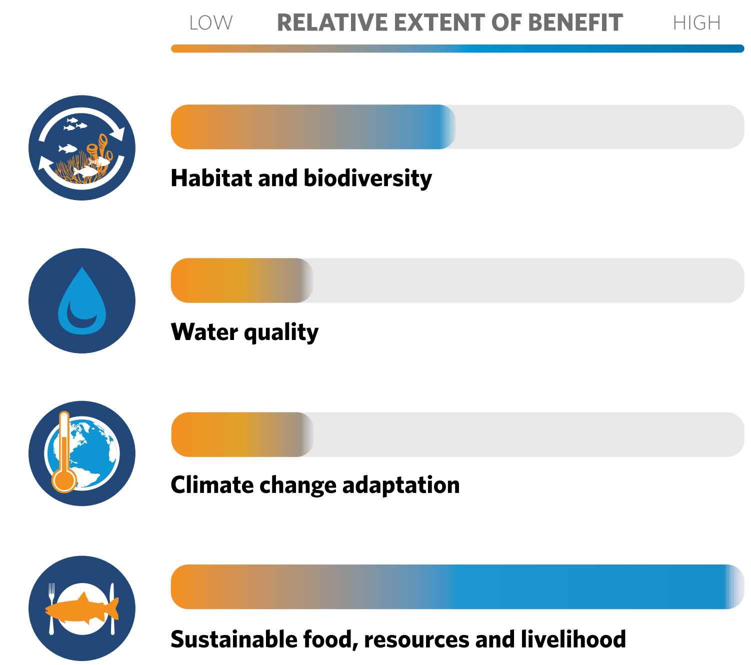


Figure 2. **Potential extent of environmental benefits from marine finfish farming.**

Extent of benefits is indicative only and relative to each other and similar systems.

IMPLICATIONS FOR MONITORING AND EVALUATION FOR REGENERATIVE AND RESTORATIVE AQUACULTURE

Pre-assessing and monitoring the suitability of sites to identify the best locations, ecologically and logistically, can support effective management of these considerations. Appropriately siting marine finfish aquaculture is one of the most important factors determining whether environmental impacts will be negative or positive. Siting finfish activities in areas that have sufficient carrying capacity, or in areas with sufficient flushing rates or deeper water, reduces the risk of waste (from feed and faeces), but can introduce trade-offs, such as increased demands on energy.

Comprehensive and effective monitoring programs are required, regionally and internally (farmer-scale), to support continual improvement and rapid detection of negative environmental impacts or unanticipated effects, including effects from trade-offs that might be associated with offshore operations, such as increased demands on energy or displacement of other users of the area.

Environmental benefits should be considered and valued across the entirety of the farm area and supply chain but have a particular focus on activities associated with net pens given the increased risk of negative environmental impacts at these sites.

Farmers and feed providers should work together to identify opportunities for regenerative farming practices upstream, so that these can be embedded within the production of wild caught and terrestrial ingredients for aquafeeds, e.g., increasing the use of deforestation free soy.

Habitat and biodiversity

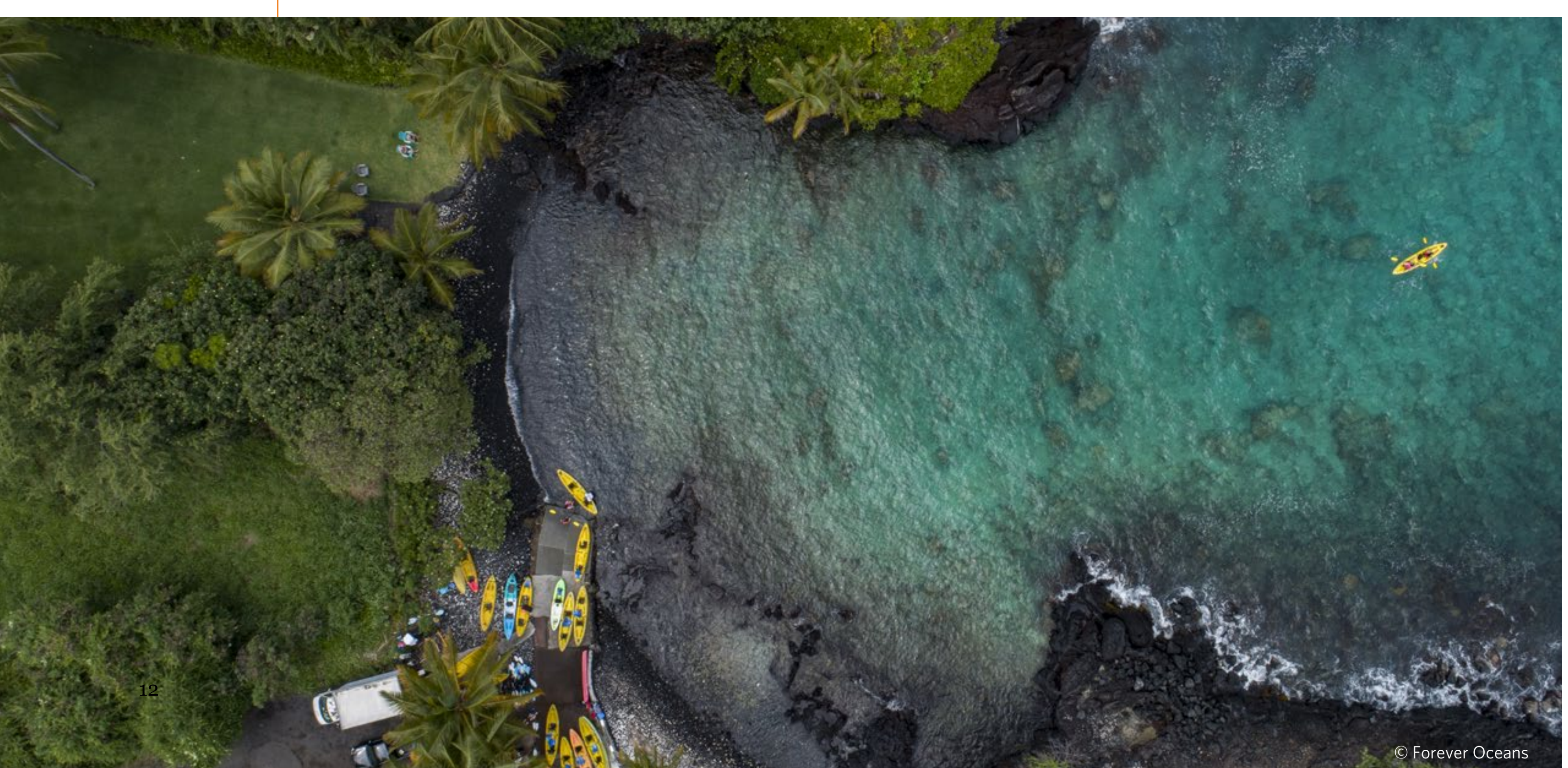
- Attraction of fish to net pens and their use of this habitat (i.e., for foraging, shelter, recruitment) should be monitored through easy-to-use methods such as underwater video, and the biomass attracted estimated using approaches that are consistent with regional stock assessment methods, so that the implications of fish attraction and potential refuge can be considered in fisheries management. Synonymous sampling of parasites and pathogens in wild populations, while difficult, can be advantageous to rule out impacts or transfer of impacts from farmed to wild stock. Thorough documentation of farm health and practices (e.g., veterinary medicine use, stock health assessments) are imperative.

- The use of the farm area by fauna, including marine mammals and migratory fish species, should be monitored regularly to establish an accurate record of species using the site and to reduce the risk of negative impacts, such as entanglement in farming or fishing gear and disturbance from shipping.

Sustainable food, resources, and livelihood

- Data on activities and inputs throughout the life cycle of production should be regularly collected, particularly information on fuel, energy and feed use, to support monitoring and responsiveness to life cycle impacts and to assist in the delivery of high-quality finfish protein with low emissions and environmental impact.

- Gendered data on employment should be collected by operators and government jurisdictions to support appropriate and effective policies for livelihood, such as support for new employment or improvements in the type or quality work for women.



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