HATCH

Hawaii's ocean opportunity

Hatch Innovation Services

www.hatch.blue

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About HATCH & acknowledgements

Hatch is an innovation and venture capital company focused exclusively on sustainable and climate smart seafood systems. It has a global presence - with offices in Hawai'i, Europe (Norway) and Asia (Singapore) - and works with governments, NGOs, research organizations, industry and new ventures. Hatch has a demonstrated track record of working on global aquaculture projects focusing on innovation impact and technology. The company works extensively to support the development of sustainable aquaculture practices by attracting private and public funding and supporting governments to develop national and regional aquaculture programs to stimulate scale and drive more innovation and to support and establish companies to accelerate sustainable growth in aquaculture and the blue economy.

Hawai'i is a critical part of our global strategy to nurture and support more innovation in ocean food production, where we are now building upon a previous three-year successful accelerator and investment program from 2019 - 2021. Hatch has received a second grant period from the U.S. Economic Development Administration (EDA) to support the development of new sustainable and climate smart food businesses in Hawai'i, in close collaboration with Hawai'i Ocean Sciences and Technology (HOST) Park, administered by the Natural Energy Laboratory of Hawai'i Authority (NELHA) in Kailua Kona. Over the next four years we plan to set up and manage a sustainable ocean food incubator to engage a wider innovation community and attract new businesses and private funding to support the blue economic development in Hawaii's coastal communities. A range of business programs will also be developed to include ideation workshops, company building activities and a continuation of our successful innovation and scale up model strategy, all with a view to driving and developing more aquaculture activity and innovation - both within Hawai'i and further afield.

We thank the Hawaiian Department of Agriculture for the funding that made this scoping study possible. We furthermore acknowledge the significant and invaluable contributions of a wide panel of stakeholders who donated time and thoughtful insights that shaped the direction and content of the research.

Department of Agriculture
STATE OF HAWAII

Glossary

AQUACULTURE
the breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in any type of water environment.

ACIDIFICATION
the ongoing decrease in the pH value of the Earth's oceans, caused by the uptake of carbon dioxide from the atmosphere.

ALGAE BLOOM
the overgrowth of algae in water. Red tides, blue-green algae, and cyanobacteria are examples of harmful algal blooms that can have severe impacts on human health, aquatic ecosystems, and the economy.

BLUE CARBON
refers to greenhouse gasses, specifically carbon dioxide, that are captured by the world's ocean and coastal ecosystems.

BLUE FOODS
or seafood include fish, invertebrates, algae and aquatic plants captured or cultured in freshwater and marine ecosystems.

BIVALVE
a shellfish or mollusk that has two hinged shells, which are called valves.

BIOACTIVE COMPOUNDS
a substance that has biological effects. Seaweeds contain various bioactive compounds that promote good health through antioxidants or anti-inflammatory properties for example.

BIOCHAR
charcoal produced from plant matter and stored in the soil as a means of removing carbon dioxide from the atmosphere.

BROODSTOCK
mature individuals used in aquaculture for breeding purposes in captivity.

ENDEMIC
refers to a species that is native to where it is found and nowhere else in the world present.

EUTROPHIC
characterized a water body that is very rich in phosphates, nitrates, and organic nutrients that promote a proliferation of plant life, especially algae.

EXTRACTIVE SPECIES
use the organic and inorganic materials and by-products from the other species for their own growth.

DETRITUS
dead organic material, typically the bodies or fragments of bodies of dead organisms and fecal material.

HATCHERY
facilities where the hatching of aquatic species is artificially controlled for commercial purposes.

HYDROCOLLOID
a compound with gelling and thickening properties used in many industries including food, medicine, and textiles. Commonly seaweeds are used to produce three main types of hydrocolloids: carrageenan, alginate, and agar.

HERBIVORES
an organism that mostly feeds on plants.

INVERTEBRATES
an invertebrate is a cold-blooded animal with no backbone

MACROALGAE
another term for seaweed. Macroalgae are sometimes described as "aquatic plants," but are actually large algae and are taxonomically distinct from plants.

MICROALGAE
microscopic version of macroalgae, single-celled and may exist independently or in colonies.

MARICULTURE
a branch of aquaculture involving the cultivation of marine organisms in the open ocean, an enclosed section of the ocean, or in tanks, ponds or raceways which are filled with seawater.

LOW- TROPHIC
species in marine ecosystems comprise organisms that are generally plankton

feeders for the majority of their life cycle.

OLIGOTROPHIC
characterizes a water body with relatively low nutrient levels (opposite to eutrophic).

Abbreviations

ACFR - Ānuenue Fisheries Research Center
CTSA - Center for Tropical and Subtropical Aquaculture
CTAHR - College of Tropical Agriculture and Human Resources
DAR - Department of Aquatic Resources
DLNR - Department of Natural Land and Resources
DOA - Department of Agriculture
HOST - Hawaiʻi Ocean Sciences and Technology
NELHA - Natural Energy Laboratory of Hawaiʻi Authority
IMTA - Integrated multi-trophic aquaculture
PACRC - Pacific Aquaculture & Coastal Resource Center
R&D - Research & Development
TNC - The Nature Conservancy
UH - University of Hawaiʻi
OECD - Organization for Economic Co-operation and Development
SDG - Sustainable Development Goals

Aloha ʻāina
is a concept for the stewardship of land and natural resources, with values deeply rooted in Hawaiian culture and tradition

'Ahupua'a'
is a land division system from mountain to sea (mauka to makai) that organized the variety of resources that a community needed

'Kapu'
means forbidden, sacred or holy and refers to the ancient Hawaiian code of conduct of laws and regulations

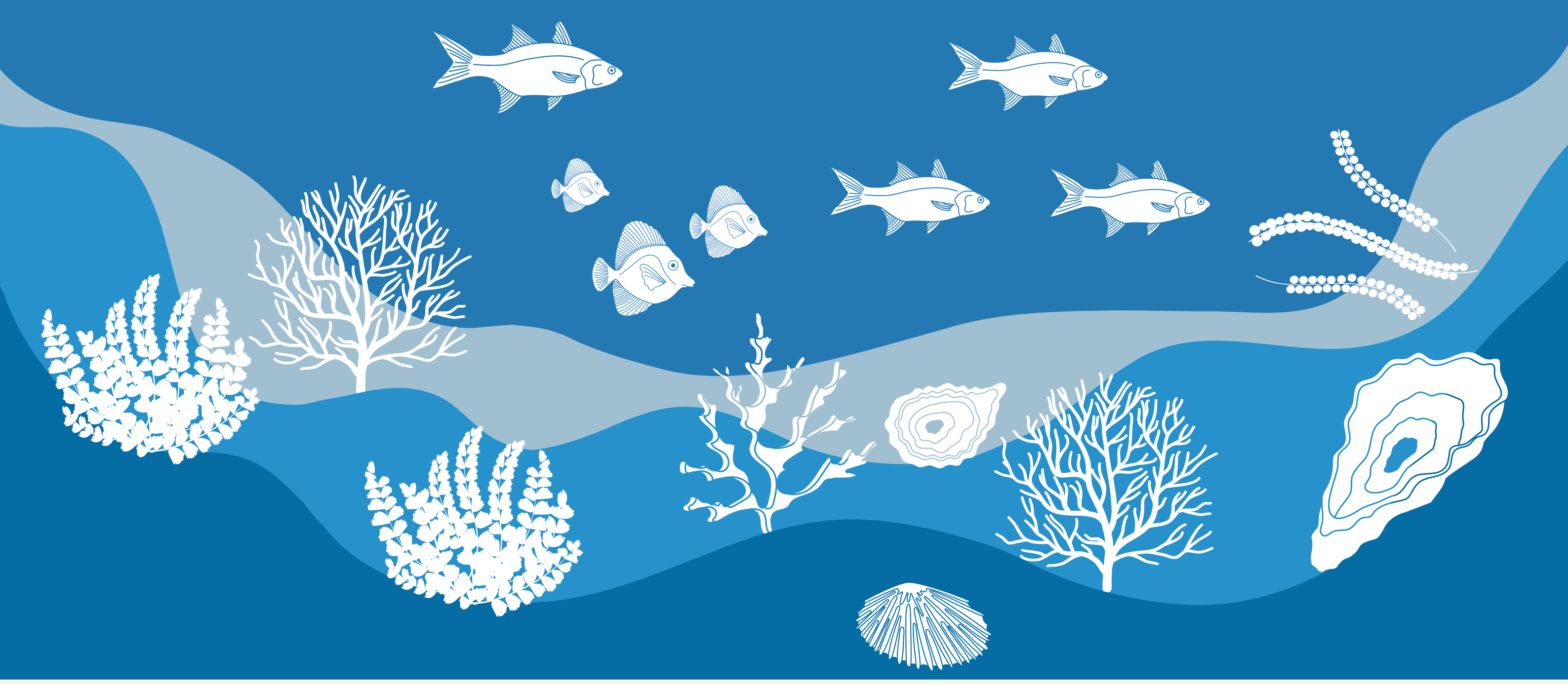
'Limu'
describes all kinds of seaweed

'Loko iʻa'
are the traditional fishponds

'Loli'
also called weli are sea cucumbers

'Mālama'
means to maintain, sustain, protect, preserve and take care for natural resources for the wellbeing of future generations

'Opihi'
is the Hawaiian limpet that holds a great significance in Hawaiian culture



HAWAII'S OCEAN OPPORTUNITY

To feed a projected population of 9.7 billion in 2050, food production must increase by up to 56%[1]. With terrestrial ecosystems already pushed to their production limits, the ocean has the largest potential to help supply this demand. If managed appropriately, it could provide over six times more food than it does today[2].

A sustainable ocean economy can create a triple win for people, nature and the economy. Effective ocean protection, sustainable ocean production and equitable human prosperity are compatible and inseparable[3].

Restorative Aquaculture is a sustainable, nature-based opportunity for blue food production.
Seaweed and shellfish involve no feed, freshwater or land to grow and farming them is coupled with ecological net benefits to the environment, that are crucial to restore oceans health and are known as ecosystem services.

ENVIRONMENTAL VALUE

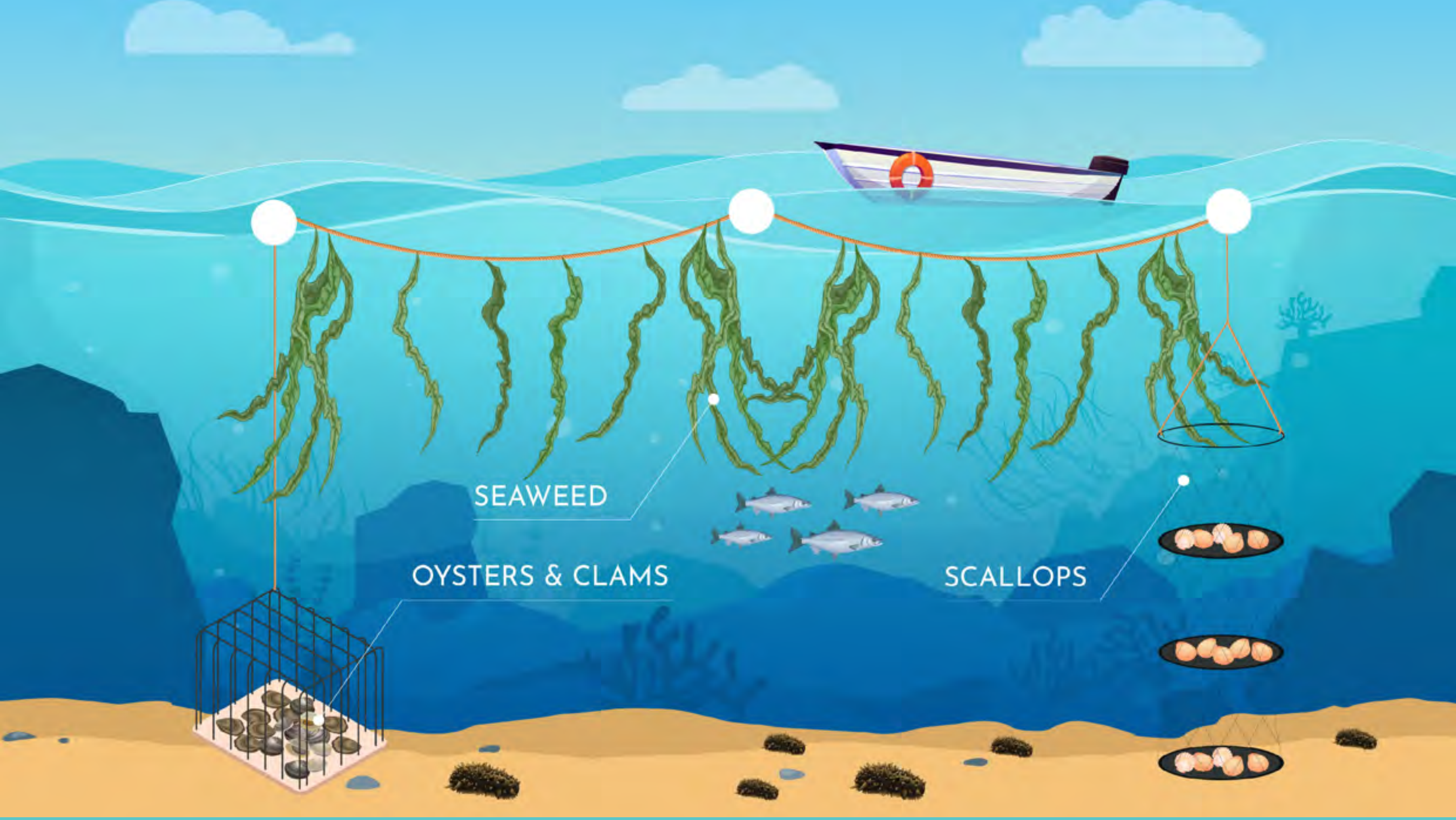
- Water quality improvements
- Habitat restoration and biodiversity enhancement
- Climate mitigation and adaptation

SOCIAL VALUE

- Restoring native Hawaiian cultural connection to the ocean resources
- Healthy, accessible, local food production
- Coastal community resilience and alternative livelihood

ECONOMICAL VALUE

- Product applications beyond food with high growth opportunities (incl. Carbon and nutrient removal credit markets)
- Green job opportunities



What makes Hawai‘i well positioned and suited for restorative aquaculture activities?

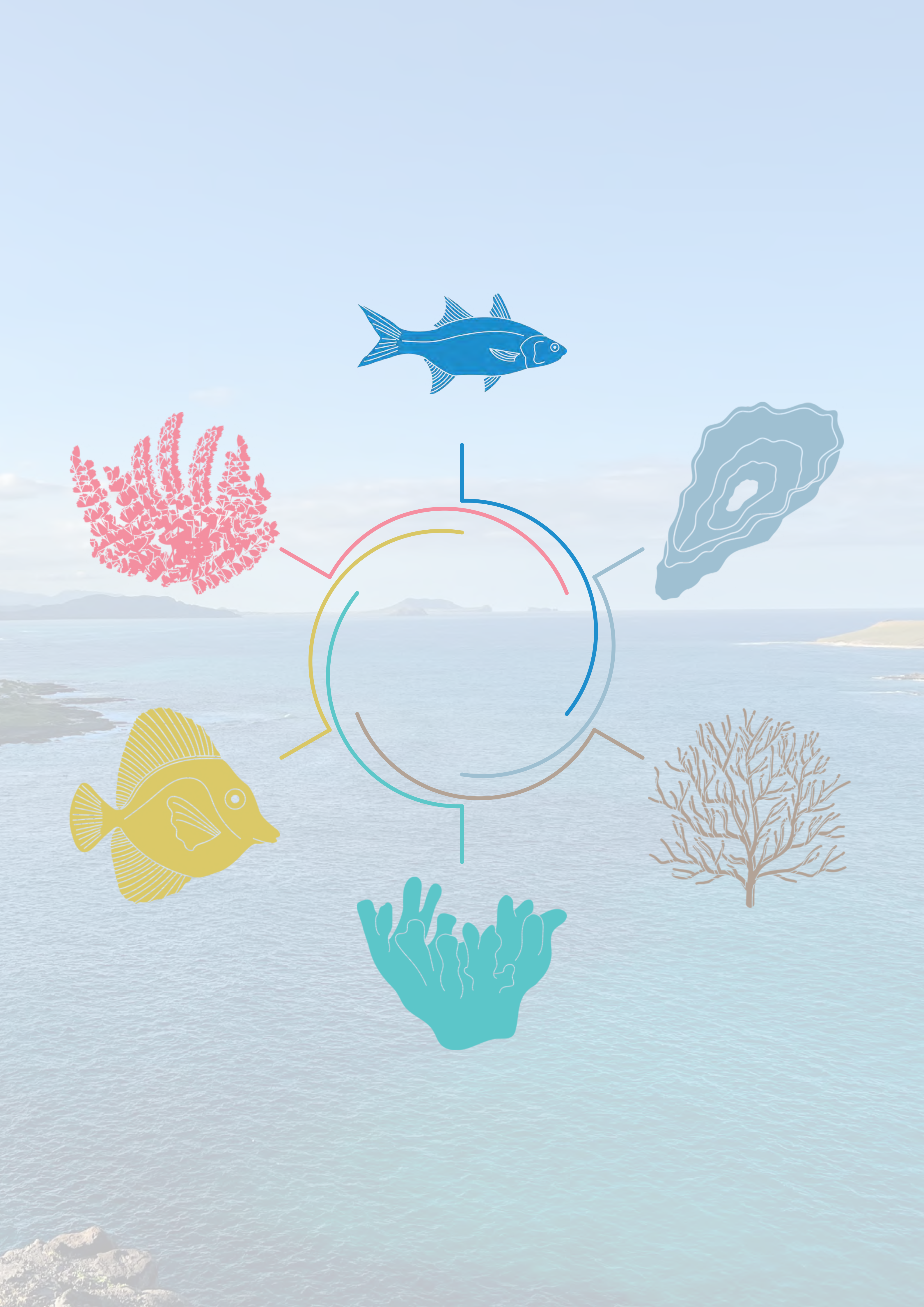
- A strong cultural foundation, based on indigenous roots and high seafood consumption.
- Unique location advantages and favorable climate with high levels of productivity and critical biosecurity through natural isolation.
- An existing R&D infrastructure and sophisticated research community.

From 2022 and beyond, the State of Hawai‘i can set an example for the climate change mitigation initiative using restorative aquaculture as a nature-based solution to rejuvenate coastal habitats, indigenous culture and improve food security whilst providing more employment opportunities in a sustainable ocean economy.

Targeted action in the **six priority areas** can put this emerging sector on the right track to fully unlock the promising potential:

- Optimise governance framework to reduce regulatory hurdles
- Coordinate and support early stage research to close knowledge gaps
- Support existing, new and aspiring farmers, practitioners and entrepreneurs and promote cross-sector collaboration to accelerate innovation
- Use knowledge from R&D to develop value chains and high value markets
- Develop a workforce and capacity building plan that includes diversity, equity, and inclusion
- Raise awareness on the benefits and potential beyond the aquaculture community

1. World Resources Institute. 2019 "Creating a Sustainable Food Future" World Resources Report.
2. Oceanpanel. 2019 "The Future of Food from the Sea' High Level Panel for A Sustainable Ocean Economy.
3. Oceanpanel 2020. "Ocean Solutions That Benefit People, Nature and the Economy." World Resources Institute. Washington, DC."



About the report

Aims and objectives

The objective of this report is to help promote restorative ocean food production as both a sustainable and profitable future for Hawai'i. Restorative aquaculture presents a nature-based opportunity, with potential to benefit people, the ocean and the climate.

Shellfish and seaweed aquaculture are forms of food and raw material production that require almost no feed, freshwater and land as well as minimal greenhouse gasses to produce. What's more, restorative aquaculture has the potential to go a step beyond impact reduction and actually improve water quality, remove excess nutrients and carbon dioxide from their immediate environments, and provide habitat to create a healthier ecosystem for marine life. In this way, if carefully designed, shellfish and seaweed farms could be part of an effective strategy for Hawai'i to help restore coastal ecosystems and mitigate climate change effects, while providing new opportunities for economic development.

Listening to science, indigenous cultural knowledge, as well as taking into account best practices that we have seen elsewhere around the globe, this report provides an overview of the conservation and socio-economic benefits from these ocean-based opportunities and explores how further commercial development of restorative aquaculture initiatives in Hawai'i could present a nature- based and market-driven opportunity for restoring threatened coastal ecosystems.

We believe that the development of a restorative aquaculture program is an important step to help support and guide the sector's development. Ideally, this report can encourage government, development organizations and investors to consider supporting shellfish and seaweed aquaculture for Hawaii's future. The involvement of each of these stakeholders will be critical to deploying restorative aquaculture at scale, ultimately meaning more food and more jobs, while reducing the environmental impact of food production.

Methodology

Inputs to this research report included reviews of sector reports and scientific papers, alongside interviews with individuals directly involved in research, businesses and development projects around the aquaculture sector in Hawai'i and abroad. The focus lay in identifying opportunities and barriers to sustainable growth in Hawaii's seaweed and shellfish aquaculture sectors.

Key findings

A prosperous restorative aquaculture sector could provide meaningful economic, environmental, social and cultural benefits to the local communities of the islands of Hawai'i, along with broader impacts nationally. In Hawai'i this type of aquaculture is still in its infancy and faces numerous challenges which are preventing it from keeping pace with positive developments seen in other regions.

Implications for relevant stakeholders

We can - and we must - produce more food from the ocean, and we have to do this in ways which mitigate climate change, preserve biodiversity, regenerate ocean health and leave no one behind. The report gives us confidence in the potential to produce more by protecting more. It also reaffirms the need to rethink ocean policy and management. The recommendations outlined in this report will not only identify ways to catalyze investment but also underscore strategies to catalyze inclusive impact in the sectors, particularly in regard to the scaling of initiatives that positively impact the climate and ocean biodiversity.

Limitations

Several possible ocean-based solutions were considered but ultimately not included in the scope of this report. This report focuses principally on opportunities especially associated with shellfish and seaweed mariculture, given the strength of scientific information supporting restorative outcomes related to these species groups. Additional possible aquaculture activities that can have restorative impact for Hawai'i, such as fish farming in traditional ponds, coral hatcheries, ornamental fish, sea urchins, sea cucumbers and opihi farming are briefly discussed, but are not addressed in depth.

1. Introduction

The health of our ocean is deeply intertwined with our well-being and prosperity.

Life on earth depends on the ocean. It provides half of the planet's oxygen[4], nourishes us, entertains us, connects us, inspires us, and powers our global economy. Oceans contribute more than $1.5 trillion a year to the global economy and support the livelihoods of 3 billion people through seafood production, shipping, energy and tourism[5]. Covering over 70% of the Earth's surface, the ocean absorbs 93% of the world's anthropogenic heat[6]. Without this regulation of the earth's temperature, much more carbon dioxide would be trapped in the atmosphere, exacerbating global climate change. Around 25% of all carbon dioxide emissions are absorbed by the ocean, making it one of the world's largest 'carbon sinks'[4].

While the ocean plays a key role in managing our planet's climate - global climate change is threatening the ocean's health.

The marine environment is already experiencing changes in temperature, acidity and oxygen levels, which in turn are having profound effects on biodiversity, productivity and ocean circulation. Additional over-exploitation, pollution, habitat destruction, biodiversity loss, and other problems are threatening its very essence. These effects already negatively impact some underserved communities[7], and in a time where Covid-19 showed us how vulnerable we can be, it is essential we ensure our oceans are well cared for.

The ocean is moving up the policy agenda, indicating the growing momentum to combat climate change and its impact.

Until recently, the ocean and coasts have received little consideration in policy proposals to reduce emissions, despite their importance in regulating our climate regulation. The urgency expressed at the COP26 Climate Change Conference to limit global warming to 1.5 °C was a pivotal moment. President Biden committed to halving greenhouse gas emissions of the United States by 2030, achieving a carbon pollution-free power sector by 2035 and a net-zero economy by 2050. The mobilization of finance towards nature-based solutions will be critical on this journey.

For Hawai'i, Governor Ige echoes the need for change after participating in the COP26, saying "(..) we do know that investments in our natural resources give us the best opportunity to capture more carbon than we emit"[8].

As much as Hawai'i is renowned for its pristine seawater quality, experts have been warning about degrading health of near-shore environments. This not only has environmental implications but also affects the local culture and economy. It is unsurprising that the loss of nursery habitat, recreational spaces, sand-producing organisms, shoreline protecting species and other effects on ocean health may have far reaching environmental, social, and economic implications to a place that is so interconnected with the ocean.

A renewed relationship with the ocean is needed, one where we consider the ocean as our partner, rather than exploiting it, one which creates a healthy ocean and a sustainable ocean economy. As stated in Hawaii's Ocean Resource Management Plan "Our past is the best guide for our future abundance, and as a State, we must mālama, protect, nurture, and care for the ocean resources that provide so much for us"[9].

Hawaii's isolation has always encouraged innovation and sustainability to survive. We must therefore harness this spirit once again to rediscover the path to sustainability that native Hawaiian ancestors once navigated long ago, showing the world what is possible.

> *"And we do know that if we give nature an opportunity, it will help us more than we ever realized,"* says Governor Ige[8].

2. A sustainable ocean economy

2.1 A new paradigm: protection, production, prosperity

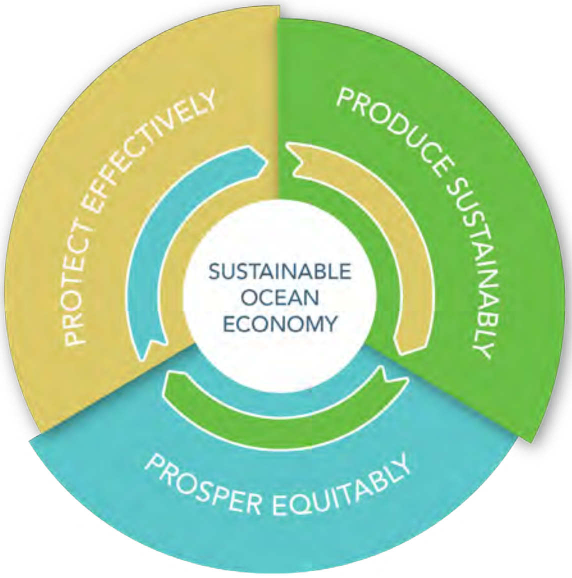
A healthier ocean is a smart investment that will deliver social, health, economic and environmental benefits.

Effective ocean protection, sustainable ocean production and equitable human prosperity are now recognized as compatible and inseparable[7].
This new ocean action agenda challenges the conventional idea that environmental protection can only occur at the expense of the economy. Instead, it introduces a new paradigm of a sustainable ocean economy that includes partnerships and collaboration across multiple stakeholders to realize all three Ps (protection, production and prosperity) in existing and future ocean activities[7].

HIGH LEVEL PANEL *for*
A SUSTAINABLE OCEAN ECONOMY

The Ocean Panel is a high level group of 14 current world leaders who have put forward a new ocean action agenda for a sustainable ocean economy.

The key to realizing this is by implementing a holistic and connected approach to managing the ocean by finding synergies amongst the three Ps. Ecosystem-based fishery management or seaweed farming for instance - can have restorative effects on the ocean while providing us with nourishment. By reassessing how we manage our oceans, we can achieve the "triple bottom line' effects of restoring our natural places, feeding people and lifting our economy[7].



Graphic 1: The 3 Ps for a sustainable ocean economy

Building sustainable solutions offers both growth potential for the economy and a regenerative focus that will maintain the resource for generations. In fact, research by the ocean panel shows that sustainable ocean-based investments can yield net benefits (economic, environmental and health) at least five times greater than the costs on a 30-year horizon. Sustainable ocean food production in particular could yield a ten-fold return on cost. In other words, every $1 invested in sustainable blue food production can yield $10 in benefits[7].

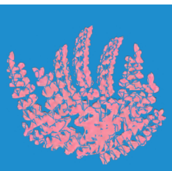
Five priority opportunities have further been identified and suggest immediate investment of stimulus funds to support a 'sustainable and equitable blue recovery' from the Covid-19 crisis:

- Invest in coastal and marine ecosystem restoration and protection.
- Invest in sewerage and wastewater infrastructure for coastal communities.
- Invest in sustainable community-led non-fed marine aquaculture (mariculture).
- Incentivize zero-emission marine transport.
- Incentivize sustainable ocean-based renewable energy.

Two of these priority opportunities will be explored in depth in the following chapters and present a foundation for a nature-based and market-driven approach to combine both.

2.2 Invest in coastal and marine ecosystem restoration and protection

Blue carbon habitats have been highlighted as a major priority area for restoration and protection.



The term "blue carbon" refers to greenhouse gasses, specifically carbon dioxide, that are captured by the world's ocean and coastal ecosystems. Seagrasses, mangroves, salt marshes, and seaweed along coastlines capture and hold–"sequester"–carbon dioxide, acting as natural mechanisms to remove carbon from the atmosphere, similar to trees on land[4]

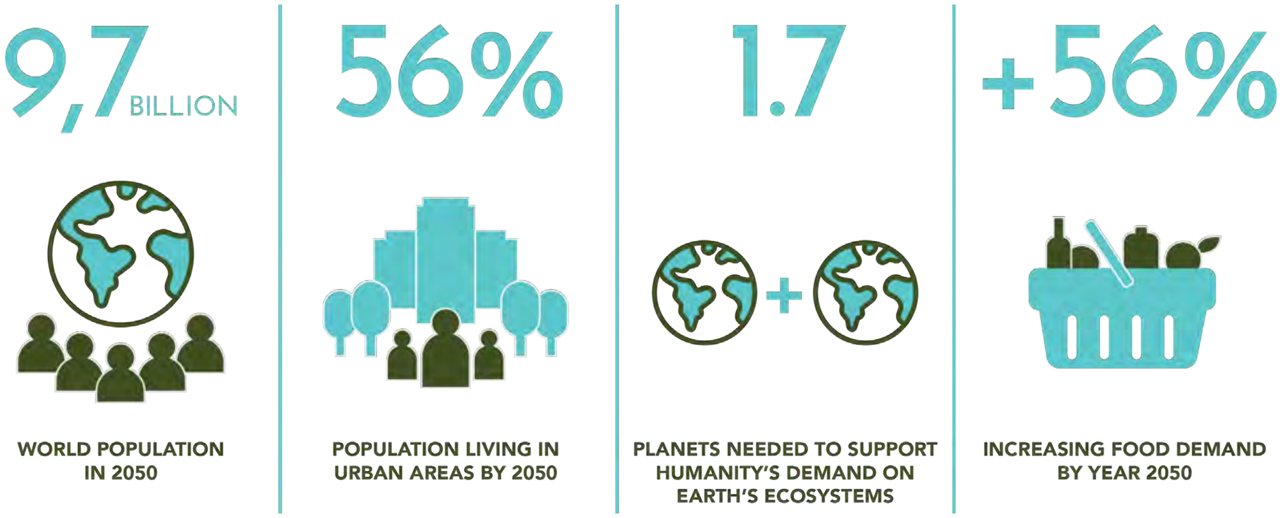
However, anthropogenic activities such as mismanaged fishing practices have damaged large swathes of the ocean floor, and decimated wild fish stocks. On a planetary scale, the rise in greenhouse gasses has led to temperature increases in the surface waters and ocean acidification. Globally, oyster reefs have declined by 85%[10] and rampant habitat conversions of important coastal areas like mangroves, seagrass meadows, and seaweed forests have led to global decline of these habitats that sequester significant amounts of carbon. Apart from the vital function to store carbon, these ecosystems naturally provide nursery habitats, shoreline protection and filtration capacities that maintain healthy fish populations and clean waters. The decline of these habitats can lead to wider repercussions on human health and safety. Future development of any ocean-based economy cannot discount the necessity to revitalize these invaluable coastal resources and safeguard the ecosystem services they provide.

2.3 Invest in sustainable community-led non-fed marine aquaculture

The increasing human population, coupled with rising wealth, fuels the demand for ocean-derived food, blue foods. According to FAO, by 2050 global demand for seafood is expected to almost double and roughly 500 million tonnes of protein will be needed to feed every human on the globe[11]. With terrestrial ecosystems already pushed to their production limits, the ocean has the largest potential to help supply this demand[2].

Over the last two decades, seafood production from wild fisheries has stagnated, while the amount provided from aquaculture, the farming of aquatic animals and plants in a water environment, has tripled[12]. Since 2016 aquaculture has superseded wild fisheries as the main source of seafood for human consumption and its share is projected to increase in the future[11].

Ocean-based protein production is inherently more efficient than terrestrial livestock agriculture. Not only are



Graphic 2 - Projected socio-economic developments by 2050 fish better at converting feed into protein than terrestrial animals, farming in the ocean allows for three-dimensional food production, which allows more protein to be harvested from the same aerial footprint[13]. This enables the ocean to provide billions with nourishment at a lower environmental footprint. Today, at least 3 billion people rely on the oceans for their main source of protein and essential nutrients, such as omega-3 fatty acids and iodine, while the marine food sector provides livelihoods for approximately 237 million people across industries like fisheries, aquaculture and processing[7].

The Ocean Panel highlights that increasing the cultivation and consumption of unfed or extractive species such as shellfish and seaweeds can bring the best outcome of increasing healthy food without compromising the health of our blue ecosystems. Increasing scientific research proves that food production which restores the environment is not only possible but also extremely efficient[13].

2.4 The case for restorative aquaculture

Restorative aquaculture – the farming of unfed or extractive species that actively contribute to the recovery of marine ecosystems – offers a solution to meet the growing demand for healthy seafood without causing a strain on the ocean's resources.

> Restorative Aquaculture can be considered as a sea-based equivalent to regenerative agriculture, and an integral part of the nature-based solution framework for sustainable future food production[14]

An expert working group led by The Nature Conservancy (TNC) has produced the Global Principles of Restorative Aquaculture, a report that defines restorative aquaculture as "commercial or subsistence aquaculture (that) provides direct ecological benefits to the environment, with the potential to generate net positive environmental outcomes"[11]. Similar to traditional aquaculture, restorative aquaculture still takes a commercial interest in culturing organisms, ultimately making it a market-driven approach. Yet, the key point when manifesting the restorative aquaculture concept is the achievement of net positive environmental outcomes in any given aquaculture project. It applies to large- and small-scale operations, freshwater (inland), brackish (estuaries) and marine (coastal and offshore) aquaculture and is not limited to any geography.

To date, scientific research strongly points to low-trophic species that are unfed or extractive and require low input to be best suited for restorative aquaculture. In particular, seaweeds and shellfish are the two species groups with the clearest potential in generating net positive environmental outcomes also known as ecosystem services. Based on extensive research in eutrophic and degraded systems, seaweeds and shellfish have strong potential to deliver three main benefits: improving water quality, habitat provision and climate mitigation[14]. Nonetheless, other low-trophic species that are less explored in literature - such as sea cucumbers, sea sponges, snails, abalone, and sea squirts - play important environmental roles in natural ecosystems and could bring about restorative benefits in well-designed farms as well.

By repositioning aquaculture as an activity which can replenish the natural environment and uplift local communities, we can continue feeding the world while restoring the planet. Recent research estimates that restorative aquaculture coupled with improved management of fisheries can increase the food we obtain from the oceans somewhere between 36% to 74% by 2050[15].

Historical foundation

Restorative aquaculture itself is not a new concept. Although the term today is perfectly aligned with our modern sustainability-oriented world, the concept has existed throughout history. Indigenous communities around the globe have lived in harmonious ways with our natural world for millennia.[16] Nearly 3,500 years ago, First Nations people in the Pacific Northwest designed clam gardens that provided a nutritious source of protein whilst simultaneously enhancing the surrounding ecosystem by increasing water quality and creating conditions for the surrounding flora and fauna to thrive[17]. In Asia, integrated rice and fish aquaculture practices have been implemented for more than 2,000 years[16]. The knowledge, practices, and technologies of Indigenous Peoples are as relevant today as they have been for centuries and have potential to inform the design of contemporary restorative aquaculture and marine resource management practices.

Environmental Value

Water quality improvement
Removal of excess nitrogen, phosphorous and suspended solids from surrounding environment

Climate change mitigation & adaptation
CO2 and nutrient sequestration / ocean mitigation / (carbon reduction potential of end-product)

Habitat provision
Creation of structured habiutat for fish and invertebrates/hatching & nursery grounds / enhances biodiversity

Social Value

Cultural significance
Restoring indiginous culture / preserving intergenerational knowledge / reconnecting to the ocean

Community health
Healthy and accessible food provision / nutritional benefits / food security

Alternative livelihood
Coastal community resilience / small business ownership & wealth creation / inclusion / climate justice

Economic value

Direct market opportunities
Commerically viable local or export market for product or application with further growth opportunities

Indirect economic opportunities
Wastewater treatment savings / blue carbon & nutrient credit markets / increased fisheries value

Green job opportunities
Direct employment growth potential / productive training opportunities and retention of talent

2.4.1 Environmental benefits

Restorative aquaculture provides valuable ecosystem services; improving water quality, providing habitat, and facilitating nutrient recovery and potential carbon sequestration. These can help mitigate key environmental impacts such as pollution, biodiversity loss and carbon emissions[14].

Water quality improvement

Aquaculture crops like seaweed and shellfish (or more specifically bivalves) naturally remove nitrogen by incorporating it into their shells and tissues. Nitrogen is a nutrient that enters coastal waters from many human sources, including fertilizers, septic systems, and treated wastewater. Excess nitrogen fuels excessive algal growth, which can result in algal blooms that negatively affect water quality and human health. When we harvest the seaweed and shellfish, the nitrogen in their bodies is removed from the water, which can improve water quality and pollution levels. ***A single hectare of restorative aquaculture removes more than half a ton of nitrogen a day, which would cost around $50,000 to remove through conventional wastewater treatment[14].***

This filter feeding behavior also enables shellfish to go beyond extracting nitrogen and reduce sedimentation in the water bodies where they are cultivated. As they graze on plankton in the seawater, these bivalves filter organic matter from the water column, which leads to higher light penetration that benefits photosynthesizing species like seagrass and coral.

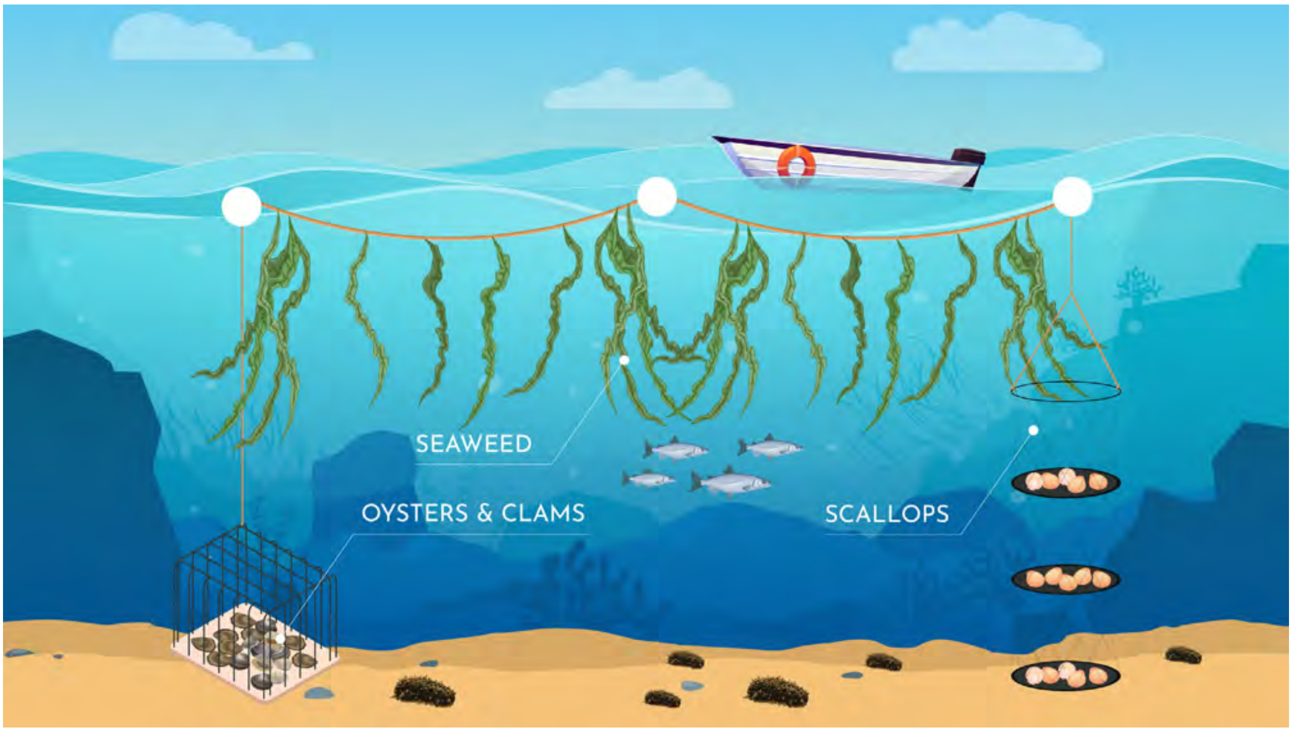
This filter function also removes bacteria and viruses, thus reducing the spread of infectious diseases in the water body they grow. ***One hectare of restorative aquaculture can filter up to 25 million gallons of water per day - enough water to fill 40 olympic sized swimming pools[14].***

Habitat provision

When farms are properly located, seaweed and shellfish aquaculture can provide habitat for other fish and invertebrate species, consequently restoring biodiversity. Dense seaweed fronds and pillars of calcium carbonate shells provide three-dimensional structures that create refuge, breeding and reproductive grounds for other marine life. The creation of aquaculture farms provides the same ecosystem function as natural nursery grounds, allowing juvenile fish and invertebrates to hide from predators and reach maturity[18].

Aside from structural benefits, aquaculture organisms and biofouling communities associated with farms can provide food resources for other marine life in the area[16]. The outcome is a higher biodiversity on the farms. In a global review by TNC of 65 studies, greater fish abundance and diversity were generally noted around bivalve and seaweed farms compared to nearby reference sites[15]. ***The researchers found that the abundance of wild fish increased by up to 5 tons per year around one hectare of restorative aquaculture farming compared to reference farms[14].***

On the local scale, seaweed aquaculture also mediates the impact of ocean acidification[21]. Ocean acidification reduces the amount of carbonate in the water, making it harder and harder for calcifying organisms, such as shellfish or coral, to form their shells and skeletons. By siting a seaweed farm upstream of a reef, the down current flowing over the reef can potentially reduce dissolved carbon dioxide and increase the pH of the water[22 23].



Graphic 3 - Restorative Aquaculture species groups (Note: not representative of the cultivation system)

Climate change mitigation and adaptation

Restorative aquaculture can capture carbon dioxide in coastal waterways and prevent ocean acidification. Seaweed aquaculture, in particular, is emerging as a potential tool to fight climate change and mitigate its impact on the local environment. Growing seaweed, through the process of photosynthesis, absorbs carbon dioxide from the atmosphere. Under the right ocean conditions, seaweed fronds breaking away from the farms can sink to the deep sea, where the carbon is locked away in the long term[19]. Equally, the intentional use of the seaweed harvests to produce long lasting applications such as building materials could reap this benefit more clearly[20] Moreover, improvement in water quality can also lead to extended preservation of other blue carbon habitats, like seagrass meadows, which also sequester carbon.

2.4.2 Social implications

The social implications of restorative aquaculture are diverse. Beyond providing alternative jobs and incomes, these practices can be a vehicle to restore indigenous culture, while the harvested crops can substantially support local food security with healthy food products.

Alternative livelihoods

From a societal standpoint, restorative aquaculture offers alternative livelihoods for coastal communities in ways that can complement traditional fishing livelihoods in many coastal regions. Beyond that they can create alternative economic opportunities where coastal communities struggling as a result of fish stock collapses. For example, in the small fishing village of Placencia in Belize, fishers turned towards seaweed harvesting as an alternative livelihood approach[14]. The seaweed farms, in turn, provided habitat for commercially important conch and lobster species that had been depleted in the wild, providing further spill-over benefits to the local fishers, similar to Marine Protected Areas (MPA).

Cultural

Aquaculture of these species also helps preserve intergenerational knowledge that would have otherwise been lost. Restorative aquaculture that focuses on establishing a connection between farming practices and local culture can enrich social ties and sense of place - key components that add to the resilience of a community[24]. In some regions, where the power distance between gender is traditionally large, it can bring intangible social benefits, such as promoting female empowerment. In Tanzania and many parts of the Asia-Pacific region for instance are seaweed farming areas typically located in the intertidal zones, where women and children can safely engage in harvesting. This physical accessibility and low labor intensity allows females to participate in this industry and earn an income for themselves and their families.

Community health

Finally, restorative aquaculture provides nourishment for coastal communities that can lead to better human health outcomes. Thanks to their high nutritional value, seaweeds are healthy components of human diets, providing a rich source of proteins, essential amino acids, minerals and vitamins necessary for proper functioning of the body and helping to mitigate the risks of various diseases[25]. Shellfish and mollusks not only provide lean protein, but are also rich sources of vitamin B12, omega-3 fatty acids, iron, selenium and zinc.

2.4.3 Economic opportunities

At a large enough scale, restorative aquaculture could create significant economic opportunities for coastal communities around the world, and add to the $264 billion revenue generated by the global aquaculture sector, which currently creates employment opportunities for 20 million people[11].

Seaweed

The global seaweed industry has grown rapidly in recent years and this growth is expected to continue as it expands into new markets. The global seaweed industry is currently worth more than 6 billion USD annually[23]. If grown sustainably, seaweed can be an incredibly climate-smart crop, precisely because it doesn't require irrigation, fertilization or pesticides. Neither does it take up valuable farmland. Most cultivated seaweeds are currently used for human consumption (90% of production), directly or as additives, the latter being predominantly hydrocolloids - including agar, alginates and carrageenan - which are used in the food and pharmaceutical industries.

Given that seaweeds are increasingly being recognized in Western countries as "superfoods", dried or semi-processed seaweeds are becoming increasingly popular as food ingredients, which can be integrated into foods such as pasta, chips and seasonings, broadening the food uses of seaweed for consumers unaccustomed to eating it directly. The extraction of biochemical and bioactive compounds for pharmaceutical applications or cosmetics results in higher value for seaweed compared to food applications[23].

Aside from human applications, seaweed can also be used in agriculture and livestock cultivation. In agriculture, seaweed is used in soil fertilizers, due to its rich plant nutrient constituents. It also provides a sustainable feed ingredient for a range of cultured aquatic animals, not just herbivorous ones. The replacement of fish oil and meal in animal feed by farmed seaweed products is seen to be vital for developing aquaculture at the scale required to sustainably feed a growing human population.

The list of potential seaweed products is endless. Most encouraging of all are perhaps those with notable climate-positive attributes that come with alternatives to fossil fuel-based products, such as seaweed-based bioplastics, textiles and dyes. Furthermore, a growing body of research supports the role of macroalgae in the production of biofuels, bioenergy with carbon capture and storage, its use in building materials, biochar and ultimately carbon credits[23]. There is undoubtedly huge potential for creating environmentally beneficial and valuable products from seaweed.

Shellfish (Bivalves)

For this group, the market use is mostly limited to direct human consumption. In the US alone, the sector was worth an estimated $350 million in 2017, making shellfish the country's most valuable farmed seafood[11]. As such, a healthy demand for seafood correlates to a strong consumer market for bivalve aquaculture, with oysters, clams and scallops presenting the most popular species groups. Nonetheless, efforts to valorise its by-products which demonstrate the use of shellfish beyond their edible flesh have been conducted in regions like the EU to stimulate a circular economy whilst promoting the expansion of the industry.

A significant byproduct of bivalve aquaculture is shell waste, which accounts for 40 to 90% of the cultivated weight of bivalves[26] The high level of calcium carbonate in this waste makes it suitable as construction material, feed supplement, fertilizer or agricultural agent.

A healthy ocean is critical to meeting the Sustainable Development Goals

Naturally, the benefits of creating a sustainable ocean economy from restorative aquaculture would not only be limited to achieving SDG 14 (on life below water) but help meet the majority of the UN's Sustainable Development Goals (SDGs)

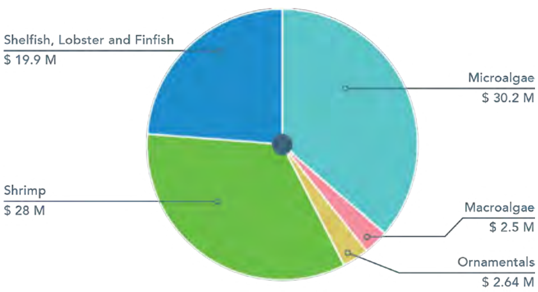
14 LIFE BELOW WATER	Ocean regeneration through assimilation of nutrient and Co2 uptake and biodiversity enhancement
1 NO POVERTY	Inclusive economic development and jobs with fair wages
2 ZERO HUNGER	Enhanced food security based on sustainable and nutritious seafood
3 GOOD HEALTH AND WELL-BEING	Healthier diets from proteins, vitamins, minerals and bioactive compounds
7 AFFORDABLE AND CLEAN ENERGY	Green energy potential for seaweed based biofuels
8 DECENT WORK AND ECONOMIC GROWTH	Direct and indirect job creation in a green economy
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Incentives for investment in innovation and infrastructure that brings prosperity
10 REDUCED INEQUALITIES	Sustainable resource use that empowers long-term prosperity of indiginous and marginalized groups
11 SUSTAINABLE CITIES AND COMMUNITIES	Strengthened coastal communities through restoration of coastal ecosystem and sustainable local development
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Efficient resource use with no inputs required for cultivation
13 CLIMATE ACTION	Low environmental footprint raw materials and carbon sequestration potential of seaweed
15 LIFE ON LAND	Alternatives to emission intensive fertilizer and feed ingredients to agriculture

3. Hawaii's ocean economy

Situated in the tropical North Central Pacific Ocean, the Hawaiian Archipelago encompasses 124 mostly uninhabited smaller islands, atolls, reefs and submerged banks to the northwest referred to as the Northwestern Hawaiian Islands (NWHI), or Papahānaumokuākea, and the 8 populated Main Hawaiian Islands (MHI). The Hawaiian Islands contain every climate region on Earth except for tundra and are home to more than 60% of the coral reefs in U.S waters.

Marine and coastal tourism and recreation represent almost 90% of Hawaiʻi's ocean economy and accounts for roughly 25% of Hawaiʻi's total economy[29].

While living resources from commercial fishing, fish hatcheries, aquaculture, seafood processing, and seafood markets comprise slightly less than 2% to the total ocean economy,[28] Hawaiʻi's marine fisheries and aquaculture contribute significantly to local culture, livelihoods and food and nutritional security. Hawaiʻi is home to among the most sustainably managed pelagic longline fisheries, with commercial landings valued at roughly $100 million annually. Further, subsistence and non-commercial fisheries are estimated to comprise 84% of total nearshore catch[9].



Graphic 5 - Hawaiʻi aquaculture production by species group (2019)

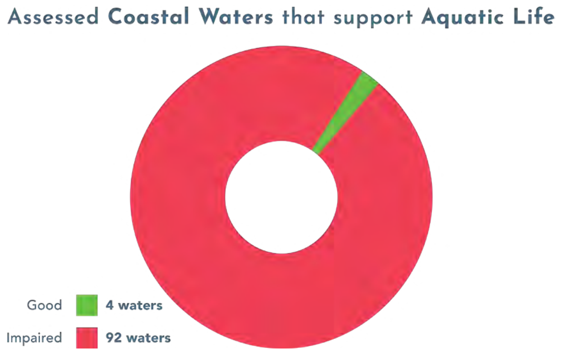
Hawaiʻi ranked sixth or seventh nationally in terms of aquaculture production value[32] with sales totaling $83,232 million in 2019 according to USDA statistics. Yet, the majority of local aquaculture production is currently oriented toward markets abroad, rather than local consumption, exporting mainly SPF shrimp broodstock, bivalve seed and microalgae. In fact, microalgae, much larger than any other aquaculture sector in Hawai'i contributed $30.2M with Cyanotech being the main producer. The macroalgae category (seaweeds and sea asparagus), mainly locally sold, in comparison only accounted for $2.5M in total sales. Shellfish production value for local consumption (whole oyster and clams) is not revealed in public statistics, but all things considered, it would be even smaller.

There is an ample opportunity to increase Hawaiʻi's production capacity and leverage locals' and visitors' preference for locally produced seafood and produce. A more diversified aquaculture sector, with a focus on native and locally consumed species, could first and foremost bolster food security in the light of diminishing wild fish stocks, but also become something more for Hawaiʻi in terms of restoring its ecology, economy and traditions. In order to continue to enjoy the economic and social benefits from these activities, they point out: 'the State must commit to preserve ocean health and to enhance Hawaii's ocean resources in the face of impacts.[9]

Hawaiʻi is the only US state located outside the North American continent. A vibrant and healthy ocean environment is essential to the quality of life in Hawaiʻi. As one of Hawaii's greatest natural resources, the ocean provides economic vitality, sustenance, and world-class recreational activities. However, the threat of climate change looms ever larger for the Hawaiian islands, and reversing it is "critical to preserving our way of life, unique biodiversity and culture", as noted by Governor Ige[8].

Hawaii's dependence on coastal ecosystem health

The quality of the coastal waters around the islands has drastically declined in line with the increased development on its shores as many of these developments are lacking in adequate wastewater treatment and stormwater discharges. A 2020 state water quality monitoring report reveals 92 of 96 analyzed coastal water bodies to be impaired for aquatic life, and only 4 in good condition[33].



Graphic 6 - Water quality status around Hawai'i

The main reasons reported were turbid (murky) waters and excessively high levels of nitrogen, phosphorus and ammonia. Consequently, the abundance of nearshore aquatic life has been challenged, which in turn limits subsistence fishing practices and other sources of food security, such as shoreline and forest gathering. This declining abundance finds examples in the local collection of limpets and seaweed for consumption. Once found everywhere, some species are now listed as endangered or even extinct[9].

In Hawai'i, culturally significant calcifying species are at risk of ocean acidification and are already experiencing population decline from fishing pressure and habitat modifications. Aside from local pollution affecting coastal waters, the insidious backdrop of ocean warming has led to statewide coral bleaching events across multiple years. The declining health of Hawaii's corals does not only impact the underwater ecosystem, but also diminishes the protective effects these reefs provide against storms. Economically, the corals are a fundamental pillar of the state's tourism sector. Losing them might lead to long-term reduction in visitors coming to Hawai'i and lower tourism revenues[9].

3.1 Restorative Aquaculture in Hawai'i

Hawaiian fishponds - the first known instances of aquaculture in the Pacific

The principles of restorative aquaculture are deeply rooted in Hawaiian culture and history. Nested within ahupua'a or traditional land and resource stewardship frameworks, loko i'a (traditional fishponds) are among the earliest examples of regenerative aquaculture systems in the Pacific. Evidence suggests that loko i'a were first implemented around 1200 A.D. These ponds were managed extensively and were often part of larger, integrated food production systems. Loko i'a as part of a broader ahupua'a system supported a population of over one million people prior to Western contact[34].

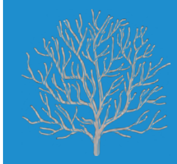
Through the lens of nutrition, loko i'a were essential for supplying a steady source of protein to the population. Fishponds were used to cultivate multiple species such as moi (Polydactylus sexfilis; Pacific Threadfin) and 'ama'ama (Mugil cephalus; striped mullet) and were estimated to produce upward of 300 pounds of fish per acre. In some instances, the cultivation of fish was integrated with other valuable food crops such as taro (loko i'a kalo), providing a ready source of nutrients for agricultural crops while providing a healthy source of protein[35].

Prior to Western Contact, estimates suggest that upward of 500 of these biocultural systems existed throughout the Main Hawaiian Islands, supplying an estimated 2 million pounds of seafood annually—yields that far exceed the production of most modern aquaculture systems.[31,32] However, by the 20th century, many pond systems had fallen into disrepair. Through the leadership of local practitioners and drawing on a combination of Indigenous and western science, many of these systems are being revitalized. Today, there are about 40 fishpond sites in different stages of restoration across Hawai'i[36].

Limu - nutritious resource from the sea

Historically, Polynesian cultures have utilized seaweeds as a staple food resource, including Hawaiians. On all the Hawaiian Islands prior to Western contact, seaweed was a regular part of the diet, accompanying most meals and provided an assortment of vitamins, minerals, flavoring, protein and fiber to the diet which were not found in the three primary food items: fish, taro and breadfruit[37]. More than 500 species of red, green and brown marine macroalgae have been documented on the archipelago, with at least 150 of them being endemic[38], meaning that they naturally occur nowhere else in the world. More than 200 species have unique names in the Hawaiian language, where seaweed is generally referred to as limu.

Limu plays a significant role in native Hawaiian traditions and ahupua'a stewardship. It is estimated that Hawaiians used over 70 limu species as an integral part of the traditional Hawaiian diet, but also for medicinal, religious and ceremonial purposes.



Limu has always held a special place in the lives of local Hawaiian women, who transmitted most of the expertise around this resource across generations. Prior to the arrival of Christianity, around 1819, under the kapu (taboo) system, Hawaiian women were forbidden from consuming pork, coconut, turtles, most banana varieties and several fish species. Lacking these important sources of nutrition, females relied on the collection and preparation of limu as a substitute[34]. As a result, knowledge about limu was passed from mothers to daughters[37].

3.1.1 Today's restorative aquaculture efforts and opportunities

It becomes evident that compared to other geographies, Hawai'i doesn't lack a consumer history of bio-based products from the oceans. The cultural importance of seafood on the islands and high consumption compared to other states makes it a promising market.

Surprisingly, only a limited number of seafood species currently produced in aquaculture systems in Hawai'i are also consumed locally. These include oysters (C. gigas, C. virginicia, C. sikamea), abalone (Haliotus sp), clams (Venerupis philippinarum), kahala (Seriola dumerili), Pacific white shrimp (Penaeus vannamei), and macroalgae (Gracilaria sp.), most of them being non-native species. Moi (Pacific threadfin) and mullets are now produced locally for grow out in fishponds.

In the 19th and 20th centuries, Hawai'i's aquaculture production was dominated by land-based practices, consisting of a combination of ancient fishponds and traditional earthen pond aquaculture brought in from Asia29. In more recent decades, Hawai'i positioned itself within the global aquaculture industry as a unique R&D base for modern aquaculture technology such as offshore farming and genetic breeding programs, from which innovation is transferred globally.

Shellfish

The shellfish industry is a prime example. Bivalve culture started in the late 1860's with the introduction of Eastern oysters (Crassostrea virginicia) into Pearl Harbor[32]. Other already commercially advanced, but non-native species such as the Manila clam (Ruditapes philippinarum) and hard clam (Mercenaria mercenaria) followed shortly after and trials have occurred periodically with different culture methods over the years. In the early 2000s, shellfish farmers from the mainland identified Hawai'i as a superb hatchery location for a biosecure, year-round production of oyster and clam spat (seed). What's more, in times of drastic climate change, the Hawai'i based hatcheries have been a lifeline to West Coast producers, who have been particularly affected by ocean acidification. Today, four large commercial oyster and clam hatcheries, plus two research hatcheries operate in Hawai'i. Shellfish trade organizations report that between 75% and 90% of shellfish produced on the West Coast of the USA spend a portion of their life at one of the hatcheries in Hawai'i, where spawning is not season-dependent, as is the case on the mainland.

Compared to the seed supply production in Hawai'i the shellfish production for consumption in Hawai'i is small-scale. In 2009, the State Shellfish Working Group formed to revive the bivalve growing industry and in the following year the Department of Health implemented elements of the State Shellfish Plan that covers water quality monitoring and classification of shellfish growing areas.

Meanwhile, some trials with clams and oysters in the fishponds demonstrated the biological feasibility for producing shellfish in restored fishponds, where they show surprisingly fast growth rates (6-9 months). Still, only a few fishponds today are growing shellfish, with Kualoa Ranch being the largest producer on track to produce 2,500 oysters per week.

The local demand for shellfish is significantly greater, and is increased by the large tourism industry. "Every month, more than 500,000 fresh oysters are flown into the islands for consumption", according to an industry expert.

Picture 1 - Native Hawaiian shellfish species
(Picture courtesy of PACRC)

The Pacific oyster (Crassostrea gigas) and Eastern oyster (Crassostrea virginicia) are mainly grown in Hawai'i today, since breeding and cultivating technologies for the species are already fully developed and commercial seed locally available, compared to the native Hawaiian counterparts.

Since modern hatcheries breed triploid oyster varieties of the non-native species for faster growth rates, these cannot reproduce in the wild, which permits them to be farmed in Hawaiian waters. Generally, new farms in Hawai'i will depend on triploid seeds of bivalve species, and also require larger seed since most do not have nurseries.

These needs have directed the Pacific Aquaculture and Coastal Resource Center, University of Hawai'i Hilo (PACRC) research activities, in collaboration with partners, to improve hatchery and nursery methods, as well as breeding and polyploid development efforts for a variety of bivalve species. The cultivation of native penshell species, another high-value mollusk, similar to scallops, is emerging into a promising case.

Limu

Over the past 20 years declining native seaweed populations, invasive species, climate change and diminishing traditional knowledge are threatening Hawaii's relation to its natural limu ressources[38].

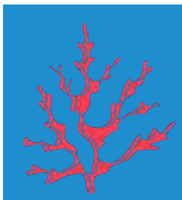
Early trials in 1974 to develop new techniques or new industries for Hawai'i with the commercial red algae species Kappaphycus and Eucheuma from the Philippines had grave consequences[39]. In the following decades, these introduced species proved highly invasive, threatening ecosystems such as coral reefs. Ever since, seaweed aquaculture efforts have been limited. Today, only three seaweed species, of which two are non-native, are being commercially produced in land-based systems[37].

Limu is still collected from the wild, but there is concern that over-collecting, restriction of freshwater flows and environmental degradation are negatively impacting wild populations[33]. With strong efforts to maintain limu and knowledge around it, non-profit and community-driven groups - such as Kua'āina Ulu 'Auamo, Limu Hui and the Ewa Limu Project - have formed. These initiatives bring together seaweed practitioners, educators, researchers and community members who are working tirelessly to educate the people of Hawai'i on the importance of protecting native seaweed species and work towards restoring and culturing them for future generations.

However, much more can potentially be done with Hawaiian species of macroalgae, as many local species are in demand and consumed by residents as well as visitors. In addition, interest goes beyond human consumption. Most recently, considerable attention has been paid to the commercial cultivation of Asparagopsis taxiformis (limu kohu), a native, iconic and high-value Hawaiian seaweed. Research has found it can reduce methane production in ruminants, thus potentially eliminating a significant amount of a major greenhouse gas.

"There are just a lot of opportunities for Hawai'i to be seriously a leader in the reduction of greenhouse gasses through the production of this limu that belongs to the state. We have a really large opportunity to create meaningful jobs and a whole new industry," explains one of the new businesses that is working at NELHA to close the lifecycle of this species.

Another attractive opportunity here is the co-location of limu farming with finfish aquaculture systems. Seaweeds grown in higher nutrient areas grow faster, without the need for additional fertilizer inputs, while those that are grown in lower nutrient areas, or in densely cultivated areas, could overcome nutrient limitations by co-culturing with finfish aquaculture in an integrated multi trophic aquaculture (IMTA) system. This approach can increase profits for aquaculturists by diversifying their production, increasing yields due to closed nutrient loops, and make the production more sustainable by lowering the water pollution[40].



Governor Ige has proclaimed 2022 to be the Year of the Limu, acknowledging the critical role that it plays in Hawaii's environment and culture and in recognizing the crucial endeavor of protecting, restoring and perpetuating both limu and knowledge about it[41].

Hawaii's strong innovative spirit and strength in research makes it a likely place for the development of such innovative production systems. It is this shortening of the value chain which can unlock massive economic benefits. Due to substantial investment costs, the establishment of seaweed farms brings a greater need to create high-value products. As such, only a handful of studies have assessed bioactive properties and biomedical uses of Hawaiian seaweeds. Consequently, unique attributes may not have been discovered yet that could lead to similar commercially valuable cases such as the unique properties of Asparagopsis taxiformis. Identifying these compounds would pave the way for creating higher value seaweed products and unlocking future revenues. In addition, the further processing involved, would help producers overcome challenges relating to the short shelf-life of seaweed, which often prevents exportation to foreign markets.

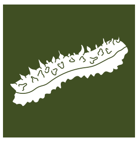
Overall, developing aquaculture methods for native macroalgae species will provide opportunities for industry development, provide nutritious food sources, and maintain unique traditions.

Other potential restorative aquaculture candidates

The cultivation of other low trophic species is significantly advancing in Hawai'i, bringing a range of restorative implications. These shall be briefly introduced below, although they will not directly be included in the latter stages of this report. A high-level overview of the environmental and socio-economic impacts of these species can be found in Appendix II.

Sea urchin

Aquaculture of the native Hawaiian collector urchins (Tripneustes gratilla) was developed in the early 2000s, primarily to remove invasive seaweed species from 'hot spots' like Kāne'ohe Bay. A dedicated urchin hatchery at the Ānuenue Fisheries Research Center (AFRC) on Oahu has optimized juvenile production over the past 20 years to restore the health of affected reefs. Once the sea urchins are 4 to 6 months old they are transferred to the reefs. There is no commercial application of these Hawaiian sea urchins so far, although the gonads (the edible reproductive organs inside the shell) are a high value product in gastronomy, most notably in Asian cuisine.



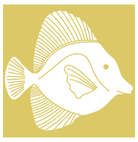
Sea cucumber

Recent research efforts indicate the potential of Hawaiian sea cucumber species for restorative aquaculture practices in Hawai'i. Known as Loli in Hawaiian language, they could be raised in fishponds where they can feed on detritus and clean the silty waters, which would facilitate the restoration and ensure a higher number of fish survive. Since the rearing of sea cucumbers is very similar to rearing bivalves, the basic infrastructure for loli production on Hawai'i is already available and much of the expertise can be transferred from Hawaii's robust bivalve hatchery practices.

Loli were once frequently consumed in Hawai'i, often as part of Japanese cuisine and also the continental U.S. is a significant importer of sea cucumbers. In the past decade, U.S. sea cucumber imports increased 36 times in volume[42]. Fetching as much as US $100 per kilogram, loli aquaculture can create lucrative economic opportunities for Hawai'i[43], especially since the commercial collection of wild sea cucumbers has been banned in Hawai'i since 2016[44].

Coral

Coral also presents an interesting opportunity in Hawai'i. According to leading experts, the potential for commercializing coral restoration activities and the cultivation of coral for the aquarium market cannot be understated. In regions such as Micronesia, similar operations have proven fruitful. The favorable, extremely fast growth rate of soft coral species on the islands lends itself to this industry. In addition, Hawaii's strong research institutions lead the fields of coral genetics and coral breeding, making this a promising location with a start for tapping into this market. However, as regulations around coral are getting more stringent as this report is being written, this potential might never commercialize.



Ornamental fish

There is also ample opportunity to accelerate the growth of the ornamental fish industry in Hawai'i, which already accounted for $3.56 million of total aquaculture sales in 2020 (USDA). Wild collection of ornamental fish is now illegal in Hawai'i, while many endemic reef species are highly sought-after for aquariums. As a result, ornamental fish aquaculture is a sustainable alternative for supplying the $1 billion ornamental fish market. Exciting efforts in this area have been shown by the PACRC and Oceanic Institute, who have made great progress in their ornamental fish hatchery.

'Opihi

Lastly, an interesting aquaculture candidate could be 'opihi, the small Hawaiian limpet, is considered a seafood delicacy and tends to be the most expensive seafood in Hawai'i (between $100-200 gallon with shell on). The established niche market, based on collection of dwindling wild stocks, encouraged considerable research efforts for aquaculture, but there are still fundamental questions to be answered before commercial aquaculture production becomes viable. The main goal remains closing the life-cycle of this very unique organism and developing a rearing system that resembles the wave intensive intertidal conditions.

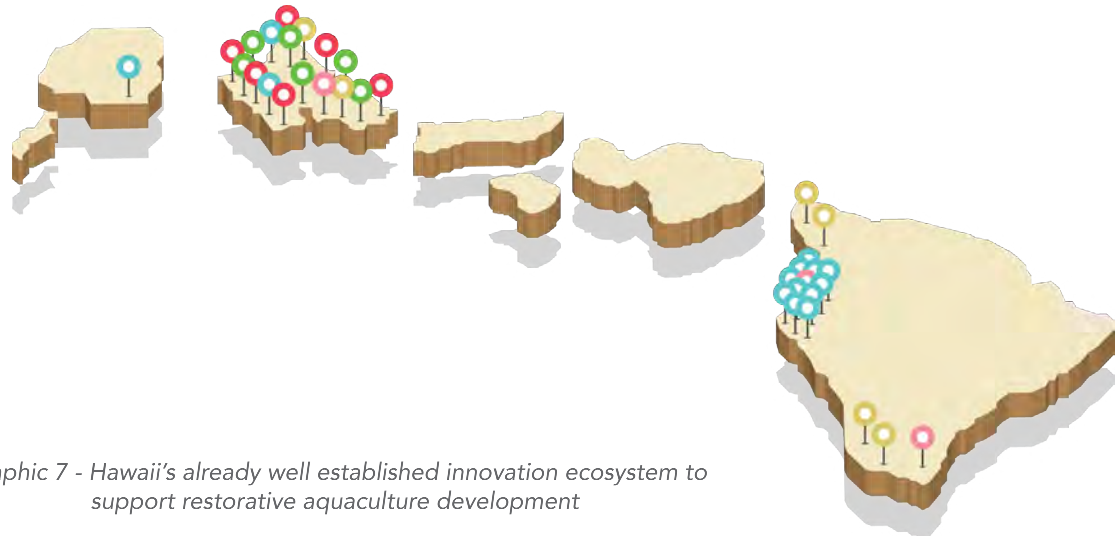
3.1.2 Hawaii's unique location and its advantages for aquaculture

Hawai'i offers unique and invaluable assets that attract entrepreneurs and researchers and support the aquaculture industry. First and foremost is the archipelago's 750 mile long coastline and abundance of fresh, brackish and saltwater reserves. The favorable climate makes a year-round production of both cold and warm water species possible, with high natural productivity due plenty of sunlight. Combined with the advantage of natural isolation and high level of biosecurity policies, Hawai'i has proven its worth to the aquaculture industry, as showcased by the success story of specific pathogen-free (SPF) shrimp broodstock and the shellfish hatcheries.

Unique infrastructure, such as the cold, deep ocean water pipeline provided at HOST on the big Island of Hawai'i, make this one of the best places to carry out aquaculture R&D and host commercial and private companies, research outfits and startups. Furthermore, Hawai'i is home to renowned universities and research institutes with extensive collaborative research facilities and trained personnel. The PACRC in Hilo presents a successful case, where an old water treatment facility was repurposed into a multi-species hatchery and research facilities, showcasing the innovative orientation of Hawai'i. In an era of rapid technological development, the global aquaculture industry is poised for a sustained period of growth and expansion and Hawai'i is home to both pioneering industry research efforts.

Picture 3 - The Ocean Technology Park administered by NELHA in Kona

As we move towards more sustainable seafood production systems, we should remember that there is a lot to learn from the past. Seeking answers from restorative aquaculture practices first incorporated by indigenous Hawaiian communities is a step in the right direction, and this holistic approach, combined with the latest technological innovations, will yield great results in years to come.



Graphic 7 - Hawaii's already well established innovation ecosystem to support restorative aquaculture development

ROLE	ISLAND	ORGANIZATION
AQUACULTURE COMPANIES	NELHA	Ocean Era Farms
	OAHU	Kualoa Ranch
	BIG ISLAND	Kona Coast Shellfish LLC
	NELHA	Taylor Shellfish Farms, Inc.
	NELHA	Pacific Hybreed
	NELHA	Blue Oceans Mariculture
	NELHA	Jamestown Point Whitney Ventures
	NELHA	Big Island Abalone
	NELHA	Royal Hawaiian Sea Farms
	NELHA	Symbrosia
	NELHA	Kohana Kai Aquafarms
	NELHA	Blue Ocean Barns
	OAHU	Olakai Hawai'i
	KAUAI	Kauai Sea Farm
GOVERNMENT	OAHU	Anuenue Fisheries Ressource Center (part of DLNR - DAR)
	OAHU	National Oceanic and Atmospheric Administration (NOAA)
	OAHU	State Department of Health (DOH) - Food Safety Branch
	OAHU	State Department of Land and Natural Resources (DLNR)
	OAHU	Center for Tropical and Subtropical Aquaculture (CTSA)
	OAHU	State Department of Business, Economic Development and Tourism (DBEDT)
INNOVATION SUPPORT	NELHA	Hatch Blue
	BIG ISLAND	Natural Energy Laboratory Hawai'i Authority (NELHA)
	OAHU	Hawai'i Technology Development Corporation (HTDC)
NON-PROFIT	OAHU	Conservation International
	OAHU	The Nature Conservancy
	OAHU	Kua'aina Ulu 'Auamo
	OAHU	Waterkeeper Alliance (Wai WaiOla, Kona Coast, Oahu, Hilo Bay Waterkeepers)
	OAHU	Waimano LimuHui
	OAHU	Paepae o He'eia
RESEARCH & ACADEMIA	BIG ISLAND	University of Hawai'i (UH) - CTAHR
	BIG ISLAND	University of Hawai'i (UH) - SOEST
	BIG ISLAND	Universtity of Hawai'i, Hilo - Marine Science department
	BIG ISLAND	Pacific Aquaculture & Coastal Resources Center (PACRC)
	OAHU	SeaGrant
	OAHU	Oceanic Institute

3.2 Environmental and socio-economic impact assessment of restorative aquaculture species in Hawai'i

Restorative aquaculture opportunity	ENVIRONMENTAL VALUE			SOCIAL VALUE			ECONOMICAL VALUE				Technological readiness (Existing scientific knowledge, proven cultivation and production systems)
	Water quality improvement	Climate change mitigation	Habitat provision / biodiversity	Cultural significance	Healthy food source	Alternative livelihood	Local market opportunities	Export opportunities	Green job opportunities	Indirect economic opportunities	
SEAWEED (LIMU)	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	MEDIUM	HIGH	LOW	LOW
BIVALVE SHELFISH	HIGH	MEDIUM	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	MEDIUM	MEDIUM	MEDIUM

Graphic 8 - Environmental and socio-economic impact framework and its application in Hawai'i

For future prosperity of Hawaii's local ocean communities, and as a complement to traditional public efforts, scaling the restorative aquaculture efforts could be part of an effective market-driven strategy to help accelerate coastal restoration. Restorative aquaculture in Hawai'i has the potential to provide significant environmental, social and commercial value without the long term reliance on grants and other external funding sources.

Environmental impact

Hawaii's Ocean Resource Management Plan already acknowledges that nearshore restorative aquaculture systems can support healthy coastal ecosystems, including improving water quality, sediment/nutrient retention, and downstream benefits to coral reef health[9]. In addition, the recent proclamation by Governor Ige underlines how limu serves key ecological and economic functions, preventing erosion and coral breakage, creating oxygen, producing sand, serving as food and shelter for marine animals, mitigating global warming through carbon sequestration, and acting as the base of the food web on which local fisheries rely[41].

In order to be able to quantify these concrete ecosystem services in the Hawaiian context, research in cultivation settings of the native species is essential. The PACRC is leading research efforts around the water filtration potential of native seaweeds and oysters. Most recently, native Hawaiian oysters (Dendostrea sandvicensis) are being used by the Waiwai Ola Waterkeepers in partnership with the PACRC for water quality mitigation purposes at six sites, and trials for commercial production are overseen by the PACRC staff. Other joint research projects have recently been granted to test a similar system using fish and shrimp effluents from pond-based grow-out systems.

Social value - grounded in Hawaiian values and guided by traditional knowledge

The loss of local biodiversity not only impacts the broader ecosystem and economy of Hawai'i, but also threatens the longevity of native Hawaiian traditions. Restorative aquaculture naturally respects this rich cultural heritage. By redirecting local aquaculture to systems that amplify the importance of native species, the future of Hawai'i could align with traditional beliefs and indigenous respect for the ocean and the Hawaiian ecosystem. Not to forget, that through collective management of these resources, important local community links are re-established[10,36].

Public sentiment is shifting towards a more food secure Hawai'i and aquaculture can align with agriculture to contribute to this important effort. In the roadmap for Hawai'i-based aquaculture, the priority should fall on meeting the needs of local consumption. This way, an isolated island state like Hawai'i can move towards becoming self-sufficient. Along those lines it is crucial to note that seafood and fresh produce are important to Hawai'i's health. Products grown in Hawai'i take less time to get from harvest to plate. They are fresher and retain their nutritional value and taste. Imported food spends a lot of time (and carbon) being transported to Hawai'i and loses its freshness and nutrients during transport and distribution.

In addition to improving food security and nutrition for Hawai'i residents, restorative aquaculture can create meaningful green jobs. Creation of the restorative aquaculture sector will see investments in communities, education and people. A quote by one of the companies working with seaweed at NELHA drives home the intent of restorative aquaculture and a vision for the future jobscape of Hawai'i: "When we think of restorative aquaculture we absolutely think of the social side. Our commitment to the restorative aquaculture industry is to restore a connection with the ocean. To restore a sense of ownership over one's career trajectory and ability to create a legacy for herself/himself or the family."

Economic value - Supporting a diversified economy that relies less on tourism

It is evident that healthy marine ecosystems go hand-in-hand with a prosperous tourism sector and thriving fisheries. Successful restorative aquaculture activities that achieve restoration of degraded coastal habitats can have a ripple effect and ultimately aggregate large-scale economic worth for Hawai'i.

Similarly, greater investment and development into restorative aquaculture can accelerate businesses and bring significant yields and returns to the state. Restorative aquaculture provides an immense opportunity to invest

PRODUCT OR SERVICE	**FIT** (potential competitive advantage / suitability for Hawai'i)	**PROFIT** (expected profit margins once product category is mature)	**SCALE** (potential size of target market)	**READINESS** (proven technology / viability)
Human Food	HIGH	HIGH	HIGH	HIGH
Animal Feed (e.g. shells for chicken)	LOW	LOW	HIGH	MEDIUM
Water filtration services	HIGH	Additional scientific research necessary	Additional scientific research necessary	MEDIUM

Graphic 9- Market opportunites for shellfish cultivation

PRODUCT OR SERVICE	**FIT** (potential competitive advantage / suitability for Hawai'i)	**PROFIT** (expected profit margins once product category is mature)	**SCALE** (potential size of target market)	**READINESS** (proven technology / viability)
Food and Food ingredients	HIGH	MEDIUM	MEDIUM	MEDIUM
Animal Feed	HIGH	MEDIUM	HIGH	LOW
Health products (Nutraceuticals, cosmetics,..)	HIGH	HIGH	HIGH	LOW
Blue Carbon *credits*	Additional scientific research necessary	HIGH	MEDIUM	LOW
Nitrogen *credits*	Additional scientific research necessary	Additional scientific research necessary	Additional scientific research necessary	LOW

Graphic 10 - Market opportunites for seaweed cultivation in green workforce development and upscale the labor force to compete in the global market. This enhancement of economic growth in a novel sector will allow Hawai'i to become more self-sufficient, relying less on imports and utilizing existing resources while building an economy that serves and is driven by the local population.

There are also the opportunities that come with the ecosystem services provided, which could save the state resources it spends today - and would be likely to have to ramp up in the future - on direct water treatment, such as nitrogen removal. Different models and payment mechanisms for these ecosystem services are currently being explored and implemented in other geographies.

Once native Hawaiian species prove their efficiency to provide these ecosystem services and they can be quantified, nothing stands in the way for similar mechanisms to be applied in Hawai'i.

> *"The umbrella term 'aquaculture' can mean so many things at once. It can mean food security... it can mean cultural preservation... it can mean restoring native ecosystems... and it can do all of that at the same time if you want it to! Aquaculture is an exercise in creativity and that's something I love about it."*
>
> - Tori Spence McConnell, NOAA fisheries policy analyst and Pacific Islands aquaculture coordinator

3.3 Gaps and barriers to growth

Building an industry around restorative aquaculture in Hawai'i will require addressing a variety of challenges.

I. Space to grow

Finding space for ocean-based aquaculture operations may be a challenge, given the lack of continental shelf near Hawai'i. In general, protected near shore areas are favored for farming, as offshore conditions can be challenging. Reasons for this include high wave action and strong currents. As a result, in the case of Hawaiian seaweed, offshore cultivation may be the long-term focus, but this will require significant R&D investments to reach viability.

Furthermore, in the few shallow bays that are found in Hawai'i, aquaculture might lead to spatial conflicts between marine users. Coupled with the fact the island is surrounded by an oligotrophic environment (one with a low nutrient content), there is a potential shortage of suitable aquaculture locations. To overcome this, restored fishponds could be an avenue for expansion, however, at present only very few are suitable for immediate use.

II. Regulatory framework

Aquaculture in Hawai'i generally operates within one of the most exhaustive regulatory frameworks in the world. This governs a multitude of environmental concerns including disease management, fish habitat, threatened and endangered species, seafood safety and spatial conflicts.

However, many of these aforementioned restorative aquaculture practices are novel, making some of these regulations ill-suited, too complex or lacking in consistency. For instance, it's debatable whether seaweed aquaculture currently falls under the same regulations listed for finfish aquaculture and there is no clear path how this can be evaluated on a case-by-case basis. Or looking at the bivalve sector that has unique shellfish sanitation rules, but lab testing capacities are extremely limited and more dedicated staff are needed.

What makes it especially difficult is the lack of a lead agency - at both federal and state levels. Establishing one could effectively coordinate and streamline regulatory and permitting processes, resulting in timely decisions and more certainty for investment in either new enterprises or expansion of existing operations. Not only commercial businesses are hampered by these circumstances. A non-profit project aimed at testing the native Hawaiian oyster for its water filtration efficiency experienced significant hindrance, because of an 18-month wait for a single permit. Under these circumstances, traditional Hawaiian fishponds remain advantageous aquaculture locations, as current legislation provides avenues of cultivation with less permitting complexity. Regulatory challenges for these sites have been considered by the government, and some steps towards streamlining the federal and state permitting processes have been made, and are accompanied by a dedicated permit application guidebook "Ho'āla Loko I'a".

III. Knowledge gaps

Existing knowledge gaps of native species present a barrier, with limited available information concerning the growth requirements and commercial applications. In the case of limu, each new aquaculture entrant currently needs to develop its own breeding knowledge, hatchery facilities, and seedstock - as there are no commercial-scale hatcheries or seed suppliers. To add to this knowledge gap, government approval for wild seaweed collection for startup inoculation can be challenging and prohibitive to new entrants. This adds to the difficulty of establishing operations, as new entrants burn excessive capital at the research stage.

Unlocking full commercial value is the next piece of the puzzle. As aforementioned, much more research is needed on the bioactive profile of native seaweed species and their commercial potential in novel applications.

Finally, ecosystem service products must be evaluated. To do this, we must study how native shellfish and seaweed farming can provide significant economic benefits far beyond the products that are sold. To do this, quantification of the environmental benefits from native species (carbon sequestration, nitrogen uptake, etc.) should be calculated, alongside carrying capacity calculations of specific water bodies (such as fishponds). Gaining reliable economic values of these ecosystem services encourages the consideration of these benefits in public policy decisions and can support methodologies to remunerate farmers for the ecological benefits that they create.

IV. Infrastructure

Although Hawaii's existing aquaculture facilities can provide the basis for more local grow-out operations, there remains an acute need for more research and innovation capacity across academia and the industry. Hawai'i already has several innovation centers, but most of these are at capacity and need to be expanded. As a result, more infrastructure is needed to accommodate innovative R&D projects solving technological aquaculture challenges.
Furthermore, investment in basic infrastructure - such as graded land and utilities - facilitates innovation. NELHA is a prime example. It provides a convenient platform for startups, allowing them to concentrate on their technology, rather than dealing with bureaucratic matters. Making headway in this area could contribute significantly to startup success and thrust Hawai'i into a market leading position.

Lastly, continued investment in production infrastructure, processing and logistics is essential. There are logistical and technological challenges involved when building a sustainable production chain. For example, sustainable processing and the application of sidestreams are potentially complex avenues which need to be explored if the industry demands circularity.

V. Workforce/ human resource

Despite the abundance of renowned universities a shortage of people with skills, knowledge and practical experience could present a challenge. Recent survey data45 identified the top technical skills needed by the aquaculture industry to be: water quality management, data analysis, equipment maintenance, hatchery skills, budget management, construction/carpentry, health/disease management, and macroalgae cultivation. Meanwhile, top professional skills needed by the industry include problem solving, communication, adaptability, critical thinking and teamwork. An additional range of harder to come by skills are required to foster innovation.

Commercial stakeholders interviewed for this report repeatedly mentioned how challenging it is to attract and retain the level of talent needed for the operations. Salaries must be competitive with the mainland and students encouraged to pursue careers in this space.

VI. Access to capital

Access to capital presents another substantial challenge for restorative aquaculture to scale. Bank loans are usually unavailable for new and aspiring farmers, since it is a novel sector with high risks involved. However significant start-up costs for equipment, seed supply and facilities often require external financing. The long growing cycles, typical for the aquaculture industry, are off-putting for most conventional capital providers. This limits any project with promising indications at a research stage to be taken to a commercial level.

VII. Market access

The export shipping costs are immense for Hawaiian producers, especially when it comes to fresh or alive (in the case of shellfish) products that need to be shipped at cool temperatures in a short time window. As a result, the export market is rather suitable for high value products. However, it should also be noted in this case, that any advantage that might be gained by farming carbon-negative species, might be superseded by the carbon footprint involved in transport.

The nonprofit GreenWave's Kelp Climate Fund, which started as a small pilot in 5 states, has recently opened up to all kelp farmers in the US. It pays farmers directly for climate benefits, including carbon, nitrogen and reef restoration, for all kelp (a subset of brown macroalgae) being grown in North America. In return, farmers provide key monitoring data on outplanting, growth rates, and harvest through a mobile app, dashboard and data collection tools.

www.greenwave.org/kelp-climate-fund

There is no ecosystem service market for either water quality improvement or blue carbon offsets in Hawai'i present today. There is strong international and local interest in these sorts of services, but it is still an emerging area of research. Given the scale required, it may be challenging to generate viable returns from carbon offsetting or nutrient capture as a stand-alone business model.

VIII. Human impact & climate threats

At last, climate change poses a threat to restorative aquaculture operations. Rising sea levels will affect large parts of Hawaii's shoreline much earlier than previously expected[46]. Especially the vulnerability of fishponds from rising water levels has hardly been discussed in this context and needs to be kept in mind. Furthermore, the warmer waters and shifting circulation caused by global climate change may lead to increased frequency and strength of hurricanes and other extreme weather events. Aquaculture farms are extremely vulnerable to these devastating events.

Increasing ocean acidification also affects the growth and survival of shellfish, both farmed and wild, as pH levels are changing and less carbonate is available to build their essential shells. This ultimately poses a threat to the harvest and economic value of the shellfish sector[47].

Among many things, development and land-based activities contribute to surface runoff of pollutants and sediment, which lead to compromised nearshore water quality. Untreated stormwater runoff is deposited directly into nearshore waters without treatment or filtration. This surge in stormwater discharge leads to elevated human viral and bacterial loads along coastal discharge points. Aquaculture in waters with too many pollutants has serious implications on the food safety of both seaweed and shellfish produced.

While limu would usually thrive in these conditions, a recent study found that climate change and land-use change induced shifts in submarine groundwater discharge, which is affecting native limu species negatively, while fueling the expansion of invasive ones[48].

Although seaweed and shellfish aquaculture can have climate mitigating effects on climate change and human caused stressors to the marine ecosystem, it is evident that a somewhat healthy nearshore ecosystem is imperative to the success of the sector.

4. Unlocking the potential

A roadmap to put Hawai'i back on the right track

There is much room to diversify Hawaii's ocean economy towards a more sustainable and resilient one, however these developments need to be guided by a clear value proposition and a pathway that addresses the current industry gaps and barriers outlined. The following recommendations recognize the unique aspects of Hawaii's context and intent to guide aquaculturists, business owners, aspiring entrepreneurs, government departments, researchers, regulatory agencies and municipalities, investors and foundations, nonprofits and communities to work towards a resilient future and a thriving restorative aquaculture sector in Hawai'i.

4.1 High level recommendations

4.1.1
Optimize regulatory and governance framework

Goal: A streamlined licensing and permitting process for restorative aquaculture

All stakeholders agree that better interagency communication is key, however there is also a lack of capacity, including funding and staffing in the agencies related to aquaculture. Streamlining the process requires the foresight of someone who understands which direction the industry wants to go in.

Other U.S states have already been very successful in streamlining their permitting processes for shellfish and seaweed producers. Joint efforts from NOAA and Sea Grant established an entire Alaska aquaculture permitting portal and guidance platform, for instance, which provides support for aquaculture license applicants within the permitting process.

In Hawai'i the clear benefits of easing the regulatory environment for responsible farming can be seen at NELHA, where the combination of pre-permitting, technical assistance and infrastructure enable both large and small companies to grow. However, this currently only concerns production in land-based facilities. Meanwhile a project from UH Hilo, led by Rhiannon Chandler from the Waterkeepers Alliance, is developing a training program on how to navigate the permitting system for restorative aquaculture activities.

Exploration of aquaculture development zones in the marine coastal areas should be a next step, to establish a responsible coastal leasing system for seaweed and bivalve aquaculture. Marine spatial planning is a method of enabling community agreement about appropriate locations for a range of marine activities, from preservation or protection through to utilization. Recently established community-based subsistence fishery management areas could be worth emulating, where engagement with native Hawaiian communities' farming practices could take place.

4.1.2
Closing knowledge gaps and promoting cross-sector collaboration to accelerate innovation

Goal: A research roadmap and shared knowledge platform to increase coordination and sharing among stakeholders.

There remains an acute need to continue to create innovation capacity in both the research and enterprise sectors. Increased investment in breeding and cultivation techniques for promising native species is therefore required. As noted above, there is a need to 'upskill' the regulators and share the expanding knowledge base as the industry develops in order to streamline the regulatory framework.

To make the knowledge gained through research worthwhile, increased coordination and sharing among Hawaii's aquaculture community - as well as more events and industry forums and research summits - are recommended.

More links between researchers, industry, community-driven groups, and the array of end-users are desired to stimulate innovation. The formation of cooperatives to support the necessary facilities, upgrades, shared space and equipment could be encouraged. Here linkages and overlaps between existing support services (supply and distribution) of fisheries and both marine and freshwater aquaculture should be examined.

One of the important factors in the early - largely successful - efforts to establish viable commercial aquaculture in Hawai'i was the coordinated effort of the State of Hawai'i, UH Sea Grant, NOAA and various USDA agencies to provide targeted funding for applied research and hands-on extension services to producers. Sea Grant and CTAHR, along with the Aquaculture Development Program, sponsored a statewide extension network that provided expert services on every island. Its long list of aquaculture publications provides a wealth of information, documenting progress with aquaculture and is invaluable to anyone considering aquaculture in the region.

Finally, collaboration can support the development of new markets and value-added products, both of which are investment opportunities. As this report further identified, is there a crucial need to study how native Hawaiian shellfish and seaweed species can provide significant economic benefits far beyond the products that are sold. Gaining reliable economic values of the ecosystem services they provide enables consideration of these benefits into public policy decisions, including systems that allow farmers to be compensated for the ecological benefits their farms provide. Real life farming experiments that quantify the ecosystem services such as nitrogen removal from the water by native species should be realized. Positive results can encourage future adoption of more such farms and "green infrastructure projects" in the region and may also have catalytic effects, by making the business case for restorative farms more attractive to aspiring farmers.

4.1.3
Supporting existing, new and aspiring farmers, practitioners and entrepreneurs

Goal: A commercialization program to accelerates the funding and development of new restorative aquaculture activities

Significant funding opportunities to enable sector establishment in its developing years are critical to bridge the gaps between research and commercialization. Concerns about the economic profitability of farming shellfish and seaweeds hamper upscaling production as of today. Designating public funds to de-risk private investments into the sector will be needed in the short-term to support starting businesses. Valorizing and capitalizing the ecosystem services provided by seaweed and shellfish species can support the business case going forward. Resources will be needed to first of all quantify the broader ecosystem services that can be accounted for and subsequently develop methodologies and standards to recognize these ecosystem services.

The recent support from the state legislature for business assistance and the revival of the Aquaculture Development Program, as well as funding for the new Hatch Aquaculture Accelerator, coupled with a follow-on fund, are positive indicators. Such an aquaculture dedicated investment fund will allow more Hawai'i-based companies to set up and grow their aquaculture businesses in Hawai'i, while simultaneously fostering collaboration with experts worldwide. Furthermore, raising awareness among conventional investors (e.g. family offices, venture capital and private equity funds, banks) to elevate the restorative aquaculture opportunity as a valuable investment opportunity should be considered and the development of other innovative, blended financing strategies promoted.

4.1.4
Developing a workforce and capacity building plan that includes diversity, equity, and inclusion

Goal: A dedicated workforce development and capacity building plan

The current labor shortfall is expected to worsen unless steps are taken to educate a growing labor pool. Engagement with existing aquaculture operators, indigenous groups and parallel industry groups - such as fishing or maritime tourism - on skill transfers, training and development programs will be critical.

Joint efforts are already well underway to increase opportunities for aquaculture education and extension to support sustainable aquaculture development. Recently, the Hawai'i Aquaculture Collaborative conducted an inventory of available aquaculture workforce development opportunities across all kinds of institutions and the approximate number of people trained. Efforts at community level to involve students at the elementary, middle and high school level and include aquaculture into their programs are growing. Many of the community colleges have some form of aquaculture education element, with aquaponics being one of the most common.

The University of Hawai'i plans to increase opportunities for participation in aquaculture education throughout its nine-campus system. Besides the aquaculture program at UH Hilo, other campuses are integrating aquaculture education into their programs in animal science, zoology, biology and marine science. This is where more specialized training opportunities for the restorative aquaculture sector should be built on.

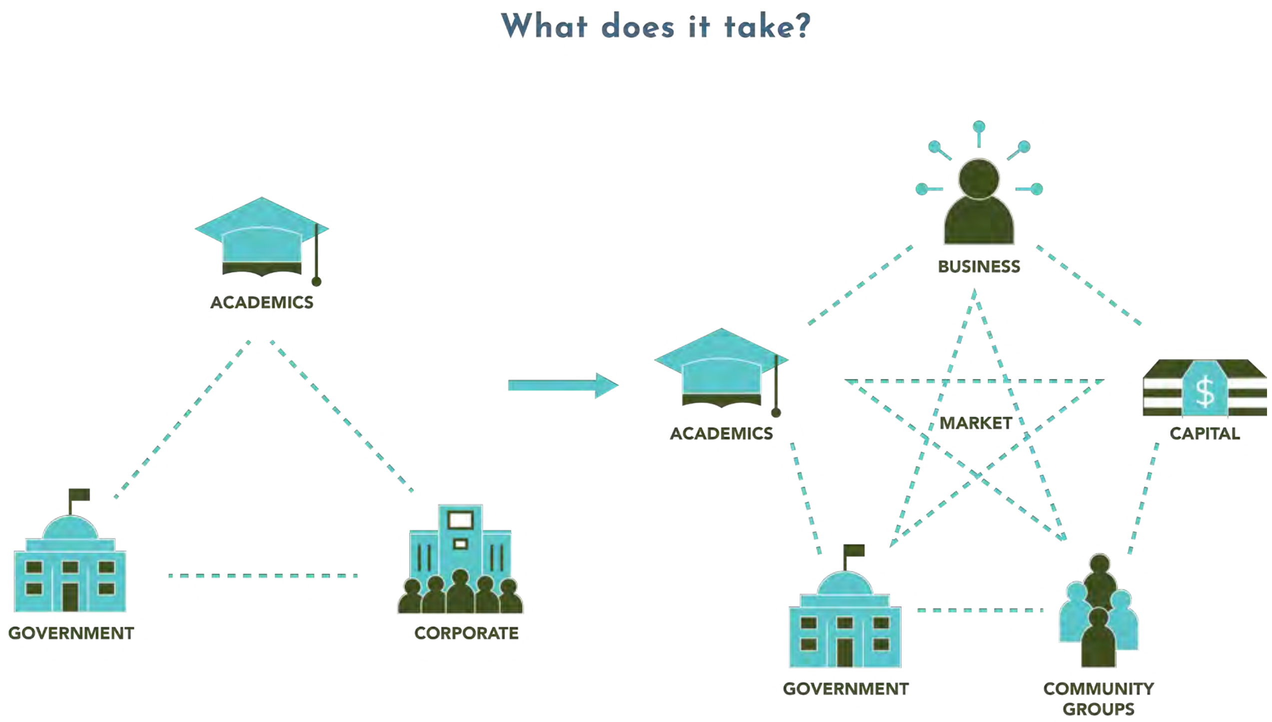
4.1.5

Raise awareness on the benefits and potential beyond the aquaculture community

Goal: An improved integration and understanding of aquaculture in Hawaii's communities

Work should be done to raise public awareness about the benefits of restorative aquaculture and it's species, the nutritional profile of the products and the contribution of the industry economically, socially and environmentally. This can be done by amplifying aquaculture through partnerships with broader food systems, agriculture networks and movements, building on a local food system story. Traceability, sustainability and conservation are among the most common concerns that consumers have when it comes to seafood[49], so it is important to capitalize on any opportunities to educate the public. Moreover efforts to communicate aquaculture research beyond publishing papers, through the creation of media outlets, for example, should be encouraged.

Finally there is a unique opportunity to expand and promote seafood branding linked to Hawai'i such as the 'Made in Hawai'i" brand. By telling the story of Hawaii's aquaculture tradition and evolution, a dedicated campaign for locally grown limu and bivalve products could harness marketing opportunities for culinary tourism and encourage Hawaiian visitors and locals to develop consumer preferences for Hawaii's unique seafood, ultimately cultivating a sense of pride in communities for Hawaii's unique seafood provenance. While Hawaii's tourism industry is proposing a transition towards a 'regenerative tourism' concept, restorative aquaculture could become a recognized part of this fresh approach.



Graphic 11 - From triple helix to Innovation driven entrepreneurship ecosystem (MIT REAP Framework)[50]

4.2 Proposed next steps / actions

The potential to develop sustainable, ocean-based bio-economies in Hawaiʻi is large and restorative aquaculture presents a market-driven pathway to achieve this. However, many of the archipelago's aquaculture efforts and initiatives are currently research focused, and too few promising scientific achievements have been commercialized. The Hawaiʻi aquaculture landscape and R&D in this space have been primarily driven by grants in the past, so have arguably missed long-term focused incentives.

Looking ahead, it will be necessary to link existing marine research to a business and innovation ecosystem and someone will have to take the lead on this. Following MIT's widely recognized theory, five key stakeholders are critical to the successful establishment of most innovation ecosystems and the subsequent growth and acceleration of innovation-driven entrepreneurship in the ecosystem[50]. Community and capital are acknowledged as equally important groups as academia, industry and government when building innovation capabilities.

MIT REAP
Regional Entrepreneurship Acceleration Program

The MIT REAP model has been widely adopted by communities across the world to strengthen innovation-driven entrepreneurial ecosystems and transform economies.

We create a restorative aquaculture innovation ecosystem in Hawaiʻi, the following key stakeholders need to convene:

- Businesses (Entrepreneurs & Corporations)
- Risk capital
- Universities
- Government
- Community groups / NGOs

Next steps

Establishment of a dedicated **task force** consisting of at least one representative from each of these five stakeholder groups.

This **task force** should further convene a wider restorative aquaculture sector group, for instance through thematic workshops, to foster collaboration and stakeholder engagement, share information and inform decision making, and set priorities and aspirations for development of the industry.

The Alaska Mariculture Task Force, could serve as a succesful reference case to draw from when creating such task force for instance. Since the launch of this task force in 2016, several state bills have been passed to support responsible growth of the industry with support from diverse stakeholders. The task force is currently developing a five-year action plan to develop infrastructure, capital, business models, training programs, marketing, public outreach, legislation and research, with the goal to build a mariculture (seaweed and bivalve aquaculture) industry worth $100 million in the next 20 years.

Initial action points of such task force could entail, but are not limited to:

- Propose suggestions to streamline the application process for aquaculture permits (a site suitability analysis tool should be part of this)
- Create a roadmap to build support and obtain funding from key state and federal government departments and impact investors for strategic research and development projects that support the sector initiatives.
- Develop seaweed and bivalve aquaculture best management practices (BMPs) with robust environmental, safety and biosecurity standards for management and monitoring of the aquaculture operations
- Establish a clear pathway for quantifying ecosystem services of limu and bivalves and identify potential ecosystem service payment schemes.

Appendix

I. High-level environmental and socio-economic impact framework for other restorative aquaculture opportunities in Hawai'i

ENVIRONMENTAL VALUE			SOCIAL VALUE			ECONOMICAL VALUE		
WATER QUALITY IMPROVEMENT	CLIMATE CHANGE MITIGATION & ADAPTATION	HABITAT PROVISION	CULTURAL SIGNIFICANCE	COMMUNITY HEALTH	ALTERNATIVE LIVELIHOOD	DIRECT MARKET OPPORTUNITIES	INDIRECT ECONOMIC OPPORTUNITIES	GREEN JOB OPPORTUNITIES
Removal of excess nitrogen, phosphorus and suspended solids from surrounding environment	CO2 and nutrient sequestration / Ocean Acidification mitigation / (Carbon reduction potential of end - product)	Creation of structured habitat for fish and invertebrates / hatching & nursery grounds / enhances biodiversity	Restoring indiginous culture / preserving in-tergeneration al knowledge / reconnecting to the ocean	Healthy and accessible food provision / nutritional benefits / food security	Coastal community resilience / small business ownership & wealth creation / inclusion / climate justice	Commercially viable local or export market for product or application with further growth opportunities	Wastewater treatment savings / blue carbon & nutrient credit markets / increased fisheries value	Direct employment growth potential / productive training opportunities and retention of talent

Restorative Aquaculture Species	ENVIRONMENTAL VALUE			SOCIAL VALUE			ECONOMICAL VALUE			Existing Scientific knowledge	Technological readiness
	Water quality improvement	Climate change mitigation	Habitat provision / biodiversity	Cultural significance	Healthy food source	Alternative livelihood	Local market opportunities	Export opportunities	Green job opportunities		
FOOD FISH IN FISHPOND	LOW	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	HIGH	MEDIUM	HIGH
CORAL	HIGH	HIGH	HIGH	HIGH	-	MEDIUM	MEDIUM	HIGH	MEDIUM	HIGH	HIGH
ORNAMENTAL FISH	LOW	HIGH	HIGH	MEDIUM	-	MEDIUM	MEDIUM	HIGH	HIGH	LOW	LOW
SEA CUCUMBER	HIGH	MEDIUM	HIGH	MEDIUM	HIGH	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
SEA URCHIN	LOW	MEDIUM	HIGH	MEDIUM	HIGH	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
LIMPET - OPIHI	?	LOW	?	HIGH	HIGH	MEDIUM	HIGH	LOW	?	LOW	LOW

II. List of the main facilities for research, education and industry development in Hawaiʻi

The **Ānuenue Fisheries Resource Center** located on Sand Island, Honolulu is operated by **The Division of Aquatic Resources (State of Hawaiʻi).** One of its earliest activities was to produce fish such as mullet for restocking efforts. Today it hosts a sea urchin hatchery and coral nursery, as well as a seaweed hatchery that supports the limu hui on their restoration efforts of wild limu stock.

The Hawaiʻi Ocean Science and Technology (HOST) Park administered by the **Natural Energy Laboratory of Hawaiʻi Authority (NELHA)** provides unique infrastructure to around 50 companies, including approximately 20 aquaculture companies, many of which are among the oldest and most successful in Hawaiʻi. The master permitted park on 870 acre prime coastal property in Kailua-Kona has grown steadily over the years since the 1970s. It offers many critical resources to new start-up companies, including business services, laboratory services and turnkey facilities.

The Pacific Aquaculture and Coastal Resources Center (PACRC) of the University of Hawaiʻi Hilo (UHH) hosts three hatcheries (two for marine fish and one for bivalves), resources for seaweed, corals and a wide variety of research and training facilities. It is a Center of Excellence for Sustainable Aquaculture, in partnership with the University of Hawaiʻi Sea Grant Program and widely used by academic, public- and private sector partners and has an active international technical assistance program.

The College of Tropical Agriculture and Human Resources (CTAHR) is currently developing an on-campus facility, the T**uahine Aquaculture Research and Education Center (TAREC)** at UH Mānoa that will provide resources for research, extension and education. Undergraduate and graduate students are exposed to aquaculture research through graduate programs in animal sciences and nutritional research, access to state-of-the-art laboratories and approaches and a range of local and international collaboration opportunities.

Oceanic Institute of Hawaiʻi Pacific University (OI), founded in 1962 is a non-profit research and development organization dedicated to aquaculture, biotechnology, and coastal resource management. It is one of the best-known aquaculture research and training facilities in the world, given its role in many of the most innovative breakthrough efforts in aquaculture, such as the development of SPF shrimp broodstock.

III. List of relevant reports and resources

This report only serves as an introduction to the opportunities around nature-based ocean opportunities. The below listed ressources have provided us with tremendous knowledge in context of this report and we highly recommend the reader to dive into any of these deeper for further reference.

Global relevance:

The Ocean Panel report "Ocean Solutions that benefit People, Nature and the Economy" illustrates how a sustainable ocean economy, where protection, production and prosperity go hand in hand, can create a healthy ocean that provides solutions to global challenges. Drawing on the latest scientific research and analyses, including insights from 19 previous Ocean Panel-commissioned papers, this new narrative is paired with an ambitious and feasible action agenda.

The Global Principles of Restorative Aquaculture report published by The Nature Conservancy provides an excellent knowledge base around the concept of restorative aquaculture, including the scientific evidence behind and global best cases.

Visit Sea Gardens platform to learn more about unique Indigenous aquaculture systems around the Pacific, where you find short geographically-referenced synopses written by a collaborative group of Indigenous scholars and partnering researchers. Each feature is linked to longer descriptions that cover the ancestral connection, geographic and temporal extents, biophysical manipulations, target species, ceremonial and stewardship, and current status.

Hawai'i-specific:

The Hawai'i Ocean Resource Management Plan published in 2020 is a great resource for anyone interested in learning more about the shared ocean resource protection goals for the State of Hawai'i. It outlines current problems that are not adequately addressed by existing laws and rules.

The Hawai'i Ocean Health Index measures and tracks the benefits and services that the ocean provides for people now and into the future. This index was developed with the support of local stakeholders to better understand how to sustainably balance current and future ocean use.

For more detailed information on the leasing and permitting requirements in Hawai'i, NOAA's state-by-state summaries for both seaweed (p.70) and shellfish aquaculture (p.110) can help. It provides an overview of the agencies involved and the formalities required in the application process.

The Ho'āla Loko I'a guidebook helps to navigate through this new streamlined permitting process for the repair, restoration, maintenance, and operation of loko i'a (traditional Hawaiian fishponds).

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