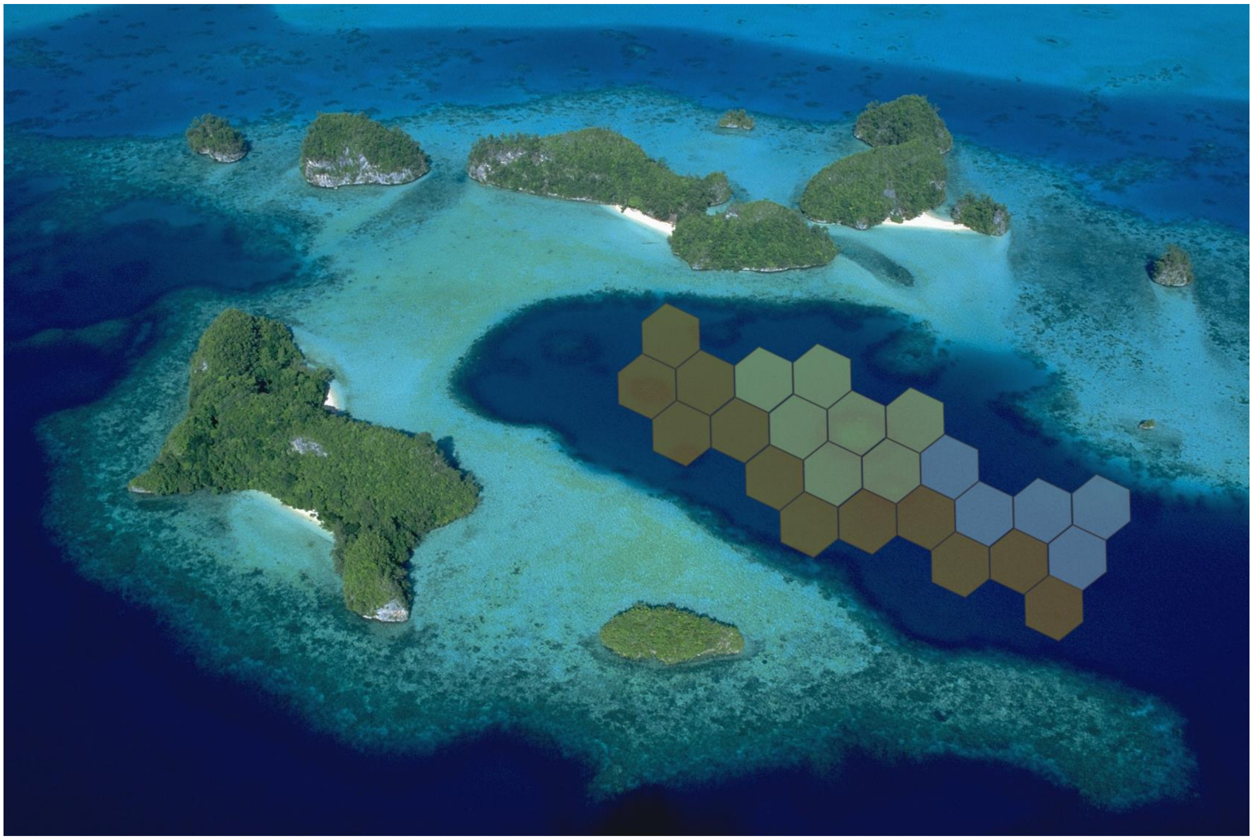
Guidance Manual for Marine Aquaculture Spatial Planning and Management In the Republic of Palau



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Environmental Quality Protection Board • Republic of Palau

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Palau Community College

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Guidance Manual for Marine Aquaculture Spatial Planning and Management in the Republic of Palau

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Republic of Palau

FOREWORD

Globally, food production systems have become strained by a changing climate and increased pressure from growing populations, urbanization, and associated pollution. In Palau, a Small Island Developing State, food security is a leading concern. With a high per capita seafood consumption and a large number of tourists visiting each year, seafood demand is high. Aquaculture has been identified as a solution to meet growing demand, supplementing the wild harvest of seafood and reducing dependence on imports.

Aquaculture in Palau has been a long-term endeavor with more than 30 years invested in the development and cultivation of various species. There have been several cycles of achievement and lessons learned as different species and techniques were demonstrated and adopted. One aspect of successful aquaculture development, which is globally recognized as a foundational consideration, is the question of "siting", or where aquaculture is located. The Guidance Manual helps to document the recipe for successful siting, a vital consideration as the industry grows.

This Guidance Manual was developed from a multi-year stakeholder-driven process and is intended to support aquaculture farmers and the National and State governments of Palau. This Manual is a technical resource to guide the sustainable development of aquaculture, balancing several considerations including water quality, sensitive habitats, economics, social, and traditional knowledge. Further development of the aquaculture industry can be supported through the adoption of good management practices, such as permitting, operational controls, and monitoring. The contents of this Manual are relevant to the lagoonal coastal waters of Palau and applicable for informing the management of marine finfish and shellfish aquaculture.

Steven Victor

Minister of Agriculture, Fisheries, and the Environment
Republic of Palau

Table of Contents

1. Introduction

1.1. Aquaculture: a global and Palauan opportunity and challenge

Aquaculture--the cultivation of finfish, shellfish, and seaweed--is currently among the fastest-growing forms of food production on earth (FAO 2018a). Already a $243.5 billion industry, the rapid growth of aquaculture holds great promise to meet the growing global demand for more sustainable forms of protein while protecting marine ecosystems. Aquaculture can occur at different scales from intensive and extensive commercial operations to artisanal, subsistence, restorative aquaculture. To date, however, commercial aquaculture production in some locations has outpaced regulation and has created environmental challenges in the process (Aguilar-Manjarrez, Soto, and Brummett 2017). These environmental challenges have included water quality impacts due to excess nutrient inputs from farms (e.g., fish and feed waste) and damage to sensitive habitats, such as coral reefs or seagrass beds. In other cases, well-managed aquaculture sectors and considerable scientific research and monitoring have provided insights into management approaches and strategies that can balance and mitigate environmental risks and impacts while allowing for sustainable aquaculture sector development.

The Republic of Palau (hereafter Palau) has been a global leader in marine conservation and environmental stewardship through actions such as the establishment of the Palau National Marine Sanctuary Act in 2015 which designated 80% of the nation's exclusive economic zone as fully protected from extractive activities, such as fishing and mining. However, Palauans consume up to 67.7 kg of seafood per capita annually, more than almost any other people in the world (FAO 2018b). The increasing number of visitors to Palau, continuing declines in reef fisheries, a projected loss of up to 25% of fisheries catch potential by 2050 due to climate change (Bell and Taylor 2015), and limited arable land for agriculture has resulted in Palau importing a substantial and increasing fraction of its food resources (86% at present). President of Palau, Surangel S. Whipps, Jr. stated "our food systems must be able to prepare for, withstand, and recover from a range of shocks and stressors so that we can continue to access safe and nutritious food, ensure nature-positive production, and achieve equitable livelihoods. Our approach is two-fold: to secure the resilience of our marine resources and reinvigorate our land-based efforts." (UN 2021).

Multiple domestic and international agencies, such as the Palau Aquaculture Center, Palau Community College Cooperative Research and Extension, United Nations Food and Agriculture Organization (UN FAO), the USDA Center for Tropical and Subtropical Aquaculture

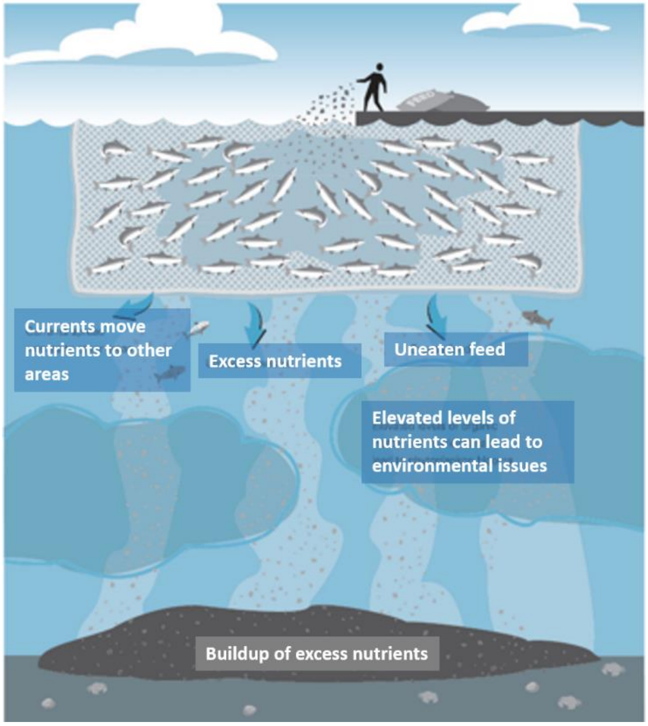
(CTSA), the Secretariat of the Pacific Community, and the Micronesian Association for Sustainable Aquaculture, have provided technical assistance to Palau for aquaculture development in recent years (Gibbons-Decherong 2018). However, aquaculture development efforts to date have focused primarily on building capacity for aquaculture production and not on building capacity for policy-based governance, export market agreements, and decision support tools for the sector, which has slowed sustainable industry development. Furthermore, hatchery development and other funding have been focused on government entities as opposed to spreading funding amongst entities including communities at higher density and reduced size so as to diversify investment and solidify the industries resources.

1.2. Mitigating risk and creating opportunities through aquaculture spatial planning

Where aquaculture operations are located is a major determinant of the environmental, social, and economic impacts of the sector. When situated in unsuitable locations that may impact sensitive habitats such as coral reefs or within important fishing areas, aquaculture can have negative impacts on the environment and create conflicts with other ocean users. The UN FAO and United States National Oceanic and Atmospheric Administration (NOAA) have developed foundational technical resources that strongly encourage the development of comprehensive spatial plans for aquaculture to ensure long-term economic, social, and environmental sustainability, particularly in light of potential climate change impacts (Aguilar-Manjarrez, Soto, and Brummett 2017). Spatial planning for aquaculture is vital to ensure equitable shared use of natural resources, the minimization of environmental interactions and impacts, and allow for industry growth. Planning for sustainable aquaculture infrastructure among current ocean use sectors (e.g., transportation, recreation, fishing, mining, and energy) is challenging, especially given the economic scale, global need, and operational space requirements of these other industries. However, safe, secure, healthy food sources and sustained economic opportunity demand the prioritization of marine aquaculture to build resiliency and feed an ever-growing global population. To meet food security goals, the allocation of space for aquaculture, based on relative compatibility with local ecosystems and other ocean uses, must be evaluated through spatial analysis.

There are many global examples of aquaculture operations that have been located on an *ad hoc* basis without employing appropriate spatial planning practices, contributing to many of the observed negative environmental and community impacts of aquaculture. An ad hoc approach, wherein suitable areas for aquaculture development are determined independently, is also often cumbersome and costly. There are also many examples where spatial planning has been employed, these approaches allow for Earth observations and other spatial data to be utilized to identify and exclude locations where potential environmental- or use-conflicts are greatest, and to identify locations of greatest opportunity for aquaculture development (e.g., locations with appropriate, stable water temperatures to support fish health). These approaches provide a multitude of environmental benefits, including minimization of potential impacts of aquaculture operations on sensitive habitats (i.e., excluding areas corresponding with, or adjacent to, these habitats), reduction of impacts of fish effluent (i.e., identifying locations with sufficient current flow to minimize benthic impacts of effluent), and reduced likelihood of fish disease (i.e., siting farms sufficiently distance from one another, and in a means that reduces the likelihood of disease or pest connectivity via currents). Further, as marine aquaculture is generally a fixed-location industry and, as such, is not transient and easily relocated, long-term sustainability requires adequate and consistent environmental conditions--particularly in light of climate change and variability--and compatible interactions with other users over both space and time. Large-scale identification of suitable locations for aquaculture operation siting through spatial planning can help inform regulatory conditions for aquaculture development that can facilitate a streamlined permitting process.

Large scale aquaculture in poorly sited areas--in waters with low current speeds and nearby sensitive habitats such as corals--can lead to negative water quality impacts and damage to sensitive habitats. Improved siting and proper aquaculture management can reduce the likelihood of these impacts



1.3. Objectives of the spatial planning and management guidance

The Government of Palau places a high emphasis on addressing the potential environmental impacts of aquaculture through effective spatial planning. However, the Government of Palau has to date lacked the tools necessary to effectively implement spatial management approaches for aquaculture. Currently, there is a need for aquaculture policy at the state and national level and enabling frameworks to grow aquaculture development. Regulations are in place for the evaluation of permit applications on a case-by-case basis, but there are no guidelines in place, and thus expectations of applicants must be managed through a tedious regulatory process which can be effected by bias.

This Guidance Manual was developed from a multi-year stakeholder-driven process. This document is intended to support the Government of Palau in developing a sustainable marine aquaculture sector of an appropriate scale. This Manual identifies appropriate areas for aquaculture development that can be supported through the adoption of good management practices, such as permitting, operational controls, and monitoring. The contents of this Manual are relevant to the lagoonal coastal waters of Palau adjacent to the major population centers and are applicable for informing the management of marine finfish and shellfish aquaculture. Enclosed (e.g., pond or tank-based) aquaculture systems also warrant appropriate management and regulatory consideration, but are not the subject of this Guidance Manual.

The objectives of this Guidance Manual are to influence policy and to fill technical gaps through the following:

- Country-level case studies showcasing successful applications of sustainable aquaculture spatial planning and management approaches,
- Palauan aquaculture status, management framework, policy gaps, the status of regulations and associated opportunities and challenges,
- Guidelines for aquaculture siting in Palau, inclusive of map-based resources derived from spatial analysis,
- Bibliography of sustainable aquaculture management references and associated technical resources.
- Curriculum development outline for higher education institute for certification and degrees in aquaculture science and business.

2. Principles of an Ecosystem Approach to Aquaculture.

The United Nations Food and Agriculture Organization (FAO) and the World Bank developed a comprehensive approach they recommend for sustainable aquaculture termed the Ecosystem Approach to Aquaculture (EAA; FAO 2010). The EAA states that aquaculture should be developed "in context of ecosystem function and services with no degradation beyond resilience; to improve human well-being with equity for stakeholders; in context of other sectors, policies, goals, as appropriate." Within this definition and approach, they outline the steps, processes, activities, and tools that governments should take in developing and implementing EAA to avoid the pitfalls of unsustainable aquaculture development, such as environmental damage and negative socioeconomic impacts. FAO makes it clear that the process of EAA is not a "what," but a "how" – a series of actions and a participatory process of how to sustainably create and manage an aquaculture sector.

We will not detail the very comprehensive step-by-step approach FAO takes to this process but will outline the stages that FAO discusses as key stages and components associated with the development and implementation of a spatial planning approach. As the reader will see, there are aspects of this approach that have already begun or have been partially completed through The Nature Conservancy (TNC) / Government of Palau collaboration (e.g. identification of potential aquaculture species, analysis of suitable areas through spatial siting). However, TNC recommends that the Government of Palau consider the full suite of elements of this approach in further developing and ultimately implementing an ecosystem-based spatial planning approach to aquaculture development.

SCOPING: EAA focuses on a stakeholder participatory approach and begins through the review of priorities for aquaculture and the identification of the relevant stakeholders for consultation. A stakeholder process should include participants that have aquaculture political authority, legal standing, property owners, information holders, and those that may not be supportive of aquaculture. This list could include, but it not limited to: farmers, fisheries, government officials, environmental non-governmental organizations, scientists, local businesses, and other marine users. The stakeholder group should define the overall priorities for aquaculture development, collect baseline data, and set objectives. This process can include reviewing current policies, regulations, and laws that are both aquaculture-specific and affect aquaculture; identifying risks and opportunities, and determining which aquaculture species and systems the group would like to pursue. (Each group will want to pursue something different, I would recommend that to make sure fewer decisions become politicized the farmers, the industry, BMR, TNC, PCC etc remain stakeholders but some of the other community groups might simply be opposed because they are opposed to any productive development in Palau.)

Status: Through a series of workshops throughout 2016 - 2022, led by PCC, TNC, and with wide participation from key stakeholders, extensive scoping has been completed.

ZONING: Once the goals and priorities for aquaculture have been determined, then the government can lead a multi-step stakeholder process to establish aquaculture zones to reduce negative social, environmental, and negative effects of aquaculture including, but not limited to environmental pollution, biosecurity and disaster risks, social use conflicts, and carrying capacity concerns. Areas suitable for the development of aquaculture should be chosen (ideally via Geographic Information Systems (GIS)) with maximum thresholds for suitability identified, analyzing factors such as bathymetry and water quality, and proximity to shipping lanes, processing and markets, infrastructure, and existing aquaculture.

Risk mapping and ecological and social carry capacity analyses for the aquaculture zones should be conducted – the former will allow for proactive management in identifying potential threats and the latter ensures that there is a maximum limit of farms in a given zone that can occur without environmental, societal, or economical damage. Additionally, aquaculture zones should ensure that there is a biosecurity and stocking strategy in place to prevent disease and should be legally designated by and regulated by the government.

Status: Through workshops held in 2019, key spatial considerations and thresholds were identified and a subsequent GIS analysis was conducted. This information is presented within this report and can be used directly to inform siting decisions and identification of aquaculture zones. Importantly, accompanying regulations are needed to support the implementation of zones, which can be informed by the case studies provided in Section 3 of this report.

FARM SITE SELECTION: Farm site selection within specified aquaculture zones is generally conducted by the private sector (with government oversight through an application and review process) that is interested in investing in and operating an aquaculture farm. Individual farm site selection can include: assessment of suitability for the specific farm site, a more detailed carrying capacity study that assesses nutrient impacts on water quality and sediments, the creation of a biosecurity and disease control plans, and obtaining legal authorization to farm generally through a lease, license, or permit.

Status: A webmap and decision support tool was created specific to this project that allows users to draw a box and produce maps. A report can be generated through this tool which could be used as part of a formal application process.

AQUACULTURE MANAGEMENT AREAS: A final component of an EAA approach to spatial planning and siting is the authorization and operation of Aquaculture Management Areas (AMA). This differs and is additive to the above in that AMAs are the process by which zoning is implemented through shared policy and allows for collective and comprehensive management of a geographic area. This process may include: determining the boundaries of the management area, encouraging a farmer's association to help provide industry representation, conducting regular monitoring of environmental impacts and overall capacity, actively controlling animal disease, recommending or requiring that better farming management practices occur, encouraging group certification, setting performance metrics that can be measured over time, ensuring proper financing for management, and setting and enforcing corrective measures.

LIMITATIONS OF APPROACH: An extensive ten-year review of the implementation of EAA approach was conducted recently in 2019 (Brugere et al. 2019), showing that EAA has raised awareness of the need and importance of an ecosystem approach and the use of spatial planning to support the management of aquaculture as a component of ecosystems. However, the review showed a lack of large-scale implementation and found that the main impediments to a successful implementation of EAA included: difficulties in managing the vast scope of aquaculture in cutting across so many administrative, legal, and institutional frameworks; lack of internal country capacity to integrate EAA without significant FAO or other organization assistance; and the complexity and cross-sectoral steps of the approach that can feel more theoretical than easily implementable.

Ultimately, the review concludes that while EAA has not been used to or been successful in addressing a country's complex institutional issues or improving aquaculture governance at a higher level, it has empowered the implementation of spatial planning and zoning (which is a focus of the above step-by-step discussion and this project) and has led to other important initiatives, such as Blue Growth. In considering the EAA spatial planning and siting approach and processes then, it is important to note that it is not a panacea for the development of a comprehensive sustainable aquaculture planning and policy framework, but should be considered as an important process in the toolkit for participatory spatial planning and siting.

3. Sustainable Aquaculture Spatial Planning and Management Case Studies

3.1. Overview

The Government of the Republic of Palau (Palau), with the support of The Nature Conservancy (TNC), has chosen to approach the management of the developing Palauan aquaculture industry through the application of spatial planning due to the myriad benefits that proper spatial planning and siting of finfish aquaculture can provide for not only coastal communities but also the sensitive marine environment. Many social, environmental, and economic challenges occur from offshore aquaculture operations that are not sustainably sited including, but not limited to: fish disease, low production, social and marine use conflicts, poor access to infrastructure that is needed for supporting in-the-water operations, and environmental challenges such as water pollution, negative impacts to wild stocks, and damage to sensitive habitats. In addition to mitigating risks and challenges, a spatial planning and siting approach coupled with strategic plans and enabling legislation can provide opportunities to create an aquaculture sector that is designed to be more resilient to climate and environmental changes and can provide increased certainty for industry and investors due to the reduced risk and increased level of information, which can lead to increased transparency and trust in the permitting process.

There are different types of spatial planning and siting tools and products including, but not limited to guideline documents and spatial decision support tools (the results of which are both outlined in this document), codified regulations, and aquaculture development zones or areas. Guideline documents and spatial decision support tools, which are created through a specialized technical skillset and with input from government and stakeholders for siting criteria, are an important first step in creating a sustainable aquaculture sector. While these documents do not delve into the more socio-economically complex policy realm of the implementation of development of aquaculture regulations and aquaculture zones, they provide a scientifically-sound foundation for future policy work. Ultimately, while the development of regulations and zoning policies may be the more time-consuming and politically difficult process, it will have the largest impact on creating a sound sustainable aquaculture management system.

However, while spatial planning and siting provide opportunities and help to address many of the major challenges associated with marine aquaculture, other central components and determinants of environmental impacts include farm management and monitoring (e.g. stocking density, feed management, escape prevention, etc.), species selection (e.g. native species, sterile species, etc.), gear type (e.g. type of netpen, mesh size, etc.), and human health protections. It is only through the inclusion and consideration of all environmental impacts, as well as social and economic considerations that a comprehensively managed and sustainable aquaculture industry can occur.

Below, we will present case studies of countries that manage a portion of their aquaculture sector using a spatial planning and siting approach. While there are many countries that manage a portion or an entirety of their finfish aquaculture sectors through spatial planning and siting, we've chosen to highlight two positive case studies of the South Australia government and the Philippines, as well as provide some overall examples of the poor environmental and social outcomes that can result without a spatial planning and siting approach.

For the positive case studies, South Australia is part of a large "developed" country that governs its aquaculture industry through an established zoning system, while the Philippines is a relatively smaller "developing" country that governs a portion of its aquaculture industry through marine parks. However, both countries, like Palau, are island nations in the Pacific and both countries have robust aquaculture industries with spatial planning and siting systems that have different elements that can be of use in considering how best to create an aquaculture regulatory system. For further case studies, we direct readers to the FAO and World Bank assessment of Ecosystem Approach to Aquaculture, which includes case studies for Chile, Indonesia, Oman, Turkey, Uganda, and Scotland's spatial planning approaches to their finfish aquaculture sectors (Aguilar-Manjarrez, Soto, and Brummett 2017).

3.2. South Australia case study

The Government of South Australia is a state within the national government of Australia, a large island nation in the Pacific that has a developed economy with strong national and local governance. At the national level, the Government of Australia provides strategic guidance for aquaculture, but has delegated the primary responsibilities for regulation and administration of aquaculture to the individual state and territory governments (Australia Government 2019). Regulating a relatively robust industry, the Government of South Australia structures the management of the aquaculture industry through a set of policies, legislation, and regulations and uses a spatial siting and planning approach to their zonal aquaculture management.

South Australia Snapshot
Aquaculture Species *Shellfish*: Pacific oysters, blue mussels, greenlip abalone *Finfish*: southern bluefin tuna and yellowtail kingfish
Primary Aquaculture Management Aquaculture Zones
Aquaculture Lease Type and Length *Production*: & 20 years, renewable Pilot: ≤ 1 year, renewal ≤ aggregate of 5 years *Research*: 5 years, renewable for duration of research project *Emergency*: ≤ 6 months, renewable for duration of emergency
Aquaculture Lease/License Cost Species-dependent (ex. Fish: US$5,041 license; US$2,480 lease)
Annual Aquaculture Revenue US$157M
Number of Marine Aquaculture Farms 424 (80.2% oysters; 7.5% mussels; 5.4% non-tuna marine finfish; 3.3% tuna; 3.6% other)
Coastline Length 3,147 miles
Marine Aquaculture Employment 637 on-farm; 231 "downstream" (retail, foodservice, local transport)
South Australia Population 1.677 million

Policy and Legislation

The marine aquaculture industry and zoning process is anchored in the South Australia Aquaculture Act of 2001 (SSAA) – however, this is a piece of policy that is not static and has been amended relatively regularly to reflect updates to aquaculture management in 2003, 2005, and 2015 (Aguilar-Manjarrez, Soto, and Brummett 2017). The SSAA's objectives are: "to promote ecologically sustainable development of marine and inland aquaculture; and to maximize benefits to the community from the State's aquaculture resources; and otherwise to ensure the efficient and effective regulation of the aquaculture industry" (South Australia Aquaculture Act 2011).

In addition to laying out the overall objectives for the State's aquaculture, the Aquaculture Act 2001 authorizes aquaculture to officially occur, defines what constitutes aquaculture (marine and land-based), defines their objective of ecologically sustainable development in a way that is consistent with the FAO's definition for Ecosystem Approach to Aquaculture, creates aquaculture zoning policies, provides leases and license requirements, and requires compliance with various environmental policies (Primary Industries and Regions South Australia 2016).

Aquaculture Zones

Arguably one of the most important sections of this Act and what marks South Australia as a leader in aquaculture management is the commitment to sustainable aquaculture management and the creation of aquaculture zones. While aquaculture is technically permitted in all State waters other than established sanctuary zones, aquaculture exclusion zones, and other various "no-go" areas, it is only through their designated aquaculture zones that the approval for aquaculture leases is encouraged and more streamlined. This streamlined process is important as it allows for increased certainty for the aquaculture industry and provides a clear and transparent avenue for development in areas that have been pre-prioritized, analyzed, and chosen by the government.

Aquaculture zone policies are established by the government and include a public consultation process. Prior to and in preparation for the establishment of aquaculture zones and exclusion zones, environmental, economic, and social conditions of the marine waters are assessed and the State "must conclude that using the area for the purposes of aquaculture will maximize benefits to the community" (Primary Industries and Regions South Australia 2016). There are currently 10 aquaculture "zone policies" within South Australia, which the State regularly reviews to ensure that the area's policy is still ensuring maximized use of the marine waters. These zone policies are associated with specific geographies and include both aquaculture zones and aquaculture exclusion zones, as well as which species are allowed to be farmed within the policy geography. For example, the Eastern Spencer Gulf Zone policy was created in 2005 with amendments in 2017, includes 10 aquaculture zones and 4 aquaculture exclusion zones, and allows for the farming of finfish, bivalve mollusks, and algae (Primary Industries and Regions South Australia 2017). This is similar to the FAO framework of Aquaculture Management Areas where zones are grouped in geographically-distinct areas and policies are created for collective and comprehensive management.

Permitting and Leases

After an aquaculture zone is established, the State requires that a competitive "public call" process occurs for lease applications. Once the public call for leases has been issued for an aquaculture zone, then all industry applications are reviewed by the State's Aquaculture Tenure Allocation Board (ATAB). The ATAB determines which applicants will "maximize benefits to the community" (a main objective within the 2001 Aquaculture Act) and then provides the top applicants to the Primary Industries and Regions South Australia Fisheries and Aquaculture department for review.

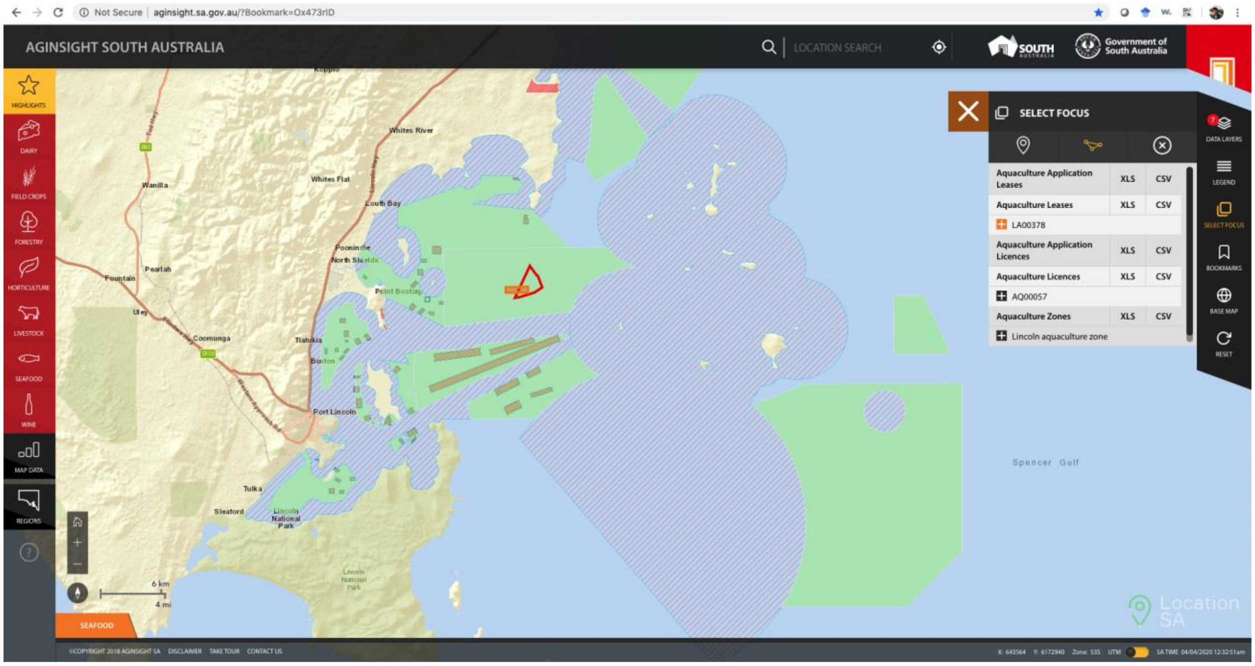
The State issues four types of marine leases within and outside of aquaculture zones:

- *Production leases:* this lease is issued only within aquaculture zones, is for commercial purposes and has the longest lease term at a maximum of 20 years. This lease is eligible for renewal and can be transferred to another party if consent from the government is provided.

- *Pilot leases:* this lease is issued only outside of aquaculture zones, is for testing the development of aquaculture in new waters and can hold a term of up to 1 year. This lease is eligible for renewal for a maximum total term of five years and may be converted to a production lease if certain conditions are met.
- *Research leases:* this lease can be issued regardless of whether it occurs in an aquaculture zone, is for conducting aquaculture research into how to improve production and has a lease term of up to five years. This lease is eligible for renewal as long as the research project period continues.
- *Emergency leases:* this lease can be issued regardless of whether it occurs in an aquaculture zone, is designed for emergency situations where the environment or an endangered stock needs to be protected and has a lease term of up to six months. This lease is eligible for renewal as long as the emergency continues (Primary Industries and Regions South Australia 2016).

Public Transparency

The Government of South Australia maintains an online GIS mapping portal that provides spatial and associated data for various industries and subject matters (e.g. infrastructure, climate, land management; AGINSIGHT South Australia 2020). Within their business and industry section, any user can explore the active aquaculture zones and leases within the State marine waters. The interface allows a user to zoom into an area of interest, see the aquaculture zones and aquaculture exclusion zones, and click on any active aquaculture lease to obtain farm-specific information such as registration ID, type of lease, species grown, farm size, and lease approval and expiration date.



Demonstration of the Government of South Australia aquaculture map viewer tool*, which provides information on managed aquaculture zones, exclusion areas, marine reserves and other key features needed for spatial planning of the aquaculture sector. Additionally, information on proposed and issued permits, and lease and license terms are provided for existing aquaculture operations.*

Each farm also provides at least two external links to the farm license and the environmental monitoring program results as part of the Aquaculture Public Register. The license includes the name of the license holder, approved species to farm, the specific farm coordinates, and lease conditions, which include the telephone number that was provided to the government in case of entanglement or escapes. The environmental monitoring report is generally brief but describes whether the last assessment was rated between levels 1 through 3 – with level 1 indicating that monitoring showed acceptable levels of environmental impact, level 2 indicating levels of environmental impact was beyond acceptable levels and follow-up from management was required, and level 3 indicating that environmental impacts were unacceptable and immediate management action was required.

This level of transparency can build public confidence in an aquaculture industry as it allows the public to: see that an assessment of the marine environment has occurred to set aside specific areas for aquaculture development and prohibit development in other areas, clearly understand the active farming leases and their ongoing requirements, be able to obtain the name and even contact information for each farm. This public transparency is also beneficial for the industry that can conduct research online to assess if there is room within an aquaculture zone to apply for a lease, what other farms and which aquaculture species will be in close vicinity to their potential farm, and what type of lease conditions may be imposed upon them.

Associated Legislation, Regulations, and Monitoring

While beyond the spatial siting and pre-permitting scope of this document to discuss, it should be noted that the Government of South Australia's policy and legislation is coupled with the more detailed Aquaculture Regulation 2016 and an Environmental Monitoring Program, and works in conjunction with other Acts focused on fisheries management, environmental protection, navigation, development, and livestock. All aquaculture farms are required to provide an environmental monitoring report each year. In addition to these regulations and requirements, the State protects itself financially by requiring that marine license holders provide a bank guarantee of $10,000 and hold public liability insurance of $10 million.

3.3. Philippines case study

Philippines Snapshot
Aquaculture Species *Shellfish and other*: seaweed, tiger prawn, oyster, mussel, mudcrab *Finfish*: milkfish, tilapias
Aquaculture Management Mariculture Parks / zones and non-zonal areas
Aquaculture Production 2.3 million metric tons
Annual Aquaculture Revenue: US$2.18M
Average Aquaculture Yearly Wage US$2,592 (compared to national average of US$2,412)
Number of Aquaculture Farms 148,694 (50% fishponds, 32.6% seaweed, 13% fish cages and pens, 4.4% other
Coastline Length 10,849 miles
Aquaculture Employment 131,312
Philippines Population 106.7 million

The Philippines is a relatively smaller "developing" island nation in the Pacific that governs a portion of its aquaculture industry through marine parks. The Philippines ranks 5th in the world in finfish aquaculture production, producing 379,700 tonnes annually, with the FAO projecting that they will increase their finfish aquaculture production 36.3% by 2030 (FAO 2020). Similar to Palau, finfish comprise the main source of protein for Filipino diets. The country's aquaculture industry is valued at US$2.18M annually and farms the key species of milkfish, tilapia, seaweed, tiger prawns, oysters, mussels, and mudcrab. The federal Bureau of Fisheries and Aquatic Resources first piloted "mariculture parks" near Samal Island in Davao del Norte in 2001 (Guerroro 2018) and there are currently 60 mariculture parks in the country (Lopez, 2017).

Policy and Legislation

The Government of the Philippines through the Department of Agriculture's Bureau of Fisheries and Aquatic Resources (BFAR) manages the aquaculture industry. The 1998 Philippine Environmental Code is the umbrella policy for all-natural environment use in-country and requires the further regulation of aquaculture. The 1998 Philippine Fisheries Code provides more detailed policies regarding both wild fisheries and aquaculture, including establishing national and municipal management councils to create development plans and advise on policy. Nested under the codes is the Implementing Rules and Regulations of 1998 which provide regulations and guidelines, which contain detailed fisheries orders (FAO 2020). Aquaculture in the Philippines has a long history in being practiced for over 600 years but began first intensifying in the 1970s with the advent of carp and milkfish culture. Due to a mainly unregulated finfish sector that allowed cages and pens to be installed anywhere, there were significant environmental and water quality degradation issues in marine waters and significant fish kills. After public concerns over these environmental and industry problems, the government created and promoted the 2006 Fisheries Office Order NO. 317 which provided a new approach to fish farming through the establishment of mariculture parks (Ferrer et al. 2017).

Mariculture Parks

The Mariculture Park Program was established not only for existing environmental concerns, but to address coastal community poverty, supplement the dwindling capture fisheries returns by promoting aquaculture as an alternative livelihood, create a shared area with infrastructure to support economic stability, and use more environmentally friendly farm practices. In establishing a mariculture park, the geographic area goes through the following steps: site selection, prioritization, and preliminary site suitability; consulting with the public; creation of resolutions and ordinances through the municipality; creation of a development plan and an environmental risk assessment; development of an Executive Management Council to manage the area; surveys for environmental compliance, a subdivision plan, and creating a site-specific layout for the moorings and cages; completion of trainings; and then issuing the leases/permits so that full operation and regular monitoring can occur (Ferrer 2017).

In promoting these mariculture parks, the government incentivizes local investors and farmers via an innovative cost-sharing model wherein they provide *shared and government-funded infrastructure*. In addition to providing shared infrastructure (mooring, navigation, and docking), the local government provides shared utilities (onshore warehouse, cold storage), shared services (technical assistance, marketing assistance, and feed and cage materials available for farmers to purchase) and pre-selected sites for investors and farmers.

Another interesting item of note in how the Philippines creates and regulates its mariculture parks is that the government has - in the absence of often very expensive (and sometimes inaccurate) models – determined a proxy for determining the carrying capacity of finfish aquaculture. While some detailed carrying capacity modeling has occurred at the park level, the government has an alternate and general policy in place to limit the maximum number of cages that should be placed per park without causing environmental damage – they require aquaculture to take place in no more than 5% of the aquatic body (Aguilar-Manjarrez, Soto & Brummett, 2017).

Permitting and Leases

The local government provides the leases to the farmers, which include setting the spatial confines of the site, the species cultured and gear type uses, a time limit, set fees, and performance and termination requirements. There is a caveat that if a leased mooring space does not have a cage installed within 6 months, then the local government can award the lease to another person.

Mariculture parks have selected sites and rankings for small, medium, and large-scale investors and the government grants leases to farmers based on the below prioritization:

- First Priority: Local fishers/residents and Filipino companies operating within the municipality where the mariculture zone is located
- Second Priority: Residents or Filipino companies operating within the province or region where the mariculture zone is located
- Third Priority: All other Filipinos or Filipino companies in the Philippines
- Fourth Priority: Foreign nationals or companies are allowed to engage in natural resource development following the existing legal framework. (Aguilar-Manjarrez, Soto & Brummett, 2017, p.296)"[i]

The above ranking demonstrates the government's priority to help develop and support local coastal community livelihoods.

Public Transparency

The Philippines government publishes a large amount of aquaculture production and revenue information online regarding their fisheries and aquaculture industries, including yearly situation reports on production by species and location to an online accessible database that provides detailed yearly and quarterly information on their Agriculture, Forestry, and Fisheries (which includes aquaculture) department, among other industries. A stated goal of the Philippine Statistics Authority, as the statistical entity for the national government, is to promote open access to national data and encourage other nations to do the same.

While there is a significant amount of information online for production and revenue, there is not the same level of information accessible (at least in English) on the mariculture park regulations, leasing conditions, and environmental monitoring.

Challenges

While mariculture parks are being championed by the government for their myriad potential and benefits over farming in non-zonal areas, there have been challenges in implementation. A 15-year review of the mariculture park program was recently published by the Economy and Environment Program for Southeast Asia (Ferrer, Francisco, Predo, Carmelita & Hopanda, 2017) and they found that challenges included low farmed species diversity, low participation overall, and despite the focus on providing fishers alternative livelihoods in their local area, low participation by local fishers. They identified the main challenges to the industry as high equipment and operational costs for fishers, expensive fish feed, low availability of fingerlings, the prevalence of disease, and increased climate change vulnerability (e.g. increasing threat of typhoons damaging gear), theft, and some poor siting conditions. They recommend interventions to help overcome these challenges, such as:

- creation of hatcheries to provide more and consistent supplies of fry;
- improvements to and BMPs for feed to encourage competition, make feed less expensive, and encourage proper feeding techniques and feed storage;
- additional research to help address technical farming challenges and;
- increased regulatory penalties for negative environmental impacts.

4. Palauan Aquaculture Situational Analysis 2020: Demonstrated Need for Distribution and Use of This Guidance Manual

Here, we provide a brief background of the history and current status of aquaculture in Palau and describe opportunities and risks. Gibbons-Decherong (2018) provides an in-depth baseline information report on the policy and activity of aquaculture in Palau. The information provided below benefits from this in-depth report, and we guide the reader to review this report for more information as needed.

4.1. Background

Palau has had a history of aquaculture operations that started during the Japanese colonial period before World War II, but these largely faltered after many Japanese left the islands (Gibbons-Decherong 2018). The Micronesian Mariculture Demonstration Center was founded in the 1973 by the Pacific Fisheries Development Foundation (U.S. National Oceanic and Atmospheric Administration), the U.S. Department of Interior, the United Nations Food and Agriculture Organization, and other international agencies made strides in the successful culture of all seven Palau species of *Tridacnidae* giant clam; (Heslinga, Watson, and Isamu 1988). In recent years, aquaculture has been identified as a priority for the national government of Palau, indicated by its inclusion as a priority in the Palau Climate Change Policy 2016 as a developmental sector to improve food security, and in the Palau Trade and Investment Policy Framework 2017 as an opportunity to supplement marine resources and generate sustainable livelihoods for Palauans (Gibbons-Decherong 2018). Further, the Palau National Biodiversity Strategic Action Plan identifies aquaculture as an opportunity to relieve reef fishery pressure and provide an alternative livelihood to fishing activities.

Within the past several years, renewed efforts by government and non-government organizations and agencies have sought to expand the aquaculture sector in Palau. Palau Bureau of Fisheries (BOF) in recent years has focused on expanding hatchery production of the most established aquaculture species in Palau--giant clam production--with the support of a grant from the Governments of Japan and Taiwan to renovate the existing hatchery. Further, a low-interest loan program administered by the National Development Bank (NDBP) of Palau was established and is available to prospective aquaculture farmers. Recently, BOF has also focused on finfish production at the Palau National Aquaculture Center (PNAC) and has supported local aquaculture of rabbitfish (*Siganus lineatus* and *S. fuscescens*) with the support from the Governments of Japan and Taiwan. Palau Community College (PCC) has also been producing fingerlings and conducting aquaculture research focused on identifying potential species of interest and associated best hatchery and production methods.

4.2. Current status

Financing: Palau negotiated and received a USD 5M loan from Taiwan in 2016 as a financial instrument intended to stimulate the development of the agriculture and aquaculture sectors for Palau (Gibbons-Decherong 2018). Administered by the National Development Bank of Palau (NDBP), the funds serve as a lending program available to farmers with a current interest rate of 4.5%. Eligibility for borrowing includes individuals, businesses, state government, and NGOs. Based on the program's current lending trends, the Bank is expecting that this loan program will continue to be available through 2021. Utilization of the loan program for aquaculture has been limited, with 26% of the total sum of loans (~$450K) closed between 2016 and 2018 related to aquaculture operations. A high collateral requirement, lack of clear permitting process, and environmental requirements were noted as a constraint of use of the loan program.

Species of Interest: Giant clams have been the primary aquaculture species produced in Palau with full hatchery services and seedlings in distribution since the Micronesian Mariculture Center was opened in the early 1970s (Heslinga, Watson, and Isamu 1988). However, the level of clam supply has not historically been able to fully meet export demand for the aquarium trade. The Mariculture Demonstration Center Facility was expanded in November 2018 with a grant from the Government of Japan. The Bureau of Marine Resources anticipated a drastic increase in capacity to supply giant clam seedlings from the former 200,000 per year to up to 1,000,000 seedlings available for distribution to farmers on an annual basis. There are currently around 60 giant clam farmers in Palau farming at 54 sites, with a total of ~80,000 clams in production. Giant clam seeds had historically been given to farmers at no cost for several decades, however, a change in policy in June 2014 resulted in farmers paying for seeds produced at the hatchery, which contributes to the Giant Clam Seed Sustainability Project Fund.

Finfish aquaculture is of increasing interest, with the PCC supplying 10,000 fingerlings annually since 2007 and the PNAC established in 2010 with the support and continued technical assistance from the Government of Taiwan to conduct research into their production. Focal species include grouper, (*Epinephelus fuscoguttatus*), rabbitfish (*Siganus lineatus, S. fuscescens*), clownfish (*Amphiprion ephippium*), and tiger prawn (*Penaeus monodon*). Rabbitfish aquaculture has been identified as the most locally appropriate and economically viable target species and is a fairly new undertaking that the BOF began supporting in 2015. Since 2015, hatchery production of rabbitfish fry has increased from 1,300 to 4,000 in 2016 to 28,000 in 2017. At this time, the types of species actively farmed for aquaculture for both domestic and international markets are limited to five species of clams, rabbitfish, and milkfish. A multi-stakeholder workshop conducted in 2017 identified the following 5 species as the highest priority candidates for food security and livelihoods in Palau: sea cucumber, milkfish, giant clam, rabbitfish, mangrove crab, and red snapper (*L. gibbus*).

Markets: The single main aquaculture species produced and exported commercially and with the widest international reach are giant clam species (Gibbons-Decherong 2018). The main market for giant clams is the aquarium sector. Rabbitfish were also exported commercially, primarily to Guam, however, it is likely more are supplied from wild harvest than from aquaculture. Milkfish and rabbitfish are currently the two main farmed fish for supply in the domestic market, with milkfish dominating the market (14 tonnes in 2017, FAO 2018). Milkfish farming is more mature, one commercial operation has been providing a consistent supply of fish for over 10 years. Milkfish are currently sold locally at USD 2.75 per pound for bone-in fish, and USD 2.85 for deboned fish. Fish purchased at the farm site by locals receive a USD 0.25 discount and are not taxed. Rabbitfish sales have recently begun and the intermittent availability of fish suggests farms are still being trialed and a consistent supply and schedule of sales have not been established. Farmed rabbitfish is sold between USD 2.00 - 3.00 per pound. The most recent estimates of total aquaculture production for Palau in 2014 estimate: 22 tonnes of milkfish worth USD 200,000 at the farm gate, and 16,000 giant clams worth USD 85,000.

Feed Supply: Giant clams do not require external feed inputs--instead of consuming naturally available plankton within the water column--thus making the cultivation of these species a highly favorable candidate for Palau’s aquaculture sector. Other aquaculture candidate species farmed in Palau, such as milkfish and rabbitfish, require external inputs of feed. At this time, there are no fish feeds manufactured domestically and they are mainly imported from Taiwan and the Philippines for purchase by farmers. Feed from Taiwan can be purchased at the BOF for a subsidized price of $0.80 per kg, while a small feed store imports alternative feed from the Philippines.

Technical Capacity: BOF under the Ministry of Agriculture, Fisheries, and the Environment is responsible for exploring, surveying, developing, managing, and conserving all nearshore marine resources. In addition to operating hatcheries, other services provided by BOF include marine surveys for interested farmers, farm monitoring, supply of seedlings, assistance with the initial permitting process for aquaculture farming in Palau, and administering the CITES permit for export. In addition, through a partnership with the Taiwan Embassy, Palau established the Palau National Aquaculture Center where the Government of Taiwan is providing aquaculture experts to work with BOF on hatchery production and training of fish farmers. Palau Community College Cooperative Research & Extension is a Land Grant System housed at the Palau Community College as a full department to implement an Agriculture Experiment Station, Cooperative Extension Service, and Residential Instruction of the Micronesia Land Grant Programs in Palau. The department operates a Multi-Species Hatchery and a Research and Development Station bolstering Palau's capacity in aquaculture. The Multi-Species Hatchery--since its establishment in 2010--has continued to augment seed stock supply for rabbitfish, grouper, milkfish, and mangrove crabs for prospective fish farmers. The hatchery is also utilized as a demonstration and training facility for those in the community who are interested to learn and developing their skills in the seed production of marine organisms. The hatchery facility operates an integrated broodstock, nursery, natural food, and larval production. It also houses a laboratory for researchers and extension agents. A phycology lab is provided for microalgae used as natural food for fish larvae grown and maintained. A few bigger private aquaculture enterprises such as BIOTA and Ngerdubch Corporation each have extended capacity to provide technical support to upcoming farmers or smaller operations and are willing to help. The Palau Aquaculture Cooperative Association (PACA) also assists its members both technical and administrative assistance. There is a need for PCC to develop a formalized aquaculture education and training program in conjunction with BOF and the Marine Science department of PCC. The program could provide hands and classroom training to build vital skills for the next generation of aquaculture farmers in Palau.

4.3. Aquaculture legal framework

Gibbons-Decherong (2018) provides a detailed summary of the legal framework of aquaculture in Palau, which is summarized below. The foundational legislation for marine resources in Palau is the Marine Protection Act of 1994. At present, there is no national legislation in place to call for the development of aquaculture as a sector. However, there are a number of national policy documents which recognize the potential of aquaculture and identify a strategic role for aquaculture in other national focal areas such as climate change and the protection of biodiversity.

Legal frameworks applicable to the management and siting of aquaculture (adapted from Gibbons-Decherong (2018)):

The Constitution of Palau	• Subject to national regulation, the states own the living and non-living marine resources from the land up to twelve nautical miles seaward from the baselines. • The national government owns and manages the resources outside of twelve nautical miles. • The national and state governments are responsible for managing all living and non-living marine resources for the general welfare and security of the citizens of Palau. • Traditional fishing rights and practices are not to be impaired. • The conservation of the natural environment shall be undertaken for the economic benefit, health, and social welfare of the citizens of Palau (Kuemlangan, 2004)
Marine Protection Act of 1994 Title 27 Division 2 Chapter 12. (later referenced amendment RPPL 7-43) Restructure of the Bureau of Marine Resources through executive order no. 283 in 2010	• Institutional and regulatory framework for the management of marine resources. • Management research and conservation of marine resources through national management and co-management with states. • Development and promotion of sustainable aquaculture activities. • Development of near shore fisheries resources. • Collection and analysis of all forms of marine resources.
Environmental Quality Protection Act Title 24 PNCA and the Marine and Fresh Water Quality Regulations	• Especially for aquaculture, these regulations are applied in the permitting process for aquaculture farm applications.
Convention on International Trade in Endangered Species (CITES) July 2004: Palau's entry to the Convention includes 28 species, 6 of which are clam species.	• Protects against or controls international trade of endangered species. • Requires listing of species. • Requires compliance with stringent import/export imperatives in order to trade in endangered species where this is allowed.
Palau Climate Change Policy 2015 REF: PCCP 2015, page 16	• Palau Government's Priority Intervention: Implement the National Policy, Institutional Framework, and Strategy for Resilient Agriculture & Aquaculture to improve farm production

National Biodiversity Strategic Action Plan (CBD) REF: NBSAP, page 18	● Objective 5.2: Establish guidelines and standards to ensure sustainable aquaculture, agriculture, and forestry development and management.
DRAFT Bureau of Marine Resources 5-Year Strategic Plan, 2013 – 2018	● Five areas are identified as key in the draft plan. Key area 3 calls for the "development and promotion of sustainable aquaculture opportunities"
Achieving Resilient Agriculture and Aquaculture: a national policy for strengthening food security in Palau as a priority climate change adaptation measure 2015. REF: ARAA 2015, pages 29, 32-33	● Ecosystem Resilience: Component 6, Natural Resource Management Goal: By 2020, 50% of Palau's agriculture and aquaculture farms are sustainably managed. ● Objective 6.1: By 2020, a 25% increase in existing aquaculture operations suitably located & managed in the seascape. ● Economic Resilience: Component 8, Government Investment ● Goal: Government and private sector investment in local aquaculture and agriculture producers and products are strengthened and enhanced. ● Objective 8.1: By 2020, to raise at least $500,000 for MNRET's Agriculture and Aquaculture Revolving Funds. ● Objective 8.2: By 2015, establish a Guarantee Program for loans to local commercial farmers. ● Objective 8.5: By 2015, grants are available for eligible agriculture and aquaculture programs through the PAN Fund ● Objective 8.7: By 2016, establish tax incentives for farms.

4.4. Aquaculture challenges in Palau

Despite the clear commitment to aquaculture development in Palau, there still exist many challenges which have kept aquaculture from advancing into an organized formal sector and have restricted the sector from gaining significant economic traction (Gibbons-Decherong 2018). Different stakeholders identify various challenges, including:

1. Low capacity of technical expertise and resources to grow the sector including the breeding, rearing, harvesting, and marketing of prime aquaculture products such as clam and milkfish.
2. Informal nature of the sector, such that administrative processes, data collection and information management, and access to farm space are not systematic or standardized, therefore information is not readily available to the public.

3. BOF's identified Palau's environmental regulations as a challenge to aquaculture management, particularly around permitting and identification of suitable sites for aquaculture operations. This has been repeatedly expressed as a main challenge also by farmers.
4. A lack of formal policy, legislation, planning documents etc. specific to aquaculture policy and management.
5. The United Nations Food and Agriculture Organization (FAO) assessment noted two important actions deemed necessary to develop the aquaculture sector: (a) for research and development to be done in collaboration with the private sector and for the private sector to carry on the upscaling of a pilot project to commercialize scale, and (b) the more fundamental need to abandon the development of species based solely on their biological attributes in favor of an integrated approach.
6. Economics of logistics associated with the remote island location of Palau hampers the profitability of aquaculture operations due to the high costs of importing feed and exporting production. Low local prices of wild-caught seafood also limit the profitability of aquaculture production.

5. Guidelines for Aquaculture Spatial Planning in Palau

The principles and guidelines described below were developed through an iterative process throughout 2019 and 2020 that involved input from key stakeholders. Participants included representatives of the Environmental Quality Protection Board, Bureau of Marine Resources, Palau Conservation Society, Palau Community College, The Nature Conservancy, and local aquaculture farmers. Workshops were conducted in Koror (and remotely) during February and October 2019, and April 2020. Through this process, we have collaboratively (1) determined guiding principles; (2) reviewed available data and key criteria; (3) identified specific criteria and associated distance-based rules (Table 1); (4) conducted a GIS-based spatial analysis to identify the most and least suitable areas for aquaculture operations; and (5) are now in the process of reviewing and interpreting the results.

5.1. Introduction

Unplanned aquaculture development around the world has been associated with significant environmental consequences, including habitat destruction, nutrient pollution, and the introduction of non-native species (Aguilar-Manjarrez, Soto, and Brummett 2017). Conversely, well-planned aquaculture development can minimize ocean user and environmental conflict while ensuring farms are sited in areas with a high likelihood of business success--achieving a triple-bottom-line of positive economic, environmental, and social outcomes associated with aquaculture development. Recent advancements in geospatial technology paired with successful aquaculture spatial management examples from multiple countries around the world have resulted in clear approaches and frameworks for aquaculture spatial planning and management that can guide future development (Gentry et al. 2016).

Specifically, the 2017 Aquaculture Zoning, Site Selection, and Area Management Under the Ecosystem Approach to Aquaculture guidebook (Aguilar-Manjarrez, Soto, and Brummett 2017) suggests that the most effective process for aquaculture spatial planning and management consists of the following key steps, as also represented in Figure 5.1:

1. *Identification of areas suitable for aquaculture operations,*
2. *Consideration of opportunities, issues, and risks in delineating aquaculture zones,*
3. *Broad carrying capacity estimation for identified aquaculture zones,*
4. *Evaluation of biosecurity and zone management strategies, and*

5. Legal designation of zones for aquaculture

Importantly, successful implementation of this framework requires a process that is science-based, but also inclusive of key stakeholder input, adjustment, and refinement to match the needs of the regulatory and sociocultural situations.

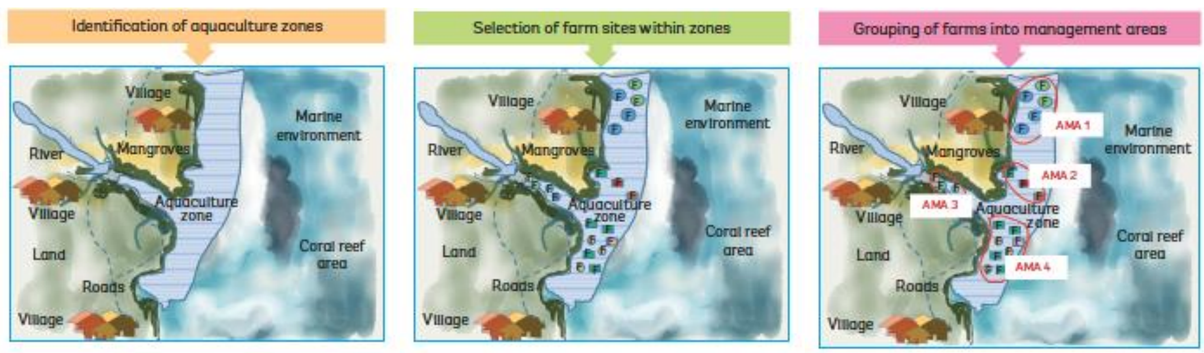
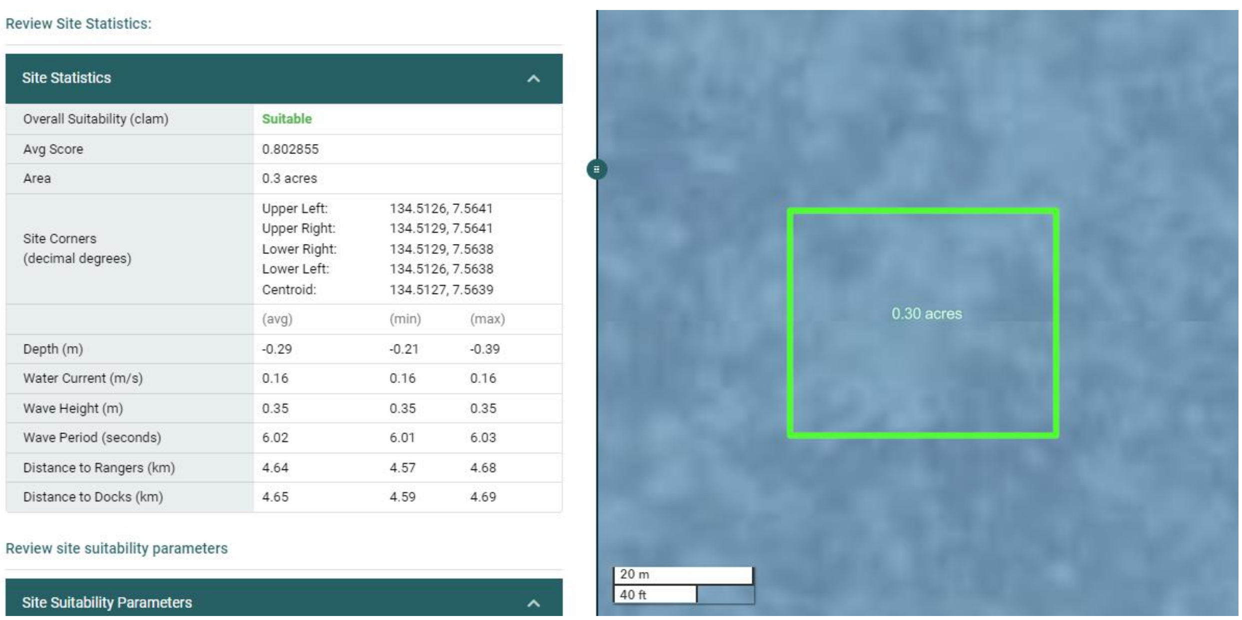


Figure 5.1. Process of identifying and managing aquaculture zones *(adapted from Aguilar-Manjarrez, Soto, and Brummett 2017).*

Identification of suitable areas for aquaculture operations requires careful consideration of the balance of relevant environmental, social, and business considerations that can be integrated within a map-based analysis and decision-support process. Environmental factors include those relevant to identifying where aquaculture operations are likely to be least impactful (e.g., avoiding coral reef areas, appropriate depth, and current regime to avoid waste accumulation). Social factors include those where impacts on existing uses of ocean space are avoided (e.g., avoiding navigational routes, important cultural areas). Business-relevant considerations include those that can improve the likelihood of financial viability of aquaculture operations (e.g., distance to markets or key infrastructure, like seafood processing).

A process driven by a combination of existing regulations, scientific guidance, and stakeholder feedback is necessary to determine rules for defining how each of these considerations individually relates to the appropriate siting of aquaculture operations. As two examples, existing regulations may exclude development activities (such as aquaculture) within 500 meters of vessel navigational channels, or guidance based on the best available scientific data may suggest aquaculture operations should be at least 200 meters from coral reefs to avoid environmental impacts. Within a GIS spatial analysis framework, these rules can be numerically applied to spatial data representing these factors, and these individual factors can be integrated and combined to identify the most appropriate locations for aquaculture operations inclusive of all relevant environmental, social, and business considerations.

Information derived from aquaculture spatial planning analyses can be used directly to inform site-specific permitting decisions and can also be integrated within a more holistic zone-based management plan (for Palau, this would require the establishment of additional supporting policy or regulations). A zone-based management plan includes the identification and delineation of broader zones suitable for aquaculture operations wherein sites for individual farm development can be selected. As described within the case study examples in Section 3, a zone-based approach has multiple advantages relative to other approaches that can result in an efficient process that can improve the public, industry, and regulatory confidence in permitting decisions. Regulators and affected stakeholders must carefully balance the opportunities, issues, and risks associated with the application of a zone-based approach. As described in Section 5.4, additional considerations around carrying capacity estimation for identified aquaculture zones, biosecurity and zone management strategies, and legal designation of zones for aquaculture represent key additional steps to implementing and operationalizing a spatial management approach for aquaculture.



Demonstration of the Palau Aquaculture Suitability Tool*, which provides information on site selection, coordinates, depth, water current, wave height, and other key features needed for spatial planning of the aquaculture sector.*

5.2. Guiding principles of aquaculture spatial planning

Environmental guiding principles

Aquaculture operations should be sited where farming activities--including establishment, existence, maintenance, and harvest of farms-- avoid negative impacts to the surrounding environment, including sensitive habitats such as coral reefs or mangroves.

- Construction of farms in sensitive habitat areas can result in direct removal of these habitats, such as destruction of mangroves, or damage to coral reefs or seagrasses through the placement of anchors or moorings and subsequent shading due to the presence of farm structures.
- The operation of large farms in sensitive habitat areas can result in the deposition of excess nutrients, such as fish waste and excess feed.

Aquaculture operations should be sited where currents and depth are sufficient to ensure excess farm nutrients do not accumulate and are dispersed.

- Farms should be located in sufficiently deep waters with sufficient current speeds to ensure fish waste and excess feed do not accumulate directly beneath farms.

Cumulative impacts--or the combined effect of multiple aquaculture operations resulting in a greater combined environmental effect than an individual farm--should be considered when siting individual aquaculture farms and considering management of the entire sector.

- Improved siting of aquaculture operations can minimize environmental impacts, but environmental impacts--such as increased nutrient input and disturbance to seafloor ecosystems--are still possible and necessitate monitoring, mitigation, and adaptive management (i.e., management approaches that are responsive to changes in ecosystem conditions).

Social guiding principles

Aquaculture operations should be sited where farming activities avoid negative impacts to existing commercial, cultural, governmental, or other human uses of ocean space.

- Farm operations should not be located in areas of conflict with existing human uses, such as navigational channels for vessels, important dive or fishing areas, and culturally significant areas. Operations should also not be located where known hazards to moorings and other farm equipment exist, such as in areas of unexploded ordnances.

- Careful attention should be paid to the determination of appropriate distances from these existing uses to reduce conflict of establishment and management of farm operations.

Business guiding principles

Aquaculture operations should be sited in areas with the greatest potential for business success, in the nearest proximity to supporting infrastructure and markets.

- Farm operations should be located where workforce access to farm sites is possible (e.g., adjacent to docks) and supporting infrastructure is available (e.g., hatchery access, cold storage for processing of harvest).
- Farm operations should be located where access to markets for the sale of harvest is efficient.

5.3. Aquaculture spatial planning guidance for Palau

The guidance described below was developed through an iterative process throughout 2019 and 2020 that involved input from key stakeholders, including aquaculture farmers, the Environmental Quality Protection Board, Bureau of Fisheries, Palau Conservation Society, Palau Community College, and The Nature Conservancy. Guided by sustainable management examples from around the world and refined through workshops and subsequent discussions, key factors of relevance for aquaculture spatial planning in Palau were identified (Table 1). Distance rules define how far aquaculture operations should be situated in relation to a given feature. Where regulations do not exist to specify distance rules, examples drawn from other countries were used to guide discussions with key decision-makers to define appropriate distances for the situation in Palau. Certain factors were considered by the stakeholder group but were not included due either to their lack of direct relevance to siting aquaculture operations or a lack of robust underlying data to support their inclusion (Appendix 8.2)

Within a GIS spatial analysis framework, these rules can be applied to spatial data representing these factors, and these individual factors can be integrated and combined to identify the most appropriate locations for aquaculture operations inclusive of all relevant environmental, social, and business considerations. Appendix 8.3 provides an in-depth overview of the technical methods utilized in the spatial analysis described here. The output of this analysis provides insights into areas highly suitable for aquaculture operations, as well as those where aquaculture operations should not be sited due to the presence of one or more conflicts. Importantly, the below-described analysis focuses largely on environmental, natural resources, social and cultural, infrastructure, and navigation and shipping. Additional opportunity-based analysis can be conducted, taking into account business-relevant considerations such as distance to docks and landing facilities (e.g., cold storage, ice), ranger patrol sites, and distance to roads (an example is provided in Figure 8.19). Biophysical-based modeling that focuses on identifying the best locations for the cultivation of multiple species of interest-based on productivity, taking into account patterns of water temperature, water clarity, and other key parameters is forthcoming, and will be the subject of a future Appendix to this report. Additionally, modeling is ongoing to develop robust estimates of the wave climate associated with the area of interest for this work.

Table 1. Factors included within the GIS-based multi-criteria exclusion (MCE) analysis, associated rules utilized to identify areas incompatible with aquaculture development, associated comments and rationale, and the legal basis (if applicable).

Consideration	Rule / Distance	Comment / Rationale	Legal Basis (if applicable) or Literature References
Environmental			
Depth (Finfish)	Depths between 8 - 30 m are suitable (score of 1.00), between 0 - 8 m are poorly suitable and should be excluded from further consideration (score of 0.00), and greater than 30 m are moderately suitable (score of 0.50).	Aquaculture operations within shallow waters can lead to the deposition of fish waste and excess feed on the seafloor, which can cause nutrient pollution and impact seafloor communities. Operations in too deep of waters can be difficult to monitor for seafloor or mooring impacts and can be costly to operate.	Fishbase 2020, Seale and Ellis 2019, Mayerle et al. 2017
Depth (Clam)	Depths between 1.5 - 3 m are highly suitable (score of 0.1), between 3 - 6 m are moderately suitable (score of 0.50), and greater than 6 m or less than 1.5 m are	Appropriate depth scores based on the relationship of existing clam aquaculture operations and the bathymetry (water depth) dataset	*See Appendix 8.4*

	poorly suitable (score of 0.00).	developed in this study.	
Hydrodynamics (Water Current; Finfish)	Current speeds (based on average) between 0.05 and 0.15 m/s are suitable for finfish aquaculture operations (score of 1.00), between 0.00 - 0.05 m/s are poorly suitable and should be excluded (score of 0.00), between 0.15 - 0.25 m/s are moderately highly suitable (score of 0.75), between 0.25 - 0.35 m/s are moderately suitable (score of 0.50), and above 0.35 m/s are marginally unsuitable (score of 0.25).	Aquaculture operations within low current flow waters can lead to build-up of fish and feed waste on the seafloor beneath farm infrastructure, which can cause nutrient pollution and seafloor habitat impacts. Operations in waters with too high of current flow can be more challenging for aquaculture gear and cultivated species.	FAO 1989, Mayerle et al. 2017 *See Appendix 8.4*
Hydrodynamics (Water Current; Clam)	*Same as above.*	Appropriate water current scores based on the relationship of existing clam aquaculture operations and hydrodynamics. Similar relationships to those identified from literature resources for finfish aquaculture apply to clam aquaculture.	*See Appendix 8.4*
Major Sediment Deposition Areas	Further review and site evaluation are necessary if within areas of major sediment outfall (score of 0.50).	Water quality may be insufficient for aquaculture operations within major sediment deposition areas.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein)
Shoreline (Finfish)	Areas within 100 m of the shoreline are poorly suitable (score of 0.00), and further review is necessary if within 200 m of the shoreline (score of 0.50).	Aquaculture operations within close proximity of the shoreline can cause damage to sensitive nearshore habitats (e.g., mangroves, seagrass beds).	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop

Natural Resources			
Corals (Finfish)	Areas associated with coral reefs are poorly suitable (score of 0.00), as determined by data derived from the Millennium Coral Reef Assessment. Further review is necessary for areas within 200 m of coral reef.	Avoid impacts of effluent (excess feed and fish waste) aquaculture operations on corals, including in cases where water currents could carry materials towards corals.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Corals (Clam)	Further review and site evaluation are necessary if within areas of coral reefs (score of 0.5).	Infrastructure and materials used for giant clam farming could negatively affect coral reefs, particularly if gear is abandoned or during storm events.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein)
Marine Protected Areas	Areas associated with marine protected areas are poorly suitable for finfish aquaculture (score of 0.00) and site evaluation is necessary for clam aquaculture (score of 0.5)	Avoid natural resource management conflict with aquaculture operations.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Social and Cultural			
Dive and tourist sites	Areas within 100 m of dive and tourist sites are poorly suitable (score of 0.00).	Avoid user conflicts with dive and tourist sites.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Historic sites	Areas within 10 m of historic sites are poorly suitable (score of 0.00).	Avoid conflicts and potential impacts of aquaculture operations atop historic sites.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop

Infrastructure			
Existing aquaculture farms	Areas within 500 m of existing finfish farms are poorly suitable, and 100 m for existing clam farms (score of 0.00).	Minimize potential for biosecurity and disease transmission issues between existing and future aquaculture operations.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Sewer outfall	Areas within 1000 m of the Malakal wastewater treatment plant outfall and two sewer emergency outfall pump locations are poorly suitable (score of 0.00), further review for areas within 500 m of other wastewater pump station locations.	Minimize potential for human waste contamination on aquaculture operations which could pose human and fish health risks.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Fiber optic cable	Areas within 100 m of the underwater fiber optic cable are poorly suitable, and 200 m for the southern area to Peleliu (score of 0.00).	Avoid potential impacts of moorings or anchors associated with aquaculture operations damaging the fiber optic communications cable.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Navigation and Shipping			
Navigational Channels	Areas within 100 m of larger vessel routes are poorly suitable (score of 0.00; further review if within 500 m, score of 0.50), 50 m for smaller vessel routes (score of 0.00; further review if within 100 m, score of 0.50).	Avoid navigational hazards associated with physical infrastructure and activities on aquaculture operations.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Anchorage or Mooring Areas	Areas associated with anchorage or mooring areas are poorly suitable (score of 0.00)	Avoid conflict between vessels within anchorage/mooring areas and aquaculture operations, as well as	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and

		potential human waste or sewage contamination.	agreed upon in October 2019 workshop
Ports	Area within 2 km of the Port of Koror is poorly suitable (score of 0.00).	Avoid conflict with large vessels and port-related activity, including military and other commercial uses of port infrastructure.	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop
Piers, docks [Class B Waters]	Further review necessary if within areas associated with existing Class B waters (score of 0.50).	Avoid conflict with existing developed areas, including potential for navigational hazards associated with aquaculture operations near docks	Aguilar-Manjarrez, Soto and Brummett 2017 (and references therein), distance discussed and agreed upon in October 2019 workshop

Table 2. Factors included in siting analyses specific to finfish and giant clam, as well as associated data sources:

Factor	**Finfish Analysis**	**Giant Clam Analysis**	**Data Source**
Environmental			
Depth	✔ (finfish-specific)	✔ (giant clam-specific)	Wei and Theuerkauf et al. 2021
Hydrodynamics (Water Current)	✔	✔	PICRC
Wave Model	✔	✔	TNC
Major Sediment Deposition Areas	✔	✔	TNC, Michael Aulerio
Shoreline	✔	✔	NOAA 2007
Sea Surface Temperature	✔	✔	SST NASA MUR DHW NASA MUR SST RCP 8.5 CMIP5

Chlorophyll a	✓	✓	MODIS
Kd490 – (Turbidity)	✓	✓	MODIS
Natural Resources			
Corals	✓ (finfish-specific)	✓ (giant clam-specific)	Allen Coral Atlas 2021
Seagrass	✓ (finfish-specific)	✓ (giant clam-specific)	Allen Coral Atlas 2021
Dugong Feeding Concentration Area	✓	✓	TNC, Michael Aulerio
Marine Protected Areas	✓	✓	Palau Protected Areas Network
Social and Cultural			
Dive and tourist sites	✓	✓	PALARIS
Historic sites	✓	✓	PALARIS
Infrastructure			
Existing Aquaculture Farms	✓ (finfish farms only)	✓ (giant clam farms only)	PALARIS
Sewer Outfall	✓	✓	Palau Public Utilities Corporation
Fiber Optic Cable	✓	✓	Palau National Communication Corporation
Navigation and Shipping			
Navigational Channels	✓	✓	TNC, Michael Aulerio
Anchorage or Mooring Areas	✓	✓	TNC, Michael Aulerio
Ports	✓	✓	TNC, Michael Aulerio
Piers, docks [Class B waters]	✓	✓	Palau Environmental Quality Protection Board

6. Sustainable Aquaculture Management, Additional Needs, and Opportunities

Global guidance suggests that the appropriate use of spatial planning and siting tools for aquaculture management is a critical first step (Aguilar-Manjarrez, Soto, and Brummett 2017). However, there are additional key components that must be considered in greater detail to ensure the development and maintenance of a sustainable aquaculture sector. While not comprehensive, three key areas that require a further evaluation are: (1) ground-truthing, validation, and site evaluation of the results of the siting analysis to ensure predictions of suitable and unsuitable areas are accurate, (2) carrying capacity modeling and assessment to evaluate the effect of carrying capacity and determine suitable aquaculture production to ensure environmental and economic sustainability, (3) biosecurity and hazard risk reduction considerations and strategies, (4) long-term environmental monitoring to determine baseline conditions and to evaluate potential impacts, and (5) effective policy, planning and legislation along with regulation development to manage the sector.

Ground-truthing, Validation, and Site Evaluation -- To ensure the results of the spatial analysis described in this report are appropriate for guiding management decisions, a field campaign was conducted in 2021 to evaluate if the analysis predictions of suitable, marginal, and unsuitable areas are accurate. This included evaluation at 40 random sites of predictions of depth, water currents, various key water quality parameters (e.g., water temperature, dissolved oxygen, water clarity), and to assessed the presence of sensitive habitats or other environmental or space-use considerations that may not have been already captured within the siting analysis. Based on the results of this assessment, which has previously been identified as a key step to ensuring validity and rigor of spatial analyses, there were adjustments and/or improvements to this report and the siting results.

Carrying Capacity Modeling and Assessment -- The subject of this report was to identify the most suitable locations for aquaculture sector development based on a GIS-based analysis of a broad area of natural resource, environmental, and sociocultural factors. Importantly, this analysis identified the locations that are most and least suitable for the development of aquaculture operations. As described above, these areas are those that would be most suitable for permitting aquaculture operations, and/or could be delineated as aquaculture zones. Aquaculture zones represent broader areas where multiple aquaculture farms or operations could be co-located. Carrying capacity modeling is an essential step to assess how much aquaculture (e.g., how many net pens of a certain stocking density and volume) can be supported within an aquaculture zone to avoid adverse impacts. However, these potential adverse impacts can be avoided when using an ecosystem approach to aquaculture development and use of multi-trophic species to mitigate excess nutrients. As part of future projects, we can provide some baseline support for carrying capacity modeling and assessment and recommend that the Palau Environmental Quality Protection Board continue to support efforts to utilize these models to inform sector management in the short- and long-term.

Biosecurity and Hazard Risk Reduction Considerations and Strategies -- Disease, parasites, and predators represent major challenges that regularly challenge the aquaculture sector globally. However, there are effective tools and strategies that have been adopted by nations around the world that sustainably manage their aquaculture sector that can support improved biosecurity and hazard risk reduction. The susceptibility of spreading disease should be considered when transporting shellfish seed, juvenile fish, broodstock, or other living organisms from foreign water bodies. Considerations around biosecurity and hazard risk reduction should be contained within a robust site-specific management plan (e.g., designation of aquaculture management areas, see Section 2).

Long-Term Environmental Monitoring -- Robust and upfront aquaculture spatial planning and siting analyses provide a strong foundation for the development of an aquaculture sector well-suited to minimizing environmental impacts. However, it is essential that baseline environmental monitoring be conducted prior to the establishment of aquaculture operations to ensure that conditions are suitable for aquaculture operations, both from the perspective of ensuring environmental and business sustainability. In the longer-term, environmental monitoring is an ongoing and essential component of ensuring aquaculture operations are compliant with existing water quality regulations and aquaculture-specific regulatory requirements. A long-term environmental monitoring plan should be developed during the permitting process that allows for adaptive management (e.g., changes to stocking density, maximum allowable biomass). This plan can leverage of future technologies (e.g., low-cost water quality monitoring sondes) and the best available scientific data.

Effective Policy and Clarified Regulations to Manage the Sector – Throughout the project, there has been an emerging need to establish and implement a National Aquaculture Policy that provides guidance on siting, permitting, monitoring, and management of aquaculture farms. Formation of a national policy would work to maximize the outcomes of continued research and development, best support effective sustainable development, and ensure social, economic and ecological objectives are met.

7. Policy Options and Opportunities, Next Steps

This first edition of the Guidance Manual for Aquaculture Spatial Planning and Management in the Republic of Palau provides discrete spatial planning products and tailored technical information to improve the management of the sector. However, to move towards an overall more sustainable and productive aquaculture sector, we propose the following next steps to move towards implementation and operationalizing this guidance:

1. **Establish an aquaculture stakeholder working group** made up of government officials, environmental organizations, farmers, and local stakeholders to:
    - review the siting guidelines;
    - create a sustainable aquaculture roadmap;
    - determine how aquaculture in Palau should be governed at the federal, state, and/or levels; and
    - meet regularly (e.g., quarterly) to review the progress of the aquaculture policy, legislation, and regulations development
2. **Develop a national aquaculture policy and legislation** to support sustainable aquaculture development that:
    - officially authorizes sustainable aquaculture development that takes into account the protection of the environment and benefits the local Palauan people for the local economy and food security;
    - delineates aquaculture zones that provide a streamlined permitting process for commercial aquaculture within the proposed "zones;"
    - uses the enclosed siting guidelines and carrying capacity modeling to help create these zones and set a maximum number of cages / fish farmed per zone based on carrying capacity modeling or best management practices from other countries;
    - provides a ranking and explicit process of how leases will be issued and renewed, providing preference to local Palauans; and
    - establishes a formal aquaculture working group to meet and regularly review aquaculture management;
3. **Develop a set of national regulations for**:

- farm management and regular monitoring that includes requirements for and reporting on factors such as: stocking density, feed management, escape prevention, water quality, impacts to habitat, and biosecurity risk management.
- species selection that ideally prioritizes native or naturalized species and, if approves a species that is not native or naturalized, requires the use of sterile fry
- gear type requirements that include requirements for factors such as netpen type and mesh type and regular maintenance
- human health requirements
- educational programs at the BOF and PCC for technical training in Aquaculture.

4. **Consider using and adapting the decision-support tool** developed in this project to make all aquaculture zones and future lease information available to the public, industry, and regulators;
5. **Continue to conduct case-by-case reviews of aquaculture in areas outside of identified zones** that require more extensive permitting requirements, including but not limited to:
    - a full environmental impact assessment;
    - a short-term conditional lease that requires monthly monitoring for a minimum of one year for key water quality and habitat impact measures to ensure that water quality is not impaired and sensitive habitats of coral and mangroves are not damaged.

8. Appendix

8.1. Aquaculture spatial planning map atlas

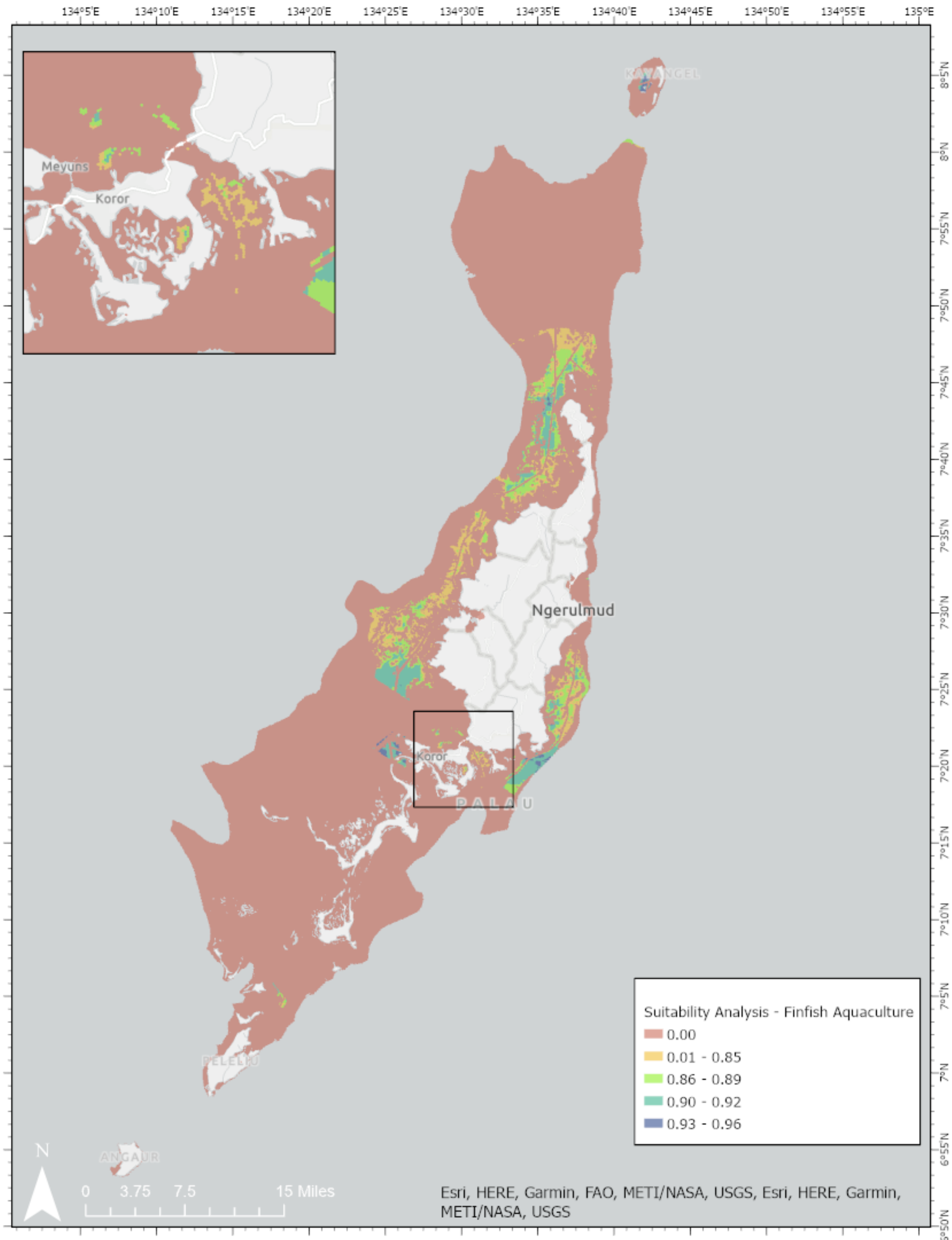


Figure 8.1 - Overall suitability for finfish aquaculture siting based on the synthesis of all relevant environmental, natural resource, social and cultural, infrastructure, and navigation and shipping considerations (based on the minimum score across all factors). Areas receiving a score close to 1.00 are most suitable and compatible based on all available data, whereas those receiving a score close to 0.00 are unsuitable for one or more criteria.

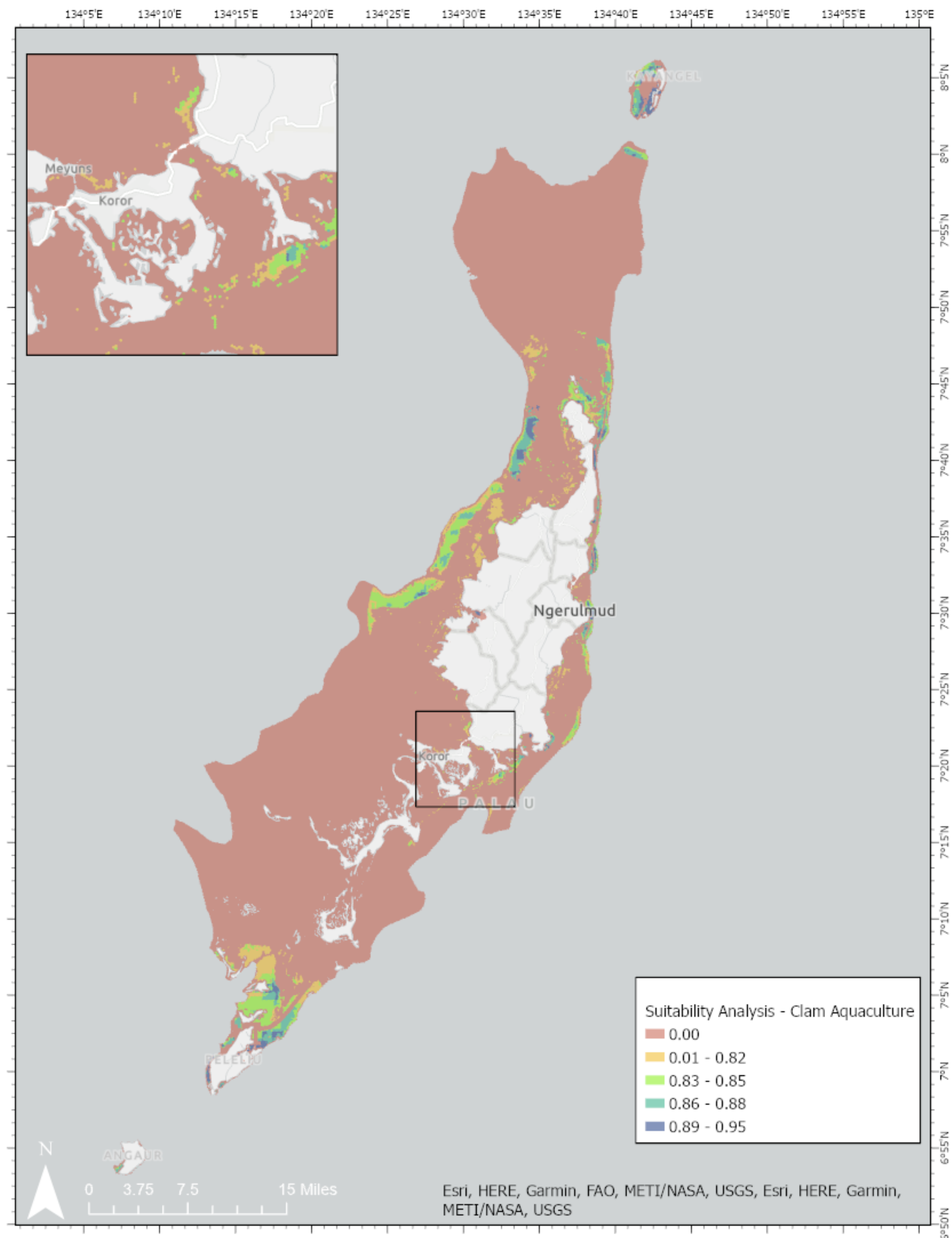


Figure 8.2 - Overall suitability for clam aquaculture siting based on the synthesis of all relevant environmental, natural resource, social and cultural, infrastructure, and navigation and shipping considerations (based on the minimum score across all factors). Areas receiving a score close to 1.00 are most suitable and compatible based on all available data, whereas those receiving a score close to 0.00 are unsuitable for one or more criteria.

For a complete list of layers and to view them, please visit:
https://maps.coastalresilience.org/palau/

8.2. Factors considered, but not included in analysis

During the 'data discovery' phase of the project, key stakeholders provided insights into the factors used in current aquaculture permitting and management decisions, as well as what information is needed or used by farmers to identify prospective farm sites. Additionally, based on global guidance (Aguilar-Manjarrez, Soto, and Brummett 2017), a number of additional factors were identified that have been applied within aquaculture siting analyses for other regions. Below, we provide an overview of some additional factors considered for inclusion, their relevance, and why they were not included in the analysis described within this report. If these data are to become available in the future, their inclusion is recommended.

Factor	**Rationale**	**Why not included?**
Fishing Areas	Aquaculture operations should not be sited in important fishing areas to avoid impacts to fishing activities.	Data unavailable.
Fish and other marine species breeding and nursery areas	Aquaculture operations should not be sited within areas of importance for various aspects of the life cycle of marine species.	Data unavailable.
Unexploded ordnance	Aquaculture operations should not be sited within areas of known unexploded ordnances due to the potential for mooring anchors, installation, or farm maintenance activities to disturb and possibly detonate.	Data unavailable.
Livestock cultivation (piggeries, etc.)	Aquaculture operations could be impacted by livestock waste if sited in areas adjacent to piggeries or other intensive livestock cultivation areas, potentially posing human health risks.	Data available, but the downstream impact of these areas is unclear with existing data. Various considerations, such as minimum depth, distance from shoreline, and major sediment areas likely capture the water areas that would be directly affected by livestock cultivation.

Land cover	Aquaculture operations adjacent to developed areas (e.g., concrete, intensive buildings, human development) could be subject to run-off and nutrient pollution from land that could affect cultivated animal and human health.	Data available, but the downstream impact of these areas is unclear with existing data. Various considerations, such as minimum depth, distance from shoreline, and major sediment areas likely capture the water areas that would be directly affected by livestock cultivation.

8.3. Technical Methods Utilized within Aquaculture Siting Analysis

Spatial planning for aquaculture operations, wherein spatial data representing key environmental and space use conflicts are synthesized to identify areas with the highest likelihood for compatibility with aquaculture operations, is a critical first step to ensure environmentally and economically sustainable aquaculture industry development. Aquaculture siting analyses involve the use of geospatial analytical tools (e.g., GIS – Geographic Information Systems) to integrate pertinent spatial data and generate map-based products that can be used to inform policy and permitting decisions regarding where aquaculture operations can be located.

Data Inventory

A comprehensive spatial data inventory was developed for the coastal lagoonal waters of Palau to inform the siting analysis. Specifically, the data inventory included data layers from the following categories: environmental, natural resources, social and cultural, infrastructure, and navigation and shipping. We conducted an exhaustive search and survey to identify web-based resources and contacts to obtain pertinent data resources. A broad suite of government agencies (e.g., PALARIS, EQPB, PAN), utility corporations (e.g., PNCC, PPUC), and research institutions (e.g., PICRC), amongst others, contributed spatial data. Data was checked for completeness and quality to ensure that the most authoritative source was used. The complete data inventory generated for this siting analysis can be found by visiting: https://maps.coastalresilience.org/palau/.

Spatial Analytical Approach

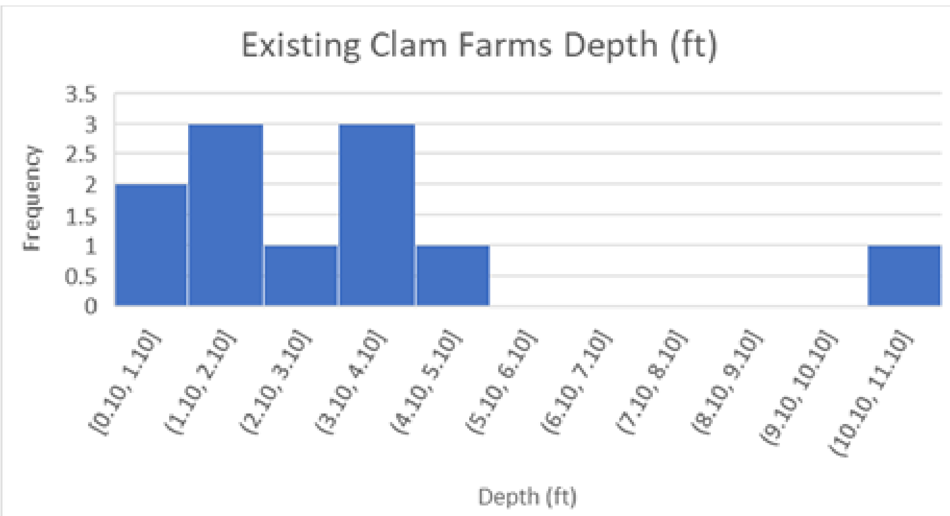
The spatial analysis to inform aquaculture siting in Palau was conducted within ArcGIS Pro 2.8 (Esri 2021), and is a type of spatial multi-criteria analysis known as suitability analysis. Suitability analyses allow for integration of multiple spatial data layers to identify areas of highest suitability, or areas with the highest likelihood of compatibility. When utilized within an aquaculture spatial planning context, suitability analyses integrate data representing environmental or space-use constraints to identify areas that minimize potential conflicts and have the highest likelihood for compatibility with aquaculture operations. Within a suitability analysis, each individual spatial data layer is re-scaled according to a defined suitability relationship (e.g., locations associated with the highest vessel traffic are assigned a score of '0', locations of lowest vessel traffic are assigned a score of '1'). Each re-scaled spatial data layer can be subsequently assigned a weight (all weights must sum to 100%; higher weights = more important conflict considerations), and all data layers can be integrated within the spatial analysis to identify locations with the highest likelihood for compatibility across all factors considered within the analysis. It is important to note that while weights can be assigned to individual spatial data layers, each layer can also be assigned an equivalent weight such that no individual factor has a greater impact on the final scores and output of the spatial analysis. In the scenarios presented in this version of the Guidance Manual, if a score of '0' was within a grid cell, then the final score would be '0', if not then the geometric mean was used to compute a final score.

Based upon the analysis boundaries criteria defined by participating stakeholders in the February 2019 workshop, we established a boundary for the 'area of interest' (hereafter 'AOI;' see Figure 8.1 for an example). We subsequently established a uniform hexagon grid within this boundary with a grid cell size of 1 hectare (10,000 m^2). This grid cell size was selected based on the spatial resolution of the available data and the footprint of existing and prospective aquaculture projects in Palau. Utilizing the comprehensive data inventory we had previously developed for the coastal lagoonal waters of Palau, we projected each spatial data layer to visualize and assess which layers were contained within the AOI. Spatial data layers contained within the AOI were subsequently scored in each grid cell using a custom Python script. Scoring was based on pre-defined rules (e.g., areas associated with marine protected areas are assigned a score of '0', locations outside receive a score of '1'; Table 1). Scoring of each spatial data layer was essential to ensure each factor was on a common scale (0 – less compatible, to

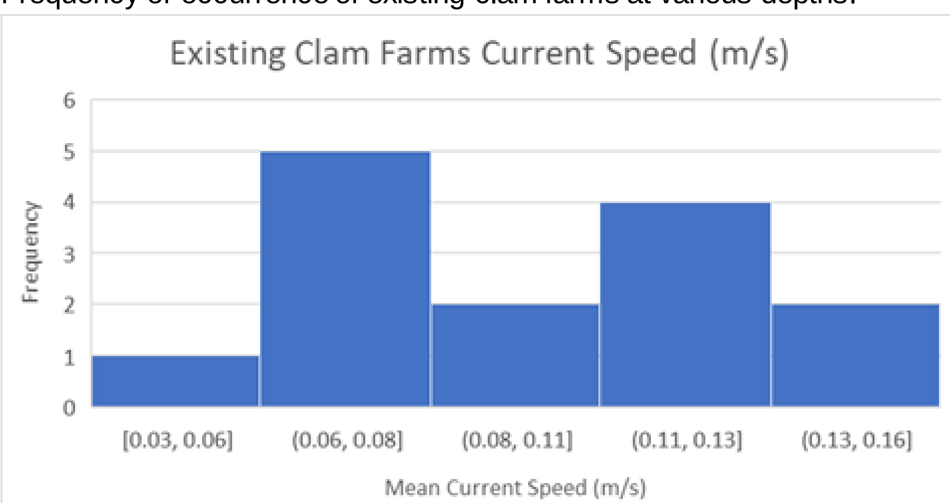
1 – more compatible). All individual layers were integrated using the method described above. On a scale of 0 to 1, grid cell suitability scores were computed for siting of aquaculture operations were ranked from highest (most suitable) to lowest (least suitable; Figures 8.1 and 8.2).

8.4. Analysis of Characteristics of Existing Aquaculture Operations

Clam - Depth information was available for 11 clam farms, and current information was available for 14. The minimum depth associated with a clam farm was 0.10 feet, maximum of 10.72 feet, and an average of 3.05 feet. The minimum mean current speed associated with a clam farm was 0.03 m/s, maximum of 0.15 m/s, and an average of 0.10 m/s.



Frequency of occurrence of existing clam farms at various depths.



Frequency of occurrence of existing clam farms at various mean current speeds.

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