BEST PRACTICES FOR AQUACULTURE MANAGEMENT

GUIDANCE FOR IMPLEMENTING THE ECOSYSTEM APPROACH IN INDONESIA AND BEYOND

CONSERVATION INTERNATIONAL

Sustainable Fisheries PARTNERSHIP

SUSTAINABLE FISHERIES GROUP UNIVERSITY OF CALIFORNIA SANTA BARBARA

Best Practices for Aquaculture Management

Guidance for implementing the ecosystem approach in Indonesia and beyond

October 2018

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THE OCEANS PLAY A MAJOR ROLE in feeding the planet, as there will be nine billion mouths to feed by mid-century. Currently, a significant part of the planet relies on seafood as a primary source of animal protein, and half of all seafood destined for human consumption is now produced in aquaculture farms. The growth of aquaculture is expected to continue in the coming decades as demand for seafood products rise. However, coastal and ocean ecosystem are also vulnerable to degradation due to careless development, and sustainable growth in the aquaculture sector will require utilization of best management practices that reduce harmful environmental impacts, habitat loss, poor water quality, and disease outbreaks.

As the world's second-largest aquaculture producer, but also a country with high marine biodiversity, Indonesia is anticipating rapid expansion of the aquaculture sector over the next five years through creation of a comprehensive national medium-term development plan (RPJMN) that should fully integrate ecosystem-based approaches to aquaculture development. Conservation International (CI), Sustainable Fisheries Partnership (SFP) and University of California Santa Barbara (UCSB) have partnered to provide this White Paper that can be considered as a background study and guidance for the development of a more environmentally responsible aquaculture sector through the RPJMN. Three stakeholder workshops, including one held in Jakarta, Bandung, and Ambon, were conducted to discuss relevant contextual aspects that inform the state of aquaculture development now and in the future and to gain insights from experts and practitioners for improved aquaculture practices in Indonesia. The workshops provided meaningful inputs for best practices in aquaculture and are summarized in this paper.

We are delighted to present this paper as a guide for both policy makers and practitioners. We offer our heartfelt thanks to The David and Lucile Packard Foundation for financial support. We sincerely express our gratitude to Bappenas, MMAF, University of Padjajaran Faculty of Fishery and Marine Science, University of Pattimura Center for Marine and Maritime Study, and other institutions, scientists, and practitioners that have participated and helped in the process of creating this paper.

Thank you.

Ketut Sarjana Putra
Vice President, Conservation International Indonesia
October 2018

ACRONYMS

AMA	Aquaculture management area
AZA	Allocated zones for aquaculture
AZE	Allowable zones of effect
AMDAL	Environmental impact assessments (*Analisis Mengenai Dampak Lingkungan*)
BAPPENAS	National Development Planning Agency (*Badan Perencanaan Pembangunan Nasional*)
BMP	Best management practices
DJPB	Directorate General of Aquaculture (*Direktorat Jenderal Perbendaharaan*)
EAA	Ecosystem approach to aquaculture
FAO	Food and Agriculture Organization of the United Nations
MMAF	Ministry of Marine Affairs and Fisheries
MMT	Million metric tons
OIE	World Organisation for Animal Health
PEQ	Population-equivalents
RPJMN	National Medium-Term Development Plan (*Rencana Pembangunan Jangka Menengah Nasional*)
RTRW	Provincial land-use plans (*Rencana Tata Ruang Wilayah*)
RZWP3K	Marine-coastal-small-islands zoning plans (*Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil*)
SIUP	Aquaculture Business Permit Letter (*Surat Izin Usaha Perikanan*)

OVERVIEW

THIS PAPER SYNTHESIZES KEY scientific and technical guidelines to help regulators and industry practitioners address three systemic, broad-scale challenges facing the aquaculture industry:

- Spatial conflicts with other users
- Exceeding carrying capacity of waterbodies
- Disease amplification and transmission.

In an effort to address these challenges, the Food and Agriculture Organization (FAO) developed the ecosystem approach to aquaculture (EAA). Although the EAA approach provides very comprehensive guidelines, its practical implementation has proven challenging. In order to provide more actionable guidelines for policy makers, we outline a suite of best management practices (BMPs) distilled from the EAA. These guidelines are built around three important tenets of the EAA:

- Performing national scoping of development goals and identifying suitable areas for aquaculture
- Incorporating waterbody carrying capacities during zonal planning and site selection
- Establishing aquaculture management areas wherein operational and emergency response procedures are coordinated to reduce disease risk and impact.

It is our hope that the BMPs and guidelines detailed herein will further the adoption of:

- Sustainable and responsible aquaculture production practices
- Industry structures that enable widespread adoption of best practices
- Approaches that allow the supply chain to more effectively engage in improving on-the-water practices.

In the final section, we demonstrate how these guidelines can be implemented, through a series of specific recommendations for Indonesia, the third-largest aquaculture producer globally (FAO, 2018). The country will soon begin drafting a new medium-term development plan, including guidance for the aquaculture sector, and will need to take action to meet its future production targets in a sustainable manner.

Although the EAA approach provides very comprehensive guidelines, its practical implementation has proven challenging. In order to provide more actionable guidelines for policy makers, we outline a suite of best management practices (BMPs) distilled from the EAA.

Admittedly, not all aquaculture-related issues can be addressed by a broader management approach. Some issues, such as the quality of feed or seed inputs or the risks posed to genetic diversity by escapes, are species-, production-system-, and/or geographically specific. We acknowledge that these are important issues to address, for some aquaculture industries more than others, but they remain outside the scope of this paper. However, the philosophy of the EAA suggests that improved governance of aquaculture at a broad level is likely to set up mechanisms capable of addressing more site-specific issues. By focusing on the foundations of effective aquaculture industry management, these guidelines are applicable to all types of aquaculture. Where differences exist, we have chosen to primarily focus on pond aquaculture and mariculture.

BOAT RIDE THROUGH A FLOATING FISH FARM IN CIANJUR, INDONESIA PHOTO KRISTEN WELLS PHOTOGRAPHY/SHUTTERSTOCK

PART 1

INTRODUCTION

SEAFOOD PLAYS A CRITICAL ROLE in global food security, providing essential nutrition for more than one billion people and livelihoods for some 57 million.[1] Aquaculture's importance and growing contribution to the seafood sector is irrefutable. As the world's fastest growing food production system, aquaculture has become the predominant source of fish protein, surpassing the amount of seafood produced for direct human consumption from wild-caught fisheries. Aquaculture is suitable throughout much of the world and, coupled with its relative sustainability compared to other animal protein production methods, particularly from a carbon emissions perspective, the potential for increased farmed seafood production is immense.[2]

> As the world's fastest growing food production system, aquaculture has become the predominant source of fish protein, surpassing the amount of seafood produced for direct human consumption from wild-caught fisheries.

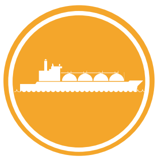
Despite its successful growth and potential, aquaculture is not consequence- or impact-free. With the rapid expansion of aquaculture in the past three decades — often in under-managed or under-regulated environments — the industry has experienced boom and bust cycles and acquired a negative reputation for its associated environmental impacts, particularly in Western markets. The direct environmental impacts of aquaculture are well-documented and include habitat loss in critical ecosystems (e.g., mangroves and wetlands), nutrient loading that contributes to poor water quality, the introduction of invasive species, and the spread of disease. These impacts can have severe ramifications, but can often be addressed by proper and effective management of the aquaculture industry.

Typically, aquaculture has been developed in an ad-hoc manner, and management has largely focused on siting, licensing, and monitoring performance and impact at the farm level. This perspective fails to acknowledge that aquaculture industries are dependent on common pool resources (namely water and space) and are tightly coupled to the ecosystems in which they operate.[3] Not only are individual farms interacting and competing with one another for shared resources, but the aquaculture industry is also interacting and competing with other users of those shared resources. As such, siting and managing aquaculture at the farm level has not been sufficient to mitigate the cumulative negative environmental impacts of all resource users, often proving detrimental to aquaculture industries by creating user conflicts, failing to protect aquaculture from the impacts of other industries, and detracting from the benefits of aquaculture.

1 FAO, *Contributing to Food Security and Nutrition for All*; World Bank, "The Global Program on Fisheries - Strategic Vision for Fisheries and Aquaculture."
2 Gentry et al., "Mapping the Global Potential for Marine Aquaculture"; Froehlich et al., "Comparative Terrestrial Feed and Land Use of an Aquaculture-Dominant World"; Hall et al., "Blue Frontiers: Managing the Environmental Costs of Aquaculture."
3 Smith et al., "Sustainability and Global Seafood."

AQUACULTURE'S KEY CHALLENGES >>>

There are a number of persistent issues associated with aquaculture that are common across various production systems and geographies. Based on workshops held across Indonesia by BAPPENAS, CI, SFP, and partner universities, we identified the following as key issues that result from inadequate management of aquaculture:



Conflicts with other resource users: Aquaculture commonly requires the allocation of public space (land, coastal, marine area, or freshwater) and may cause significant habitat conversion or modification. This can have direct and indirect impacts on all resource users if access rights and equity are not properly accounted for. Included here are conflicts that arise as a result of inadequate protection of high-value and sensitive ecosystems.

Exceeding waterbody carrying capacity: Many types of aquaculture are dependent on a reliable supply of good-quality water, and aquaculture is rarely the sole user of a water body. Aquaculture is directly impacted by upstream users and directly impacts downstream users through the release of waste products into the surrounding environment. Exceeding the environmental carrying capacity (or assimilative capacity) of a waterbody leads to negative environmental impacts (e.g., eutrophication, hypoxia, benthic impacts, and groundwater abstraction) and loss of ecosystem services.

Disease amplification and transmission: Disease is a major limiting factor in most aquaculture production.[4] It is costly, not only due to reduced growth and increased mortality in stocks — and the associated additional resource use — but also due to the costs associated with treatment, control, and management.[5] Certain pathogens, such as those listed by the World Organisation for Animal Health (OIE) can also have implications on trade, reducing the ability to export animals and in some cases commodities to other areas or countries free of those pathogens.[6] Pathogens associated with aquaculture may also pose a risk to wild aquatic animal stocks, which can be detrimental to both the environment and the industry's reputation.[7]

Applying a broader management approach to aquaculture — one that integrates the industry into coastal zone management and is ecosystem-based — is critical for the industry to address the persistent challenges described above and to achieve its full potential in a manner that is socially, economically, and environmentally sustainable.

4 Jennings et al., "Aquatic Food Security."
5 Ferreira et al., "Carrying Capacity for Aquaculture, Modeling Frameworks for Determination Of."
6 OIE, "Aquatic Animal Health Code."
7 Peeler and Taylor, "The Application of Epidemiology in Aquatic Animal Health -Opportunities and Challenges."

THE ECOSYSTEM APPROACH TO AQUACULTURE >>>

The ecosystem approach to aquaculture (EAA) was established by FAO in 2008[8] and further detailed in 2010.[9] It is generally considered the most appropriate framework for integrated management of aquaculture and is defined as a "strategy for the integration of the activity within the wider ecosystem, such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems."[10] The EAA was developed on three principles, which are that aquaculture must:

1. Be in harmony with its environment
2. Be beneficial for the local people involved
3. Recognize and facilitate the co-use of different activities.

Since EAA's emergence over a decade ago, there has been increased awareness of the holistic and participatory approaches outlined in the approach (for example, major elements can be seen within Blue Growth and Blue Economy approaches); however, the practical implementation of the EAA has been slow.[11] In an effort to facilitate implementation of the EAA, FAO published comprehensive guidelines on the EAA framework in 2017, under the title *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture: A Handbook*.[12] This handbook provides an excellent, detailed step-by-step guide to the EAA, but remains inaccessible and cumbersome to many due to its length and detail. Herein we distill the comprehensive EAA framework to identify BMPs that are foundational to addressing the systemic, broad-scale challenges of aquaculture outlined above:

- **Spatial Planning and Zoning:** the process through which public and private sectors aim to influence the spatial distribution of people and activities at differing geographic scales.
- **Waterbody Carrying Capacity Limits:** determining the level of resource use, by all resource users, that can be sustained over the long term without harming ecosystems or provision of ecosystem services.
- **Aquaculture Management Areas:** waterbodies, or parts thereof, where certain management practices are coordinated across all aquaculture operators in the area, to minimize cumulative impacts and risks.

8 Soto et al., "Applying an Ecosystem-Based Approach to Aquaculture: Principles, Scales and Some Management Measures."
9 FAO, *Aquaculture Development*.
10 FAO.
11 Brugere et al., "The Ecosystem Approach to Aquaculture 10 Years on—a Critical Review and Consideration of Its Future Role in Blue Growth."
12 Aguilar-Manjarrez, Soto, and Brummett, *Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture*.

These BMPs do not target individual issues, but rather are designed to address multiple challenges. For example, spatial planning and zoning can both help reduce user conflicts and maintain proper water quality. Similarly, setting carrying-capacity limits will protect water quality and lower disease risk. Thus, the guidelines in this document intend to explain how implementing these broader BMPs can address each of the key challenges facing the industry. While these core practices are complementary and interdependent to some degree, they need not be adopted all at once. They may be implemented at different rates or in different orders, depending on the context of the aquaculture industry management under review. They are presented here together in order to help identify where data and information needs may overlap and hence could support the adoption of multiple BMPs through one system. These guidelines are broadly applicable across all aquaculture production industries; however, we strongly recommend reviewing the FAO Handbook for further detail and nuanced considerations of case-specific concerns.

Interactions with Wild-Capture Fisheries

In the absence of effective regulations, aquaculture can interact with, and may negatively affect, wild-capture fisheries. On the other hand, well-managed aquaculture can improve livelihoods and enhance wild populations while minimizing environmental impacts. Understanding these interactions is critical for a sustainable aquaculture sector that does not develop at the expense of the capture fisheries sector.

Throughout this document, we will use text boxes like this one to identify key interactions between marine aquaculture and wild fisheries and highlight areas where coordinated management could yield synergistic benefits.

THAI FISHERMEN AND BOATS, PHOTO KONMESA, SHUTTERSTOCK

PART 2

MANAGING FOR SPATIAL CONFLICTS BETWEEN RESOURCE USERS

THERE ARE NUMEROUS USERS OF the marine environment (e.g., aquaculture, tourism, fisheries, marine transport), and many of these users differ dramatically in terms of their objectives, goals, and resource needs, often putting them in direct conflict with each other. To date, most development has been done on an ad hoc basis, with little consideration of interactions and long-term sustainability. Many examples demonstrate that inadequate planning can lead to adverse environmental impacts, lack of economic feasibility, and/or social conflict.[13] Marine spatial planning is a systematic process through which the public and private sectors work together to influence the spatial distribution of people and activities at differing geographic scales.[14] This process is a fundamental component of ensuring successful and sustainable aquaculture development, and has been shown to minimize conflicts between competing users and maximize overall value of the marine environment.[15]

Fishery Interactions: Habitat Conversion and Modification

Coastal and marine areas are directly affected by aquaculture farms via land conversion and modification, such as replacing mangroves with shrimp ponds or adding artificial structures (e.g., cages, seaweed lines) to sensitive marine habitats like coral reefs and seagrass beds. Farms can also impact these areas indirectly through nutrient loadinwg, shading, and changes in hydrodynamics.[16] Degradation of these coastal and nursery habitat types has major implications for wild-capture fisheries and should be minimized.[17] Aquaculture remains the top replacement use (30 percent) for mangrove deforestation across Southeast Asia, and proper aquaculture siting will be pivotal to minimize habitat degradation as the industry expands.[18]

13 Sanchez-Jerez et al., "Aquaculture's Struggle for Space."
14 Aguilar-Manjarrez, Soto, and Brummett, *Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture*.
15 Gentry et al., "Offshore Aquaculture"; Sanchez-Jerez et al., "Aquaculture's Struggle for Space."
16 Ruiz, Pérez, and Romero, "Effects of Fish Farm Loadings on Seagrass (Posidonia Oceanica) Distribution, Growth and Photosynthesis"; Fabricius, "Effects of Terrestrial Runoff on the Ecology of Corals and Coral Reefs"; Loya et al., "Nutrient Enrichment Caused by in Situ Fish Farms at Eilat, Red Sea Is Detrimental to Coral Reproduction."
17 Mumby, Edwards, and Lindeman, "Mangroves Enhance the Biomass of Coral Reef Fish Communities in the Caribbean"; Sundblad et al., "Nursery Habitat Availability Limits Adult Stock Sizes of Predatory Coastal Fish.
18 Richards and Friess, "Rates and Drivers of Mangrove Deforestation in Southeast Asia, 2000–2012."

SPATIAL PLANNING AND ZONING >>>

In its simplest form, spatial planning for aquaculture should follow this basic hierarchy:

1. National-level scoping and feasibility assessments
2. Regional-level zoning of activities
3. Site selection for individual aquaculture farms
4. Developing aquaculture management areas (AMAs)

In this section, we focus primarily on national- and regional-level zoning. Site selection and aquaculture management area development are discussed in more detail in the *Managing for Water Quality* and *Managing for Disease* sections, respectively.

National-level scoping and feasibility assessments

Scoping helps governments proactively and strategically plan for sustainable aquaculture development and management. The main objectives of this step are to define the boundaries of management units and the ecosystem, determine the relative importance of development and conservation goals, and ensure that stakeholders are well-informed about the costs and benefits of aquaculture development. The national-level scoping initiative should be led by an aquaculture task force. Throughout the scoping process, it is imperative that this task force consult closely with relevant stakeholders, including government officials, policy makers, scientists, farmers, fishers, and other competing marine environment users, to ensure a balanced and successful planning process.

The task force should start this process by evaluating national priorities for aquaculture, the motivation for development (food security, income generation, etc.), and aquaculture's relative importance to conservation priorities and other industries. This will help determine the direction and magnitude of development within the country. In the scoping process, the task force should collect and review three broad types of baseline information which may affect development:

1. Aquaculture statistics (farm location, production, and area), which will help planners understand the nation's current aquaculture status, data quality, and gaps in data availability
2. Economic overview (national and international market demand), which will aid planners in selecting target species and market limitations for aquaculture
3. Policy and regulatory landscape (existing aquaculture policies, regulations, and institutions), which will help planners identify areas in which legislation may need to be strengthened or developed, and determine the roles and responsibilities of all regulatory bodies.

Ultimately, scoping is an information-gathering process that helps planners and governments understand the status of aquaculture and what is needed to ensure a successful and sustainable future.

Fishery Interactions: Socioeconomic

Declines in available fishing grounds, navigational disturbances, variation in landings, and competition with fish farmers for catches have all been observed following the introduction of aquaculture to an area.[19] Small-scale fisheries are often limited to nearshore coastal areas due to vessel size and power constraints. Spatial conflicts between these fisheries and aquaculture are likely to increase in the future as nearshore and coastal space becomes increasingly scarce. Conversion to coastal shrimp and fish ponds can also privatize public lands that were formerly accessible to small-scale fishers and intertidal gleaners.[20]

Products from wild fisheries and aquaculture compete in the market, affecting the prices that fishers and farmers receive, as well as the demand for seafood products. The result is a higher, more resilient global seafood supply with lower prices and reduced price volatility.[21] However, at the fishery level, the effects of market competition depend on numerous factors, including the species and technologies involved, the degree of substitutability between products, the fishery management in place, and the presence of other interactions (spatial, ecological) outside of the market.

TRADITIONAL FISH CAGES ON LAKE TOBA, NORTH SUMATRA, INDONESIA, PHOTO ALEXANDER MAZURKEVICH, SHUTTERSTOCK

Regional-level zoning of activities

Zoning is the process of identifying the desired geographic location and extent of aquaculture and other activities in a region based on ecological and socio-economic criteria (see Chilean case study in Appendix A). Policy makers, government officials, scientists, farmer groups, industry representatives, local authorities and regulatory bodies, and community members should be directly involved in this process, to ensure well-represented stakeholder engagement. When done properly, zoning can minimize negative environmental impacts, biosecurity risk, and stakeholder conflict.

19 Aguilar-Manjarrez, Soto, and Brummett, *Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture*; Akyol and Ertosluk, “Fishing near Sea-Cage Farms along the Coast of the Turkish Aegean Sea”; Sanchez-Jerez et al., “Aquaculture’s Struggle for Space”; Troell et al., “Does Aquaculture Add Resilience to the Global Food System?”

20 Primavera, “Overcoming the Impacts of Aquaculture on the Coastal Zone.”

21 Asche, Dahl, and Steen, “Price Volatility in Seafood Markets”; Jennings et al., “Aquatic Food Security.”

Within the zoning process, stakeholders should ensure that they properly identify suitable areas for aquaculture using the following criteria:

- **Ecological considerations:** Suitable zones should have abundant water resources and adequate water quality for target species. In addition, planners should consider how aquaculture's impact on the water column, benthic environment, and surrounding sensitive ecological areas and populations might impact other users (e.g., wild-caught fisheries, tourism) when selecting areas.

- **Socio-economic considerations:** Aquaculture is ideally placed in areas with few existing users (e.g., shipping, tourism, wild-caught fisheries) to minimize potential user conflicts, and areas with access to production infrastructure (e.g., roads, energy) and markets for both inputs and outputs.

- **Risks and Issues:** Planners also need to be aware of issues and risks in all steps of the aquaculture production process, as well as their respective impacts, scales, and likelihood of occurrence. For pond aquaculture, risks like floods, droughts, severe winters, earthquakes, volcanic eruptions, and tidal surges/storms/tsunamis should be considered in the zoning process. For cage aquaculture, zoning should consider risks like oil/chemical spills/runoff, pollution, ice, storms, harmful algal blooms, and hypoxia.

Once zones have been selected, it is critical that planners determine the carrying capacity of these zones (outlined in greater detail in the *Managing for Water Quality* section). In aquaculture, carrying capacity helps broadly define the upper bounds of production that can be sustained based on the available resources. There are four main types of carrying capacity:[22]

In aquaculture, carrying capacity helps broadly define the upper bounds of production that can be sustained based on the available resources.

- **Physical** carrying capacity quantifies the total area in a waterbody suitable for aquaculture.

- **Production** carrying capacity determines the limits of aquaculture production at the farm level.

- **Ecological** carrying capacity estimates the amount of production that can be sustained without causing irrevocable damage to or altering ecological processes, species, populations, and habitat.

- **Social** carrying capacity estimates the amount of aquaculture production that can be supported without generating user conflicts.

22 Byron and Costa-Pierce, "Carrying Capacity Tools for Use in the Implementation of an Ecosystems Approach to Aquaculture."

Fishery Interactions: Wild Fish Inputs

Aquaculture may use wild fish in the form of feed. Fed aquaculture of carnivorous species like shrimp largely depends on commercial feeds made from fishmeal, which are derived from wild-caught species such as sardines and anchovies.[23] Rising fishmeal prices may incentivize overharvesting of these fisheries, many of which are important sources of income and employment. An emerging concern is the depletion of so-called "trash" fisheries for direct feeding or use in lower-quality farm-made feed.[24] These low-value fisheries are generally not closely managed, putting them at risk for overexploitation.

Within the EAA approach, ecological carrying capacity is of the utmost importance for ensuring the long-term sustainability of aquaculture operations. If the ecological carrying capacity is exceeded, it can have negative environmental impacts, such as eutrophication, hypoxia, and harmful algal blooms, and drive regime shifts, which can both directly and indirectly affect aquaculture production itself and other industries. Planners should also consider the environment's assimilative capacity, or ability to receive additional nutrients, waste, and pollution without causing damage, particularly for fed aquaculture. These estimates help planners understand the zone's maximum allowable production levels, and thus the appropriate number of farms in relation to the surrounding environment.

Finally, it is important to develop biosecurity and aquaculture management area strategies within established zones, to minimize disease spread, poor environmental conditions, and impacts from aquaculture escapes. Crucially, management areas should be spaced to enable control and quarantine of areas, in order to prevent the spread of disease across the whole industry. Disease and poor water quality can be devastating for aquaculture production and farm value. They can also both directly and indirectly impact other neighboring industries that share the same water body.

Fishery Interactions: Escapes

Farmed individuals that escape from aquaculture farms will compete for resources (e.g., food, space) with wild counterparts, potentially increasing mortality.[25] If farmed and wild individuals interbreed, it could reduce genetic diversity and result in a wild population that is less resilient to environmental pressures.[26] When planning and zoning for aquaculture, additional measures, such as avoiding the siting of production in close proximity to native conspecifics, can be taken into consideration to decrease the risk posed by escapes. Farming of non-native species should be strictly prohibited, to avoid introductions of invasive species.

23 Tacon and Metian, "Fishing for Aquaculture."
24 Cao et al., "China's Aquaculture and the World's Wild Fisheries."
25 Naylor, Williams, and Strong, "Aquaculture-A Gateway for Exotic Species."
26 Naylor et al., "Fugitive Salmon."

Selecting sites for individual aquaculture farms

Site selection is similar to the regional planning process, but occurs at a smaller scope with much finer detail. It determines where farms will be located, what kind of aquaculture will be permitted, the species to be farmed, and the likely impacts of such proposed aquaculture. The goal is to ensure that sites are appropriately located to maximize production and minimize adverse social and environmental impacts. Siting is typically led by the private sector, but the government provides structure and standards for site licensing, zonal usage, and environmental impact assessment.

Developing aquaculture management areas

This final step in spatial planning and site selection is the development and establishment of aquaculture management areas (AMAs). AMAs are a collection of farmers and producers that participate in common management practices. While individual farmers are responsible for the operation and performance of their farms, AMAs establish and implement common management goals and objectives for the betterment of all farms in the area, generally focusing on issues that can only be resolved collectively (user rights conflicts, limited access to inputs, and management of risk, waste, and disease, etc.). AMAs develop management plans that establish goals and objectives, common management practices, monitoring programs, and biosecurity strategies. AMAs can increase collective negotiating power, market presence, and information sharing, while decreasing environmental impacts and disease.

SCHOOL OF SCAD NEAR A DOCK IN ALYUI BAY, WAIGEO ISLAND, RAJA AMPAT, INDONESIA. PHOTO ETHAN DANIELS/SHUTTERSTOCK

SCOPING

Main Tasks

- Collect baseline information on current aquaculture production, markets and regulatory frameworks
- Define national priorities for aquaculture
- Set broad objectives
- Identify relevant stakeholders to consult

Data needs

- Economic or market (international and national) feasibility information
- Current regulations or institutions relevant to aquaculture development
- Aquaculture production, area, and location
- Suitability requirements for target culture species

SITE SELECTION

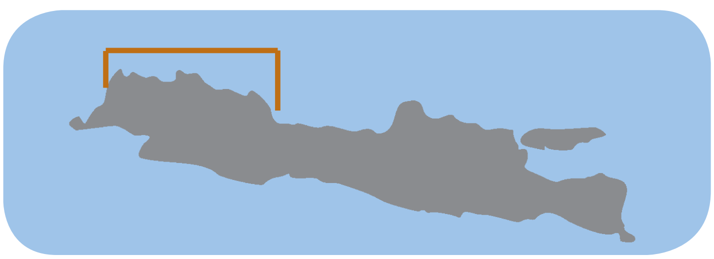
Main Tasks

- Assess aquaculture suitability
- Estimate site carrying capacity
- Plan for biosecurity and disease control
- Develop authorization procedures for proposed sites

Data needs (site-level)

- Water quantity and quality
- Hydrodynamics and bathymetry
- Site suitability and carrying capacity estimates
- Accessibility (infrastructure, markets, roads, electricity, inputs)
- Proximity to sensitive habitats, pollution sources, and other fishing and aquaculture zones

ZONING



Main Tasks

- Identify suitable aquaculture areas
- Identify regional issues or threats
- Estimate zonal carrying capacity
- Develop biosecurity and zoning strategies
- Designate zones for aquaculture

Data needs (zone-level)

- Water quantity and quality
- Hydrodynamics and bathymetry
- Suitability requirements for target culture species
- Accessibility (infrastructure, markets, roads, labor)
- Proximity to sensitive habitats, pollution sources, and other fishing and aquaculture zones

MANAGEMENT AREAS

Main Tasks

- Consult with stakeholders to delineate management area boundaries
- Develop and enforce a management body and plan
- Establish carrying capacity and environmental and disease monitoring procedures for management areas

Data needs

- Proximity to nearby farms
- Information on:
  - Waterbody
  - Water source
  - Species farmed
- Environmental impact information (water turnover, feed conversion rate, benthic diversity, bottom anoxia)
- Carrying capacity

Aquaculture is suitable throughout much of the world and, coupled with its relative sustainability compared to other animal protein production methods, particularly from a carbon emissions perspective, the potential for increased farmed seafood production is immense.

BIG EYE TREVALLY IN INDONESIA, PHOTO DRAY VAN BEECK/SHUTTERSTOCK

PART 3

MANAGING FOR WATER QUALITY

AQUACULTURE IS SELDOM THE ONLY operator in a given waterbody, and managing multiple users in an integrated fashion is essential. Water is the most basic common-property resource that aquaculture is dependent on. As such, it is important both for an aquaculture farm to maintain minimum levels of on-farm water quality for husbandry practices and for the impacts of all resource users to be managed within the carrying capacity of an ecosystem.

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The concept of carrying capacity is integral to ecosystem-based management and is complementary to spatial planning and zoning. Ross's study proposes the characterization in Table 1 of the various steps in spatial planning and management of aquaculture following an integrated approach.[27] This helps depict the differences and complementary nature of these steps and serves as a good blueprint for sustainable growth that can be applied across different issues and tools.

Carrying capacity in the context of EAA aims to establish the upper limits of aquaculture production in a given area based on environmental and social limits.[28] Assessments of carrying capacity can be conducted at various scales, from farm-level to zone; however, the focus herein is on broad carrying-capacity estimations (i.e., areas greater than just farm level) to support the integrated management of aquaculture.

Various integrated management practices have been proposed to improve water quality management of both inland and coastal aquaculture based on regulation of farm density and spacing, including (i) allocated zones for aquaculture (AZA) in spatial plans[29] and (ii) standards for assimilative capacity of coastal systems or lakes and reservoirs, which would predicate consent for discharges from individual farms or collected effluent.[30] An overview of each of these management approaches is provided below; for more technical recommendations refer to Appendix B.

27 Ross et al., "Carrying Capacities and Site Selection within the Ecosystem Approach to Aquaculture."
28 Aguilar-Manjarrez, Soto, and Brummett, *Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach to Aquaculture*.
29 FAO, *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture*; Sanchez-Jerez et al., "Aquaculture's Struggle for Space."
30 Tett et al., "Carrying and Assimilative Capacities."

Table 1. Attributes of key steps (estimating culture potential, zoning, siting, and carrying capacity) in spatial planning management of aquaculture (reproduced from Ross et al., 2013)

	Culture Potential	Zoning	Siting	Carrying capacity estimate
Main purpose	Plan strategically for development and eventual management	Regulate development; minimize competing and conflicting uses; reduce risk, maximize complementary uses of land and water	Reduce risk; optimize production	Sustain culture; protect environment/ ecosystem
Spatial scope: Administration	Global to National	Subnational	Farm or farm clusters	Farm or farm clusters
EAA Scale	Global	Watershed or waterbody	Farm/s	Farm area to watershed or waterbody
Executing entity	Organizations operating globally; National aquaculture departments	National, state/ provincial/municipal governments with aquaculture responsibilities	Commercial entities	Regulating agencies
Data needs	Basic, relating to technical and economic feasibility, growth, and other uses	Basic environmental, social, and economic sets	All available	Data to drive models
Required resolution	Low	Moderate	High	High
Results obtained	Broad, indicative	Directed, moderately detailed	Specific, fully detailed	Moderately to fully detailed

ALLOCATED ZONES FOR AQUACULTURE >>>

The process of zoning, as described in the spatial planning section above, may lead to the designation of allocated zones for aquaculture (AZA), which are specific areas where aquaculture development is prioritized over other uses.[31] AZA is a promising technique for managing water quality, particularly in areas where other cumulative uses impact water quality (industrial discharges, microbial loading in wastewater). However, the creation of an AZA does not in and of itself mandate limits on farms or stocking densities, which are key for sustainably managing water quality.

31 Sanchez-Jerez et al., "Aquaculture's Struggle for Space."

This can be overcome through regulation establishing allowable zones of effect (AZE) for fish cages in coastal systems, or a maximum total area and stock for pond culture. AZE can help determine minimum separation of cages, which mitigates organic enrichment and hypoxia in bottom sediments. Various models can be used for planning, including simple models such as DEPOMOD[32] and ORGANIX[33], and more complex 3-D hydrodynamic models such as FVCOM or DELFT3D. However, O'Hagan's study notes that insurance companies are wary of the AZA approach, preferring to diversify spatially rather than concentrate risk in a smaller area[34] — this is particularly relevant for pathogens and is further addressed in the *Managing for diseases* section.

ASSIMILATIVE CAPACITY >>>

Assimilative capacity — defined as "the ability of an area to maintain a healthy environment and accommodate wastes"[35] — is a complementary concept to carrying capacity that is usually considered for fed aquaculture. The assimilative capacity (or carrying capacity) of a coastal system, lake, or reservoir can be estimated and used to inform discharge licenses or standards.

Where integrated approaches are used, they are not without challenges, because the multi-stressor effects on receiving waters can make it problematic to set scientifically sound standards.

Policies for discharge consent are common (e.g., The Independent Aquaculture Licensing Review Group in Ireland[36] and Department of Primary Industries in Victoria, Australia[37]), but are most often applied on a farm-by-farm basis, rather than from an integrated perspective. Where integrated approaches are used, they are not without challenges, because the multi-stressor effects on receiving waters can make it problematic to set scientifically sound standards. For instance, in Brazil, licensing of tilapia farms in reservoirs is based on a whole-body assessment using the very simple Dillon & Rigler phosphorus loading model.[38] Regulators have mandated a maximum concentration of 30 mg P L^{-1}(~1mM) in the water body, of which 5 mg P L^{-1} are allowed for aquaculture, the remainder being allocated for urban waste, agricultural discharges, etc. Aquaculture licenses are issued incrementally until that threshold is met; the intent being that this will provide reservoir-scale control of eutrophication. While this approach is better than an unmanaged system, it still presents a high risk, because it (i) averages out the physical aspects through dilution in a larger area; (ii) does not focus on the localized particulate waste, particularly if several farms are concentrated in one area (e.g., due to logistics); and (iii) is based on only one environmental indicator.

32 Cromey, Nickell, and Black, "DEPOMOD — Modelling the Deposition and Biological Effects of Waste Solids from Marine Cage Farms."
33 Cubillo et al., "Role of Deposit Feeders in Integrated Multi-Trophic Aquaculture — A Model Analysis."
34 O'Hagan et al., "Regional Review of Policy-Management Issues in Marine and Freshwater Aquaculture."
35 Fernandes et al., "The Scientific Principles Underlying the Monitoring of the Environmental Impacts of Aquaculture."
36 Independent Aquaculture Licensing Review Group of Ireland, "Review of the Aquaculture Licensing Process."
37 Department of Primary Industries, "Planning Guidelines for Land Based Aquaculture in Victoria."
38 Dillon and Rigler, "A Test of a Simple Nutrient Budget Model Predicting the Phosphorus Concentration in Lake Water."

In land-based systems such as ponds, the definition of within-pond (i.e., outflow) thresholds for eutrophication indicators (i.e., Bricker's study[39]) and best practices for disposal of sludge between culture cycles are two important management measures; however, concentration limits on single-pond outflow do not resolve the issue of cumulative discharge. In some situations, depending on the dilution volume and hydrodynamic characteristics of the receiving body, it may be preferable to consolidate discharge from multiple ponds into one location, perhaps released through a submarine outfall, rather than deal with multiple diffuse sources. This, combined with a greater or lesser degree of land-based treatment, is the standard sanitary engineering solution to address multi-source discharges of nutrients and organic matter from an urban area. In practice, a complex network of fed aquaculture ponds can be expressed in terms of population-equivalents (PEQ).[40] Simple physiological models can be used to calculate PEQ from organic and inorganic losses in terms of annual discharge. More complex models such as FARM[41] can calculate aggregate emissions from a pond.

The design, dimensioning, and implementation of sewage networks for urban wastewater, which is largely empirical and rudimentary in many parts of the world, is far better established than its application to aquaculture pond systems. Furthermore, there are equally well-established guidelines for integrated coastal zone management that predicate the relationship between emissions from urban areas and the quality of adjacent waters, whether riverine or coastal. We suggest there are important transdisciplinary lessons that may be applied when considering integrated management of pond aquaculture.

The concepts above apply to measures dealing with land-based aquaculture, but space allocation in inshore waters as a basis for integrated management is an area that currently relies on the application of mathematical models of different types. Ferreira et al.[42] developed an extended review for FAO detailing the kinds of tools that constitute the state-of-the-art for both system-scale (i.e., integrated) and local (farm-scale) carrying-capacity assessment.

For marine culture, a promising integrated management strategy is to move structures to deeper waters offshore. A geographic information system (GIS) analysis by Kapetsky et al.[43] shows that there is no shortage of suitable areas, and environmental mitigation would be substantial. Nevertheless, here too there are associated capital costs in mooring and cage improvements, marginal costs for transport, and increased risks, which will be reflected in insurance costs. Collectively, these costs result in lower competitiveness on price, and will only be acceptable if there is a premium associated with improved quality of both product and environment.

39 Bricker, Ferreira, and Simas, "An Integrated Methodology for Assessment of Estuarine Trophic Status."
40 "The amount of oxygen-demanding substances whose oxygen consumption during biodegradation equals the average oxygen demand of the wastewater produced by one person. For practical calculations, it is assumed that one unit equals 54 grams of BOD per 24 hours." (United Nations, 1997).
41 Ferreira et al., "Analysis of Production and Environmental Effects of Nile Tilapia and White Shrimp Culture in Thailand."
42 Ferreira et al., "Progressing Aquaculture through Virtual Technology and Decision-Support Tools for Novel Management."
43 Kapetsky, Aguilar-Manjarrez, and Jenness, "A Global Assessment of Offshore Mariculture Potential from a Spatial Perspective."

Fishery Interactions: Fish Attraction

When located in the ocean, the artificial structure and potential food source (wasted feed) provided by aquaculture can act as fish aggregating devices that attract (or repel) a wide variety of wild fish.[44] By attracting fish, aquaculture farms may make them easier to catch, decreasing costs for fishers but potentially exacerbating overfishing. Farms may also serve as de facto marine protected areas (MPAs) if fishing is excluded from the area. This effect could harm fishers by attracting fish away from traditional fishing grounds. However, it is also possible that fishers would benefit via a "spillover" effect, whereby the protection offered by the aquaculture farms increases the abundance of fish available to fishers. Such outcomes depend on the species and scale of protection, but have been demonstrated for some MPAs.[45]

FISH FEEDING AT A FISH FARM IN BRAZIL, PHOTO BOSSTIAAN/SHUTTERSTOCK

44 Dempster et al., "Coastal Salmon Farms Attract Large and Persistent Aggregations of Wild Fish"; Hehre and Meeuwig, "A Global Analysis of the Relationship between Farmed Seaweed Production and Herbivorous Fish Catch."

45 Halpern, Lester, and McLeod, "Placing Marine Protected Areas onto the Ecosystem-Based Management Seascape."

PART 4

MANAGING FOR DISEASE

DISEASE IS ONE OF THE TOP challenges facing the aquaculture industry, and it is a primary constraint to continued growth. It has been estimated that disease outbreaks cost the global aquaculture industry approximately US$6 billion per year.[46] Addressing fish disease issues is a necessary condition to improve stability in production, which, in turn, will reduce economic risks, reduce environmental impact of fish loss due to disease, and attract new investment to the aquaculture industry.

Fishery Interactions: Disease Transmission

Disease and parasite outbreaks are the largest cause of economic losses for the aquaculture sector and can endanger wild populations targeted by capture fisheries.[47] Though marine diseases are natural phenomena originating from wild fish, they usually persist in the environment in low numbers. Poor aquaculture practices (e.g., high densities, poor water quality) increase the risk and frequency of disease outbreaks and the ability of farmed fish to transfer them to wild populations. Effluent from fed aquaculture, such as shrimp ponds and fish cages, contributes to poor water quality and is a major factor in the outbreak of marine diseases.

Diseases can be broadly categorized as production (i.e., often endemic), emerging, or listed, and can be caused by bacterial, fungal, viral, parasitic, and environmental agents. FAO maintains an extensive list of significant pathogens for key aquaculture species.[48] This list covers both finfish and shellfish, however less is known about pathogens of seaweeds, which is a growing area of research.[49] Though the focus of management and control may differ for different aquaculture species and among disease categories, the principles are the same: prevention, early detection, isolation, management/control, and adaptation.[50]

One of the main aspects of this process is understanding the key drivers and risk factors for disease, which largely fall under the headings of: contact network, host susceptibility, environmental drivers, husbandry practices, and other stressors (Figure 1). The balance of risks is likely to be different for

46 World Bank, "Reducing Disease Risk in Aquaculture."
47 Johansen et al., "Disease Interaction and Pathogens Exchange between Wild and Farmed Fish Populations with Special Reference to Norway"; Lafferty et al., "Infectious Diseases Affect Marine Fisheries and Aquaculture Economics"; Meyer, *Aquaculture Disease and Health Management*.
48 FAO, "Cultured Aquatic Species Fact Sheets."
49 Largo, "Recent Developments in Seaweed Diseases."
50 Peeler and Taylor, "The Application of Epidemiology in Aquatic Animal Health -Opportunities and Challenges."

each type of culture practice and farming environment (offshore, inshore, inland), so it is important to conduct site-specific assessments and develop action plans.[51]

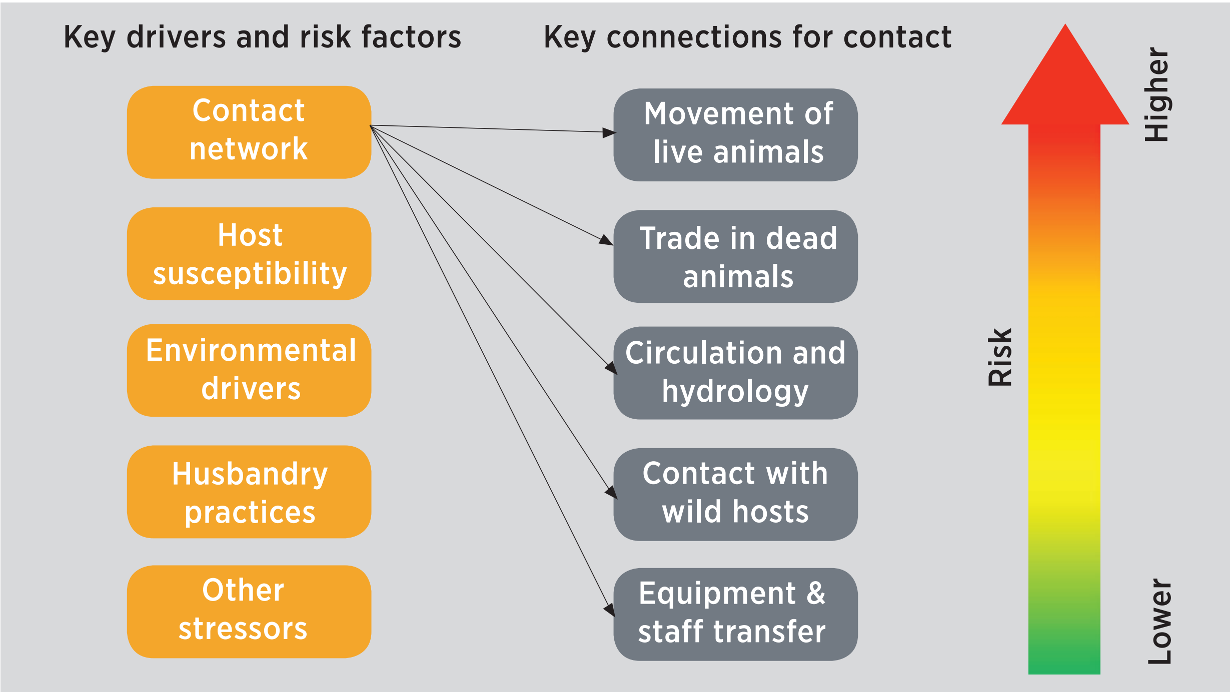

Figure 1. Key drivers, risk factors, and connections for pathogen spread

UNDERSTANDING KEY DRIVERS AND RISK FACTORS FOR DISEASE >>>

Contact networks determine the risk of a site getting and spreading a pathogen, and the extent to which it may spread throughout an area or sector.[52] Key connections to consider, ranked in order of risk, are: the movement of live animals (including imports from other countries), trade in dead animals or commodities,[53] hydrological (land) and hydrodynamic (ocean) connections, contacts with wild hosts and carrier/vector species (including birds and other terrestrial animals), and transfer of equipment and staff among sites (Figure 1). Sites and areas with large numbers of outward connections are termed "super-spreaders," since if a pathogen is introduced to them they have the potential to rapidly spread the pathogen.[54] Those sites with high numbers of inward connections act as sinks for infection and are at the greatest risk of having a pathogen introduced. Understanding connections and key nodes (i.e., sites) is central to developing effective surveillance programs, defining epidemiologically distinct areas, and controlling pathogen spread in the event of an outbreak.

51 Thrush et al., "A Simple Model to Rank Shellfish Farming Areas Based on the Risk of Disease Introduction and Spread."
52 Tidbury et al., "Predicting and Mapping the Risk of Introduction of Marine Non-Indigenous Species into Great Britain and Ireland."
53 Pearce et al., "Do Imports of Rainbow Trout Carcasses Risk Introducing Viral Haemorrhagic Septicaemia Virus into England and Wales?"
54 Green, Werkman, and Munro, "The Potential for Targeted Surveillance of Live Fish Movements in Scotland."

Additional factors control the likelihood of a disease being expressed if a pathogen is introduced to a site via the contact network. Susceptible host species must be present for a disease to be expressed, but the environmental conditions must also be conducive to disease expression.[55] Though other environmental factors can be important, as practically all aquaculture species are poikilothermic, water temperature is often the key factor in determining the occurrence of disease (e.g., Taylor et al.[56]). Understanding the permissive thresholds and conditions for disease allows the development of risk indices and risk maps that can allow high-risk areas to be identified in time and space, aiding in the development of effective surveillance and control.[57]

Sites and areas with large numbers of outward connections are termed 'super-spreaders', since they have the potential to rapidly spread pathogens.

Husbandry practices at the site level are also key to managing the occurrence of disease. As discussed above, farm trading practices and contacts determine the likelihood of introducing pathogens, but good practices on site can reduce this risk and also reduce the likelihood of expression if a pathogen is introduced.[58] Knowing the provenance of introduced stock is critical to safe sourcing, and good biosecurity practices on site can further reduce the risk of pathogen introduction. Early detection through regular monitoring can reduce the risk of disease occurrence and impact, and for some pathogens appropriate vaccination and treatment regimens are important. Minimizing husbandry stressors such as high stock densities and handling, and other stressors such as exposure to predators, is also important when attempting to reduce disease impacts.[59]

COORDINATED DISEASE CONTROL >>>

Coordinated disease control should be implemented at several different levels,[60] and disease should be considered as a driver for the development and coordination of area management.[61] Some clear examples of coordinated disease management can be found in Europe — such as the control of Spring Viremia in Carp (SVC) in the UK or of Infectious Salmon Anemia (ISA) in Atlantic salmon aquaculture in Scotland, Norway, and the Faroe Islands — both of which are detailed as case studies in Appendix C.

55 Taylor et al., "The Role of Live Fish Movements in Spreading Koi Herpesvirus (KHV) throughout England and Wales."
56 Taylor, Wootten, and Sommerville, "The Influence of Risk Factors on the Abundance, Egg Laying Habits and Impact of Argulus Foliaceus in Stillwater Trout Fisheries."
57 Thrush and Peeler, "A Model to Approximate Lake Temperature from Gridded Daily Air Temperature Records and Its Application in Risk Assessment for the Establishment of Fish Diseases in the UK."
58 Thrush et al., "The Application of Risk and Disease Modeling to Emerging Freshwater Diseases in Wild Aquatic Animals."
59 Turnbull et al., "Stocking Density and the Welfare of Farmed Salmonids."
60 Stelzenmüller et al., *Guidance on a Better Integration of Aquaculture, Fisheries, and Other Activities in the Coastal Zone*.
61 Jackson et al., "The Drivers of Sea Lice Management Policies and How Best to Integrate Them into a Risk Management Strategy."

In general, coordinated disease control should be driven, regulated and co-coordinated at a national level, but needs active engagement at the site level and may benefit from additional coordination at the area and sectoral level.[62] At the national level, countries should have a legislative framework governing aquaculture, and the monitoring and control of disease aligned with international laws, World Trade Organization rules, and the OIE Aquatic Animal Health Code. This should be regulated by a national authority, which should regulate and enforce trade in live animals, set and enforce farm authorization conditions, and develop and coordinate national surveillance, monitoring, and control.[63] In adopting and implementing a regulatory framework, it is critical that there is good information exchange and consultation between industry representatives and policy makers — the authority can be key to facilitating this exchange.

National coordination helps ensure consistency of monitoring and management standards among areas, as areas often interact and therefore influence the disease status of one another. For example, if testing to demonstrate disease freedom at the area level is not conducted to the same standard, buyers of live fish from an area adopting high standards could import fish from a high-risk area that has been declared disease-free based on a poor surveillance system. The authority should therefore set minimum standards for monitoring and testing, and develop disease-control plans and operations manuals that should be tested and improved through contingency-planning exercises. Standardization among areas may also be improved by having a centralized inspection and diagnostic testing service, though these can be provided at the regional level if appropriate standardization and coordination is in place. The authority should also ensure that all testing and inspection services meet with international standards to enable trade. The authority should also ensure appropriate reporting to the OIE and other relevant international bodies, as well as public reporting on web-based portals or in annual reports.

National coordination helps ensure consistency of monitoring and management standards among areas, as areas often interact and therefore influence the disease status of one another.

A national data repository is highly beneficial in helping to regulate and monitor aquaculture sectors and respond to disease incursions. This should hold the location, contact details, and production figures for each site. It should also hold details of any inspection visits, test results, and disease issues. Live animal movement, mortality, and treatment records are also of considerable benefit to epidemiological investigations, the development of risk assessments, and zoning. A national research program into aquatic animal disease will also facilitate these and help identify and prevent emerging diseases from becoming established.

62 Peeler and Taylor, "The Application of Epidemiology in Aquatic Animal Health -Opportunities and Challenges."
63 Taylor et al., "Modelling the Koi Herpesvirus (KHV) Epidemic Highlights the Importance of Active Surveillance within a National Control Policy."

In some cases, appointing a regional or sectoral governance body may be useful if it is given a clear operational mandate and minimum standards. This mandate can include:

- Coordination of regional management efforts
- Local management decisions, including planning, authorization, monitoring, and regulations that account for local issues and concerns
- Application of regional (or sectoral) knowledge to regulate site location and set density and production limits
- Collation of production and disease data to the required quality standards to report back to the national authority
- Provision of inspection and diagnostic services (adhering to the scope and standards set by the authority)
- Help to improve disease awareness and communication throughout a region.

For national or area management to be effective, it is critical that individual farms are engaged and work with regional and national authorities to ensure they help prevent disease issues in the area. A key aspect of this it that they are given clear authorization conditions under which they produce their stocks. These conditions should include production limits, the requirement to keep and provide stock, mortality and treatment records, and a biosecurity plan (including typical operations and an emergency disease response plan).

Farms should adhere to good husbandry practices (which may be governed by regulators or trade bodies) that adopt appropriate stocking levels and minimize stressors. Farm staff should be trained in recognizing clinical signs and screening for common pathogens. Farms should take part in regular testing for specific pathogens and have appropriate support to control and manage disease from veterinary services and governing bodies.

PART 5

MANAGING AQUACULTURE IN THE CONTEXT OF INDONESIA

INDONESIA HAS ALREADY established itself as a major global aquaculture producer but will need to update its regulatory framework in order to meet its ambitious future production goals sustainably. The country will soon begin drafting a new medium-term development plan that includes aquaculture and is in a position to create a management system that embraces the core principles of the EAA. In this section, we extend our guidelines into context-specific recommendations for Indonesia. In addition to the central BMPs, we highlight the importance of regulatory policies that protect critical habitats, track the spatial footprint of aquaculture production, and support the sustainability of wild-capture fisheries that feed into the industry.

FISHERIES AND AQUACULTURE SECTOR OVERVIEW >>>

The fisheries sector (wild-capture and aquaculture) is a major priority of the government and is critical to Indonesia's food security and economic development, especially as the population is forecasted to grow by more than 67 million people by 2035. In order to meet this projected demand, Indonesia has set ambitious future production targets for aquaculture of 31.4 million metric tons (MMT) by 2027 and 37.6 MMT by 2030, with an annual rate of increase of approximately 5.7 percent.[64]

As of 2015, seaweed farming is Indonesia's largest aquaculture sector by volume (~10.2 MMT), followed by brackish pond aquaculture of shrimp and milkfish (~2.5 MMT) and freshwater pond aquaculture of tilapia, catfish, and carp (~2 MMT).[65] Floating net pen and cage aquaculture of finfish such as groupers and barramundi are considerably underdeveloped relative to other forms of aquaculture (Figure 2). Despite recent notable growth trends in the aquaculture sector, the year-over-year growth rates have failed to meet the targets set out in the initial years of the 2015-2019 strategic plan.

The government has estimated that there are some 12 million hectares where aquaculture can expand; 8.4 million hectares are considered suitable for marine aquaculture, 1.2 million hectares for brackish water aquaculture, and 2.2 million hectares for freshwater aquaculture. However, such expansion and rapid rates of growth — both recently observed and anticipated — are exposing the aquaculture industry to several critical risks, such as those outlined in this document (user conflicts, water quality, disease), among others. These risks, if not managed for, will limit the growth potential and undermine the sustainability of the aquaculture industry.

64 Directorate General of Aquaculture (DG Aquaculture), "Roadmap, Aquaculture Development 2017-2021."
65 "Statistics Indonesia."

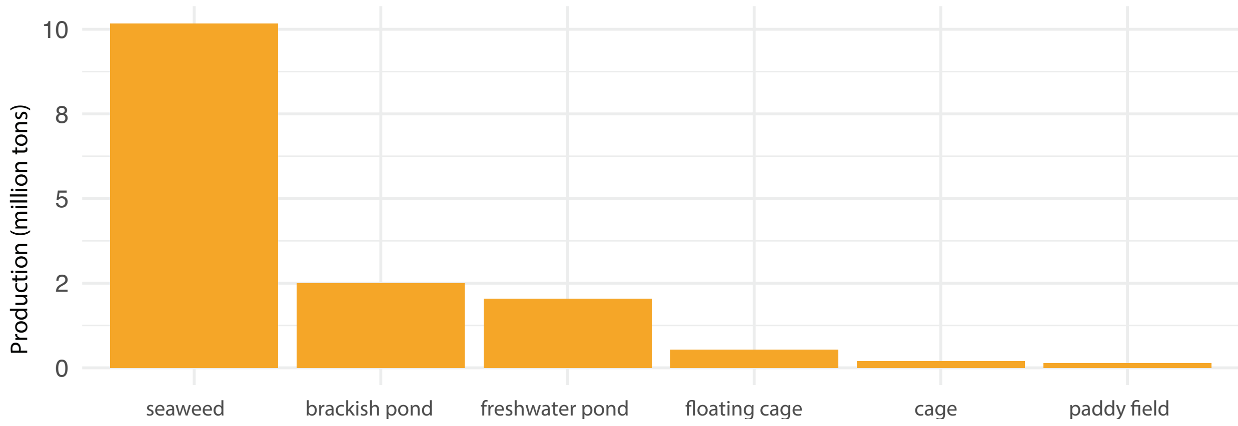

Figure 2: Production (million tons) by aquaculture type in Indonesia in 2015[66]

Many ambitions within the Strategic Plan of the Directorate General of Aquaculture currently focus on technical improvements and farm-level practices (e.g., genetics of seed, feed quality, vaccinations, production system technology). Although these are important considerations in developing economically viable aquaculture operations, they need to develop within a context of effective planning and management, to ensure that investments in innovation and improvements (ideally made by industry) are protected. Establishing appropriate regulatory frameworks and management systems will be imperative to actualizing the 2030 growth targets while safeguarding Indonesia's environmental quality and economic prosperity.

RECOMMENDATIONS FOR SUSTAINABLY MANAGING INDUSTRY GROWTH THROUGH 2030 >>>

In light of Indonesia's ambitious growth targets and the pivotal role that aquaculture will play, below are some key recommendations for sustainably managing the growth of Indonesia's aquaculture sector by 2030.

RECOMMENDATION 1: Strengthen nationally identified areas for aquaculture by integrating them into provincial land-use plans (RTRW) and/or marine-coastal-small-islands zoning plans (RZWP3K). This may require extension support to regional governments to provide the structure, skills, and capacity needed to complete the spatial planning process.

The top need for establishing adequate management of the aquaculture industry in Indonesia is to reform spatial planning approaches and regulations to provide a roadmap for industry growth (be it intensification and/or extensification). At the national level, responsibility for Indonesia's fishery sector rests with the Ministry of Marine Affairs and Fisheries (MMAF) and is regulated by Fisheries Law No. 45/2009. Indonesia is organized into 34 provinces, each containing their own legislature and elected government, and provinces are further subdivided into a hierarchy of regencies or cities, and administrative villages.

66 "Statistics Indonesia."

The MMAF has broadly identified suitable areas for aquaculture expansion by production environment (marine, brackish, and fresh water; Figure 3). Previously, regency governments have had full authority over spatial planning and utilization of coastal resources within the first four miles of their marine areas (UU No. 26/2007, UU No. 27/2006). However, according to UU No. 23/2014, provincial governments are held responsible for the management, use, and conservation of marine resources within their provincial waters, defined as extending 12 miles from shore. On one hand, this change in jurisdiction to provincial government bodies allows a more holistic view of the utilization of coastal and marine resources, minimizing conflict between regencies. On the other hand, these changes require provincial governments to have adequate experience and resources to ensure effective implementation at the regency level.

By co-managing marine resources with local fishers and farmers, regency governments are in a strategic position to develop aquaculture in ways that are compatible across many scales (regency/provincial/national). Regency governments are also the most familiar with the social needs and ecological conditions of the area, which translates well to the hierarchy dictated in the EAA. These broad areas defined by the MMAF need to be integrated into provincial land-use plans (RTRW) and/or marine-coastal-small-islands zoning plans (RZWP3K) so that their suitability can be assessed in context, accounting for regency stakeholders and provincial environmental variations. In addition, the national government should invest in support programs to transfer skills and planning capacity to the provincial governments.

Source: DJPB MMAF, 2017

Potential for freshwater cultivation Potential for brackish water cultivation Potential for marine cultivation

Figure 3. Distribution of potential aquaculture fisheries areas

RECOMMENDATION 2: The suitability of nationally identified areas for both aquaculture intensification and extensification approaches should be assessed within the provincial land-use plans (RTRW) and/or marine-coastal-small-islands zoning plans (RZWP3K) for further aquaculture growth.

There is considerable heterogeneity in the distribution and magnitude of the various forms of aquaculture across Indonesia. This makes blanket polices of intensification or expansion unrealistic, and possibly even detrimental, to apply in all contexts. For example, brackish pond farming occupies more area (~715,000 ha) than all other forms of aquaculture combined and is most prevalent in East Kalimantan and Central Sulawesi (Figure 4).

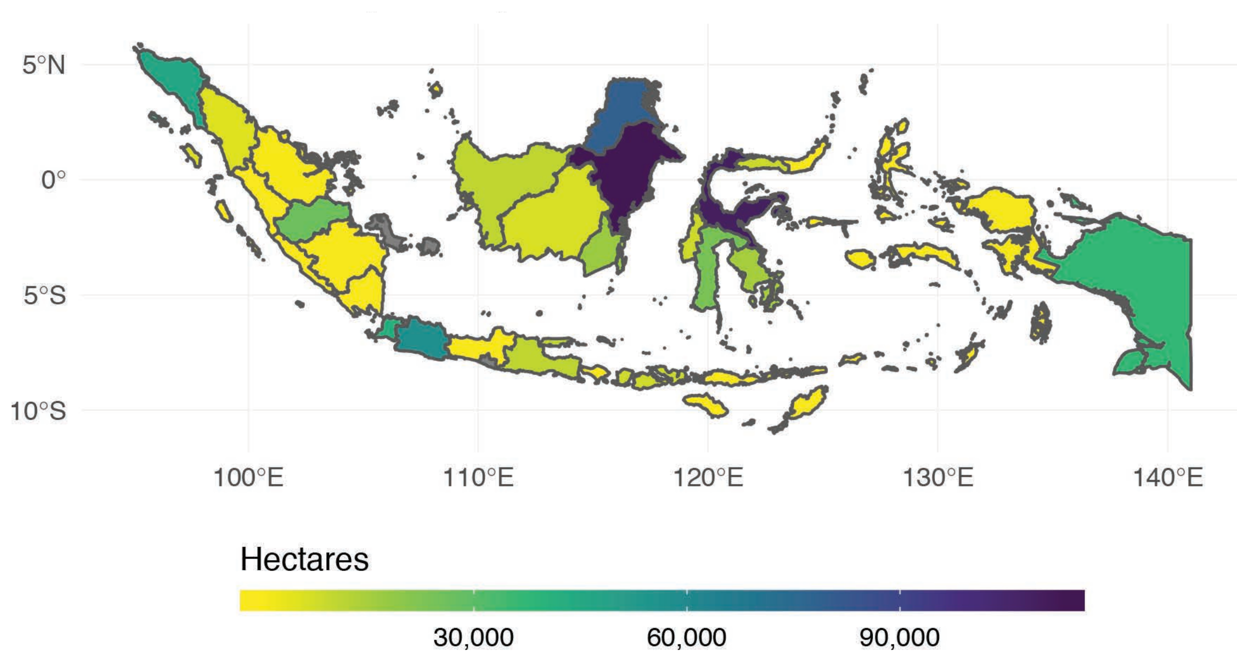

Figure 4. The extent of brackish pond aquaculture (hectares) by province in 2015[67]

The intensity (tons per hectare) of brackish pond aquaculture also varies considerably throughout Indonesia (0.04 to 44.23 tons per hectare; Figure 5). There is potential to increase production from brackish pond aquaculture via intensification of existing farm areas; if all farms operated at an intensity of at least five tons per hectare, national production from brackish pond aquaculture would more than double. However, the impacts of such a transition would need to be assessed at a local and regional level first, as intensification is unlikely to be sustainable throughout Indonesia without changes to resource management and infrastructure, and without increasing risks, such as disease.

67 "Statistics Indonesia."

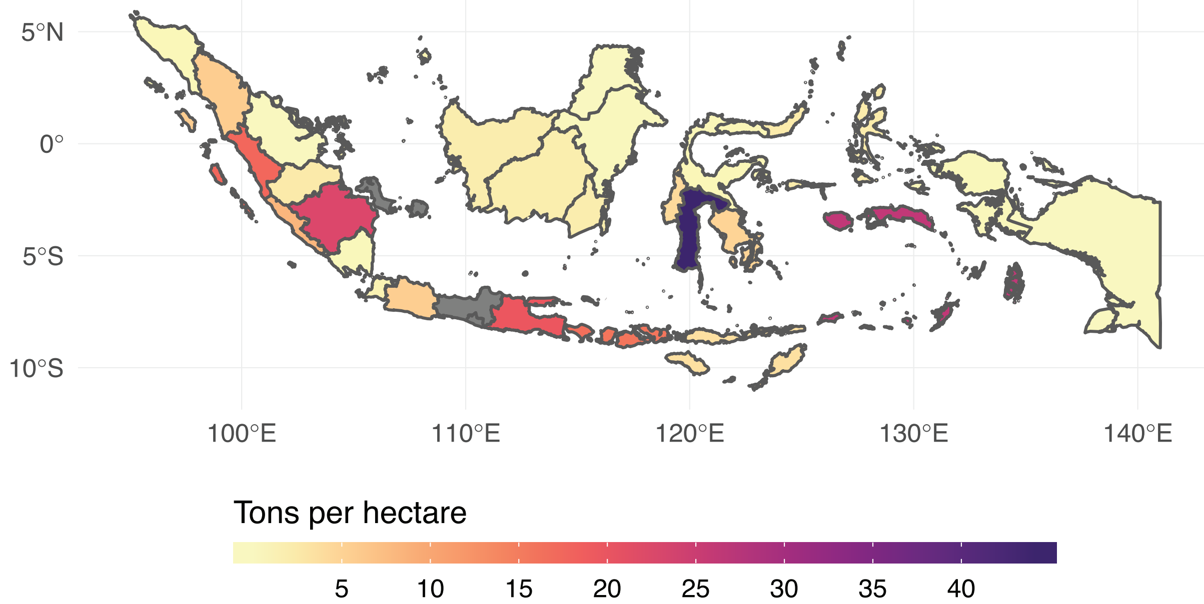

Figure 5. Intensity (tons per hectare) of brackish pond aquaculture by province in 2015[68]

Marine finfish farming in cages and floating net pens produces 232 tonnes (on average) per hectare per year from an area less than 1 percent of the estimated suitable area for development (Nurdjana 2006). By increasing the area covered, rather than intensity, marine fish production could significantly contribute toward meeting growth targets if sustainability risks in feed, disease, water quality, and access can be managed. Some areas, such as Sumbawa, Lombok, Manado, and Morotai, have been identified as suitable areas for further expansion and development. However, new operations need guidance to limit conflicts with the tourism sector and conservation efforts, as well as direct ecological impacts on sensitive habitats such as coral reefs and mangroves. Furthermore, there are significant opportunities to expand operations at existing sites.

To this end, Pegametan Bay in northwest Bali is an encouraging example of Indonesian efforts to implement components of the spatial planning process outlined in this document. With high-resolution layers (Figure 6) of environmental conditions, farm locations, bathymetry, tidal trends, and coastal uses, planners were able to holistically evaluate the site suitability of current and future farms. Of the existing operations, they identified three farms operating outside the suitable area and two farms that were exceeding their ecological carrying capacities. Furthermore, in looking ahead, the planners were able to identify sites that could sustainably expand production, as well as locations of new farm sites.[69] This assessment is currently being revisited by Gondol and BROL research stations, with support from Longline, SFP, and the Walton Family Foundation, and will provide updated tools to enable improved management.

68 “Statistics Indonesia.”
69 Mayerle et al., “Spatial Planning of Marine Finfish Aquaculture Facilities in Indonesia.”

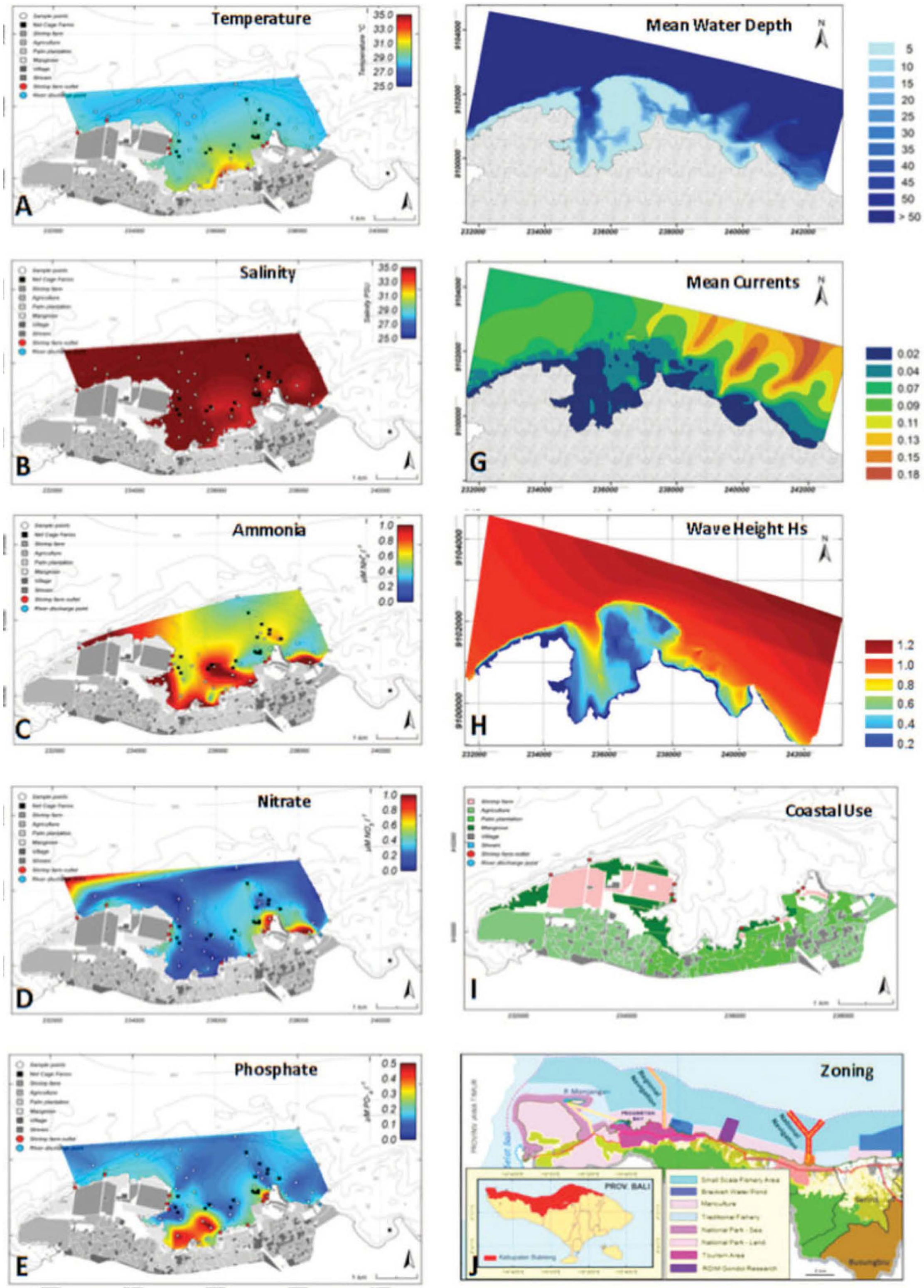

Figure 6. Mapped high-resolution data of Pegametan Bay[70] (figure reproduced from Meyerle et al.)

70 Mayerle et al.

RECOMMENDATION 3: Incorporate mangrove protection and restoration into the provincial land-use plans (RTRW) and/or marine-coastal-small-islands zoning plans (RZWP3K) process to identify suitability of aquaculture extensification and intensification.

Mangrove deforestation continues to be a key environmental impact of the expanding aquaculture industry in Indonesia.[71] Mangroves are nursery areas for many commercially relevant species, such as shrimp and grouper, and provide coastal protection, carbon sequestration, and many other environmental services. Mangrove protection and restoration (in the case of abandoned shrimp ponds) is an important input to consider in the spatial planning and zoning process. For example, mangrove conversion to low-intensity shrimp aquaculture, which is primarily occurring in East Kalimantan and Sulawesi, is driven by socio-political pressure. Expansion should be curbed and resources diverted to intensifying production in existing ponds, recognizing that this will require investment in technological advances on farms, increased human capacity, and a management system based on understanding environmental carrying capacity and disease risks across the local industry.

RECOMMENDATION 4: Assess the carrying capacity of waterbodies identified for aquaculture development in provincial land-use plans (RTRW) and/or marine-coastal-small-islands zoning plans (RZWP3K), accounting for all users in the identified zone to ensure cumulative impacts are managed. Aquaculture siting and licensing should be based on these carrying-capacity assessments (e.g., establish limits on farm number, size, and/or production volume).

Once spatial plans are developed and areas for aquaculture development are identified, the carrying capacity (or assimilative capacity) of selected waterbodies needs to be assessed. This will help inform the scale of development that can be sustainably realized and can provide clarity on priorities for the types of aquaculture that will be supported in the area (species, production-systems, small-scale/large-scale). The current siting and licensing frameworks for aquaculture in Indonesia require companies to obtain an Aquaculture Business Permit Letter (SIUP, *Surat Izin Usaha Perikanan*), which is issued by either the Indonesian Investment Coordinating Board (BKPM) or its local offices (BKMPD), depending on scale and siting of the operation. Issuance of an SIUP is not based on criteria or limits for the maximum size or number of farms or the maximum production volumes allowable within a certain area. Furthermore, environmental impact assessments (AMDAL) are only for aquaculture farms greater than 50 hectares in size, while those smaller than 50 hectares only require environmental management and monitoring measures (UKL/UPL). This leads to an incomplete understanding of cumulative impacts being exerted on an ecosystem, both by the aquaculture industry as whole and by multiple users. This results in uncertainty for potential aquaculture growth and investment, as it is unclear whether the area around a new proposed farm might be opened up for other activities that may reduce the success of the aquaculture operation.

Once spatial plans are developed and areas for aquaculture development are identified, the carrying capacity (or assimilative capacity) of selected waterbodies needs to be assessed.

71 Richards and Friess, "Rates and Drivers of Mangrove Deforestation in Southeast Asia, 2000–2012"; Polidoro et al., "The Loss of Species."

RECOMMENDATION 5: Identify and implement AMAs wherein clusters of farms coordinate management practices to reduce the risks of disease introduction and transfer.

Following the integration of aquaculture into spatial plans and zoning, an effective regulatory framework and management system should look to coordinate aquaculture management practices among multiple farms. This is particularly important for the effective management of disease and reduction of the shared risk posed to the industry by disease introduction and spread. Disease is a key issue limiting production for most established industries, both in Indonesia and globally, and it is a commonly cited reason for lowered investment confidence in the aquaculture sector. The open nature of aquaculture means that even the best managed farm is at risk of disease introduction if sited next to (or downstream from) a poorly managed farm. Indonesia's aquaculture industry structure, where 80 percent of aquaculture farms are small enterprises, inherently increases the risk of disease to the industry. The MMAF has banned the importation of shrimp and natural feed infected by Early Mortality Syndrome and Acute Hepatopancriatic Necrosis Disease; however, there are no regulatory requirements for coordinating disease management measures. Designating AMAs — clusters of farms that share common risk factors — and having producers within the AMAs commit to a minimum standard of operational practices (e.g., BMPs that cover seed sourcing) would help to reduce the likelihood of disease introduction and spread. Furthermore, emergency disease response plans should be created so that in the event of a disease outbreak it is clear who will lead the corrective actions, what the corrective actions are, and the compensation structures for crop loss. Establishing such coordinated management measures across the aquaculture industry will lend to a more robust, adaptive industry.

The open nature of aquaculture means that even the best managed farm is at risk of disease introduction if sited next to (or downstream from) a poorly managed farm.

RECOMMENDATION 6: Improve the management of the feed fish industry through innovations and fishery improvement projects (FIPs) to ensure long-term sustainability of fisheries and security of access to fishmeal and fish oil resources.

As noted in the fisheries interaction text box, *Wild Fish Inputs,* on page 16, some types of aquaculture are dependent on wild-caught fish as a key input, and this is anticipated to be a limiting factor to industry growth, both globally and in Indonesia. The global production of fishmeal has been in overall decline since 1994.[72] Despite notable gains in feeding efficiencies in many aquaculture sectors, growth of the industry will continue to drive demand for fishmeal and fish oil, while production is projected to remain relatively stable.[73] In Indonesia specifically, it has been projected that meeting the 2030 growth targets for aquaculture under business-as-usual operations would require 7.8 MMT of marine fish as feed ingredients;[74] this level of demand is only slightly more than the total amount of Indonesian wild-capture production in 2015. Indonesia currently imports about a quarter of the fishmeal used in aquaculture feed production. Under decreased availability or increased costs of fishmeal and fish oil, the aquaculture industry will be required to find efficiency gains through innovation. To date,

72 FAO, *Contributing to Food Security and Nutrition for All*.
73 World Bank, "Fish to 2030: Prospects for Fisheries and Aquaculture."
74 Phillips et al., "Exploring Indonesian Aquaculture Futures."

however, a fishmeal- or fish oil-free feed has yet to be realized and, hence, is unlikely to be realized as an industry-wide solution in the medium term. There is also currently no IFFO RS-certified whole fish or byproduct raw material, or fishmeal plants, in Indonesia, although there are currently seven BAP-certified feed mills. These mills are likely importing fishmeal to meet BAP standard requirements for marine ingredients, meaning they should have a vested interest in developing local sources of certified raw material. Effective fisheries management of forage species fisheries is imperative to protecting stocks and ensuring long-term sustainable access to the resource. Notably, governments hold the primary responsibility for fisheries management, but all value chain actors (buyers of shrimp and fish for market, farmers reliant on feed, feed companies reliant on fishmeal, and fishers reliant on stocks) should actively support improved management of these fisheries.

RECOMMENDATION 7: Establish and implement a protocol for tracking and monitoring the environmental impacts of aquaculture as part of the national One Data policy.

For any regulatory framework and management system to be effective, it should generate and be informed by quality data and information. Indonesia currently conducts and publishes an annual aquaculture census, which provides a general sense of the country's aquaculture spatial footprint at the provincial level. Though certainly useful, this limited understanding of current aquaculture locations and production could pose fundamental management challenges for regulators and practitioners. Effectively managing an aquaculture industry requires tracking the precise locations of individual farms, aquaculture areas, and production, as well as information on farm quality and the expansion and retirement rates, to understand the cumulative pressures on the region. Some of these data may already be monitored and collected by various government ministries and institutions in Indonesia; however, this is not currently done in a standardized or consistent manner. Ultimately, improving the quality of spatial data will help further the development of a Blue Economy and improve Indonesia's understanding of the value of its ocean resources.

The *One Data* policy — a joint initiative by the Executive Office of the President and the National Development Planning Agency (BAPPENAS) — aims to develop and strengthen Indonesia's data system, sharing, and governance for achieving optimum development targets.

The *One Data* policy — a joint initiative by the Executive Office of the President and the National Development Planning Agency (BAPPENAS) — aims to develop and strengthen Indonesia's data system, sharing, and governance for achieving optimum development targets. The initiative, which has an associated "One Map" policy specific to spatial planning data, mandates that each and every dataset produced by government agencies should comply with an official standard of data production (that requires common standards of interoperability, metadata, and methodology). This presents a unique opportunity to establish a baseline protocol for tracking and monitoring the spatial footprint of aquaculture that could greatly accelerate the management of the industry. To this end, multiple countries have undertaken initiatives to create online inventories of their aquaculture sector, which can be viewed online at the FAO's National Aquaculture Sector Overview (NASO) website. Indonesia has started to make progress in this direction with its SIDATIK data portal.[75]

75 Ministry of Maritime Affairs and Fisheries Data, Statistics, and Information Center (PUSDATIN-KKP), "SIDATIK."

Once a protocol for collecting location data is in place, tracking new aquaculture farms is easy. However, obtaining the location/distribution of farms in areas where aquaculture is already established is more challenging. Fortunately, over the last few decades, remote sensing with satellite imagery has proved a significant support tool for aquaculture management, including mapping, site selection, and environmental monitoring. Accurate measurements require high-resolution images, which can show definition of levees, dikes around ponds, and other aquaculture systems. Paired with remote-sensing techniques and machine-learning algorithms, these images can produce estimates of aquaculture's spatial footprint in a region of interest.

The ambitions of the Indonesian government to see the aquaculture sector grow by approximately 5.7 percent annually until 2030 will undoubtedly be challenging to realize. While there are limitations on technical knowledge and farm-level practices that, if addressed, could accelerate short-term growth, the most notable challenge is that existing regulatory systems are not sufficient to effectively manage and integrate the anticipated industry growth. Improved regulatory frameworks and management systems can reduce barriers for new entrants into aquaculture and reduce the shared risks that are most potentially damaging to the growing sector. Ultimately, this will create the conditions necessary to improve farm-level practices at a broad scale, attract investment, and support sector-wide growth.

FISH AUCTION IN REMBANG, CENTRAL JAVA, INDONESIA, PHOTO LIM W/SHUTTERSTOCK

APPENDIX A

CASE STUDY OF MANAGING FOR SPATIAL CONFLICTS BETWEEN RESOURCE USERS

In this document, we outlined the methodology of the EAA and how it can help improve farm-scale outcomes when applied properly. After initially publishing the EAA in 2008, the FAO partnered with many aquaculture-producing countries around the globe (i.e., Nicaragua, Kenya, and the Philippines) to incorporate these principles into their national legislation.[76] Events in the global aquaculture sector have shown how a lack of proper spatial planning at a national, zonal, and site level can have devastating effects on an industry. A poignant example of this is the 2007 Infectious Salmon Anemia (ISA) outbreak in Chile.

Salmon aquaculture in Chile got its start in the 1980s, and Chile quickly became one of the leading salmon exporters in the global market. Encouraged by the transfer of social and economic benefits to a traditionally impoverished region, the government promoted rapid ad hoc expansion of production.[77] But this growth quickly outpaced the capacity for effective monitoring and regulation. Areas marked as optimal for aquaculture supported very high densities of farms, leading to heavily degraded water quality.[78] While some broad spatial planning regulations were in place in Chile at the time, there was a failure to account for cumulative processes and to coordinate disease control at a zonal level.[79] Poor wastewater management, insufficient biosecurity measures (fish transfer between farms was common), and lack of spatial buffers between farms greatly exacerbated the risk of disease transmission.[80]

ISA was first officially documented in Chile in 2007 and had spread to 134 different farms by 2009, rendering vast amounts of product unsellable.[81] This had serious consequences for the Chilean economy, with production dropping from a high of 631,000 tons in 2008 to 230,000 tons in 2011.[82] Following the outbreak, public-private collaboration to implement more robust spatial planning in the short term is credited with helping curb the epidemic and restore high production levels.[83] These

76 Brugere et al., "The Ecosystem Approach to Aquaculture 10 Years on — a Critical Review and Consideration of Its Future Role in Blue Growth."
77 Alvial et al., "The Recovery of the Chilean Salmon Industry."
78 Sanchez-Jerez et al., "Aquaculture's Struggle for Space."
79 Alvial et al., "The Recovery of the Chilean Salmon Industry."
80 Ibieta et al., "Chilean Salmon Farming on the Horizon of Sustainability: Review of the Development of a Highly Intensive Production, the ISA Crisis and Implemented Actions to Reconstruct a More Sustainable Aquaculture Industry."
81 Sanchez-Jerez et al., "Aquaculture's Struggle for Space."
82 Bustos-Gallardo, "The ISA Crisis in Los Lagos Chile"; Niklitschek et al., "Southward Expansion of the Chilean Salmon Industry in the Patagonian Fjords."
83 Sanchez-Jerez et al., "Aquaculture's Struggle for Space."

measures included a reduction of allowable stocking density, fallowing periods, and zonal biosecurity measures.[84] Additionally, the Chilean government approved the creation of “barrios,” self-determined aggregations of neighboring farms for management purposes. Similar to AMAs, these divisions allowed for synchronized operations across farms and improved coordination for disease control (see Figure A1 for an example of the different spatial scales of aquaculture management in present-day Chile).

In recent years, the government has attempted to further decrease the intensity of production post hoc, by creating new areas for aquaculture to the south and providing financial incentives to relocate. This diffusion of production may help stymie future disease outbreaks, but researchers have concerns about unchecked extensification. For example, Niklitschek[85] argues that the establishment of zonal carrying capacities is of paramount importance and that no leases should be awarded until the comprehensive impacts of aquaculture on a shared water body are established. Understanding these dynamics is critical to prevent habitat deterioration and the increased risk of disease.[86]

While this case study has focused on disease control, the need for spatial management and impact assessment at aggregated scales can be easily transferred to other aspects of aquaculture best management practices (e.g., water quality and benthic impacts).

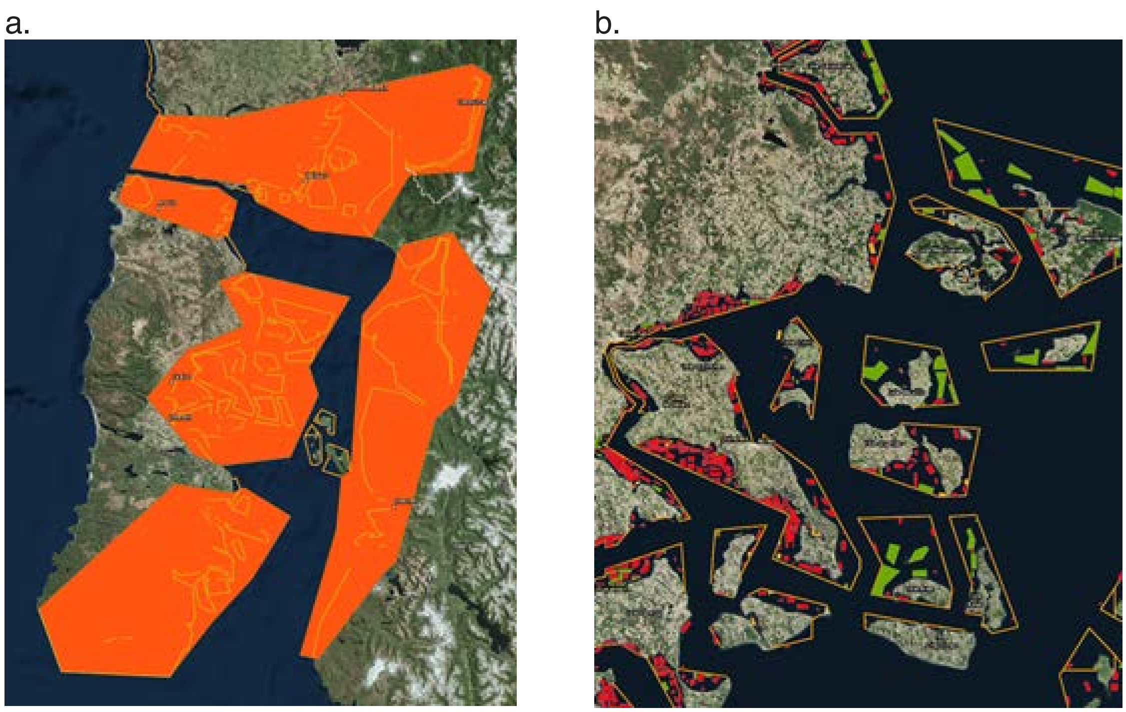

Figure A1. An example of spatial planning of aquaculture in Chile.

a. This image shows areas that have been designated by the Chilean government for aquaculture in orange. b. This image shows aquaculture farm sites, both proposed and approved (green and red polygons, respectively) and AMAs (yellow/orange outlines). These images were taken from Map Viewer: Map Viewing Application for the Undersecretariat for Fisheries and Aquaculture.

84 Alvial et al., “The Recovery of the Chilean Salmon Industry.”
85 Niklitschek et al., “Southward Expansion of the Chilean Salmon Industry in the Patagonian Fjords.”
86 Alvial et al., “The Recovery of the Chilean Salmon Industry.”

APPENDIX B

CASE STUDIES OF MANAGING FOR WATER QUALITY

Case studies that can be offered for worldwide application in the areas of carrying capacity/ assimilative capacity and water quality are not abundant. Nevertheless, methodologies for site selection[87] and disease risk[88] are potentially useful for this purpose, since they attempt to optimize the use of space and use connectivity as a metric for potential problems. The lack of generality in solutions occurs partly because issues differ in scale and nature (e.g., eutrophication in Norwegian fjords when compared to estuaries receiving shrimp pond discharges); however, broadly speaking, best management practices should combine monitoring with modelling. The application of the tools used to manage aquaculture within carrying-capacity limits such as those described in this document have a number of challenges:

1. In emerging economies, the legal framework is often more focused on chemical indicators than on ecosystem-based management. Sanggou Bay, in NE China, which produces about 150,000 tons per year of shellfish, seaweeds, and finfish at an average density of about 1 kg/m^2, is a good example of a system where the Chinese national assessment methods for eutrophication do not account for top-down control of algal blooms by organic extractors such as scallops and kelp.[89]

2. The vast majority of areas where aquaculture takes place tend to be data-poor, which complicates the use of mathematical models. Often, a simplified approach such as the Dillon-Rigler model[90] is applied to a problem it was never designed to address. However, in recent years, the use of global satellites and other tools is helping to address data paucity.[91]

3. Finally, the logistic and financial capacity for monitoring, together with data interpretation and application for models, is a significant challenge. This can be compounded by governance issues — taken together, these aspects affect integrated management, even in cases where best practice can be defined.

The most advanced approaches to integrated management of aquaculture are deployed in Canada, Europe, and the United States, where land-based aquaculture is practically non-existent (FAO, 2016).

87 Silva et al., "Site Selection for Shellfish Aquaculture by Means of GIS and Farm-Scale Models, with an Emphasis on Data-Poor Environments"; Brigolin et al., "Space Allocation for Coastal Aquaculture in North Africa."

88 Skarðhamar et al., "Modelled Salmon Lice Dispersion and Infestation Patterns in a Sub-Arctic Fjord."

89 Xiao et al., "Trophic Assessment in Chinese Coastal Systems - Review of Methods and Application [Unk]o the Changjiang (Yangtze) Estuary and Jiaozhou Bay."

90 Dillon and Rigler, "A Test of a Simple Nutrient Budget Model Predicting the Phosphorus Concentration in Lake Water."

91 Filgueira et al., "Ecosystem Modelling for Ecosystem-Based Management of Bivalve Aquaculture Sites in Data-poor Environments"; Silva et al., "Site Selection for Shellfish Aquaculture by Means of GIS and Farm-Scale Models, with an Emphasis on Data-Poor Environments"; Brigolin et al., "Space Allocation for Coastal Aquaculture in North Africa."

For coastal systems, these approaches are (i) often supported by costly and complex mathematical models, (ii) constrained in good part by social license, and (iii) the cause of significant barriers to entry which result in permitting delays and reduced sector growth. The transposition and adaptation of European or North American agriculture management models as a proxy for land-based aquaculture in SE Asia, South America, or other parts of the world is a possibility, but here again there are substantial caveats: (i) in the United States, the most significant problems with eutrophication symptoms, such as elevated chlorophyll and hypoxia in coastal areas, are thought to be linked to non-point discharges (e.g., Turner et al., 2005); (ii) efforts in Europe to limit nutrient emissions to coastal areas by means of instruments such as the Water Framework Directive (2000/60/EC) have resulted in a reduced ability of (land) farmers to compete economically.

Although there is no single solution for integrated aquaculture management with respect to water quality and carrying capacity, the following aspects may be identified as contributing to best practice:

- Understanding of scale. Effects in the water column (e.g., eutrophication) manifest themselves on a scale of days to weeks, which helps define both the loading capacity and the spatial area of interest. Effects on sediment are on a longer time scale, but smaller spatial scale. An understanding of scales provides guidance on regional planning.
- Boundaries may be more important than internal processes, both as a function of water residence time and mesoscale events. In the case of some issues such as offshore harmful algal blooms, integrated management is currently reactive and can provide no control measures apart from interdiction.
- Co-cultivation of different trophic levels may help mitigate some water quality impairment, but this is limited to specific conditions — for instance in coastal culture in the West, currently permissible stocking densities do not make this a realistic solution. The situation may differ in restricted environments such as ponds, but the trend toward industrial aquaculture increasingly promotes monoculture.
- Land-based aquaculture (shrimp, finfish) will respond much quicker than open-water culture to unsustainable conditions. If there is a need for excessive water renewal and waste removal, this is a clear indicator of potential problems, both within the system itself and as an externality to the receiving water.
- Integrated water abstraction and discharge for areas of land-based culture where multiple ponds exist may help to define environmental metrics in a more rigorous way and help control loads. For instance, the specification of a maximum distance between intake and outfall could help to internalize regulation.
- In many situations, land-based and marine systems operating in excess of ecological carrying capacity exhibit clear visual or other symptoms of degradation, such as excessive algal growth or anoxic sediment — complex mathematical models are not required for diagnosis.
- Ecosystems respond non-linearly to stressors, and this is exacerbated with multiple stressors, which results in the challenge of managing assimilative capacity. Prediction of tipping points is usually impossible, but adequate environmental monitoring can make a significant contribution

to the timely identification of ecosystem trajectory — the variance is more important than the mean.

- Environmental monitoring is a key aspect of several of the points above — good quality data, obtained both through direct observations and techniques such as remote sensing, are essential for integrated management. For coastal systems, mathematical models can help determine the spatial extent and resolution of a sampling program, and characterize the major temporal scales of variability.

INDONESIAN FISHERMEN, FROM THE ISLAND OF FLORES, NEAR A CORAL REEF, PHOTO ETHAN DANIELS/SHUTTERSTOCK

APPENDIX C

CASE STUDIES OF MANAGING FOR DISEASE

Whether aiming to eradicate a notifiable pathogen following its introduction, or manage an endemic disease concern, coordinated disease management can be highly effective. Some of the clearest examples of coordinated disease management come from Europe, as there is a robust regulatory framework in place that facilitates it. A good example of the effective application of coordinated disease management in inland systems is the control of Spring Viremia in Carp (SVC) in the UK. [92] SVC is an OIE-listed disease that affects many cyprinid species and emerged in the UK in 1977.

In 2005, the UK adopted a coordinated control and eradication program and was successfully recognized as being free of the pathogen in 2010. This was possible as the pathogen was listed in legislation that allowed national measures to be implemented and made it a legal obligation for anyone suspecting the disease to report it to the authority, thus forming the basis of a passive surveillance program. To optimize this passive surveillance program, the authority worked closely with a wide variety of industry bodies, veterinarians, and other government agencies to help them recognize signs of the disease and explain the reporting procedure and its importance.

In addition to passive surveillance, the authorities conducted active surveillance in collaboration with other government and industry bodies, which focused on testing aquaculture sites, traders, and imports at particular risk of the disease. Testing was conducted at high-risk periods relating to temperature thresholds for the disease and targeted moribund or unhealthy-looking animals wherever possible, to help maximize the likelihood of disease detection. On initial suspicion of the disease, the authority would place temporary movement restrictions on a site until testing confirmed whether the disease was present, to prevent the potential for onward spread. Due to the importance of the test results, the test methodologies were conducted to a very high-quality standard and followed OIE guidelines to ensure accuracy.[93]

On confirmation of the disease, sites were placed under official controls preventing the movement of animals on or off site until all stock was culled and the site was disinfected to the satisfaction of the authority, or the site had undergone three consecutive years of testing negative for the virus. Following disinfection, sites may also have been required to undergo a fallow period before restocking. Where culling and disinfection was not possible, sites were required to implement stringent biosecurity measures.

All sites linked to infected sites either by a live fish movement or significant hydrological connections were also tested for the presence of the pathogen and subjected to the same controls if testing positive. To prevent further introductions of the pathogen, a large focus was also placed on trade. On

92 Taylor et al., “Spring Viraemia of Carp (SVC) in the UK.”
93 OIE, “Access Online.”

formally declaring that the UK was entering a control and eradication program for the SVC, imports of live fish were restricted to countries or compartments certified free of the disease. Additional testing was also carried out on selected consignments of fish on arrival at the border inspection posts, to further ensure the safety imports. A strong focus was also placed on detecting and preventing the illegal import and movement of fish, which relied heavily on developing a good relationship with stakeholders and other government agencies to inform a strong intelligence network.

The measures implemented at a national level proved highly effective for the eradication of SVC, but they have also proven effective for the control of disease in marine systems. A good example of this is for Infectious salmon anaemia (ISA), which is another OIE-listed pathogen that has caused significant disease issues in global Atlantic salmon aquaculture. Scotland, Norway, and the Faroe Islands, which have all been affected by ISA, adopted similar measures to those described for SVC to control and eradicate the pathogen.[94] In these systems, one of the key challenges is to prevent the hydrodynamic connections between sites, and substantial efforts have been made in each of these cases to create disease management zones, often based on the results of mathematical modelling studies, in which to apply controls and reduce the likelihood of spread between farming areas.

In the case of endemic disease, the same principles apply as documented above; however testing tends to be done pen-side by the site itself, and the focus tends to be on management to minimize impacts to production and wild animals, rather than eradication. Where possible, an integrated approach to management is adopted across aquaculture areas that combines chemotherapeutant treatments with other control and prevention measures. The most obvious example of this is the control of sea lice within salmon aquaculture.[95] Sea lice are often managed at the area level, with sites within an area being required to conduct regular monitoring for lice and submit counts to the regulating body. Once one site reaches a count beyond a certain threshold, all sites in that area are required to treat to reduce the parasite burden. Sites within an area may also be subject to synchronized harvesting and fallowing periods ("all-in-all-out"), and area-based limits may be placed on total permissible biomass and the length of production cycles.[96]

Coordinated disease management, as described above, is starting to be adopted in shrimp aquaculture, but the level of coordinated management across countries and regions seems variable at present, and the focus of management is still at the farm level. Guidelines on shrimp health management have been issued by organizations such as The Marine Products Export Development Authority (MPEDA) and Network of Aquaculture Centres in Asia-Pacific (NACA) (MPEDA/NACA 2003), and Worldfish have provided training in health management in countries such as Bangladesh, which has aided production increases. These guidelines and training cover aspects of management such as: biosecurity, crop planning, pond preparation, disease surveillance, risk assessment, and

94 Miller et al., *International Response to Infectious Salmon Anemia*; Mardones, Perez, and Carpenter, "Epidemiologic Investigation of the Re-Emergence of Infectious Salmon Anemia Virus in Chile."; Murray et al., "Epidemiological Investigation into the Re-Emergence and Control of an Outbreak of Infectious Salmon Anaemia in the Shetland Islands, Scotland."

95 Jackson et al., "The Drivers of Sea Lice Management Policies and How Best to Integrate Them into a Risk Management Strategy."

96 Werkman et al., "The Effectiveness of Fallowing Strategies in Disease Control in Salmon Aquaculture Assessed with an SIS Model"; Arriagada et al., "Evaluating the Effect of Synchronized Sea Lice Treatments in Chile."

control. Social science and risk analysis are playing an important role in understanding current behaviors and drivers, which is in turn helping to develop guidelines for good practice.

Research into shrimp diseases has received increased attention over the past decade, with a large focus on diagnosis and detection. This research is leading to the development of rapid pond-side testing to allow farmers to detect disease early and make decisions on whether there is a need for an emergency harvest in order to prevent outbreaks of white spot syndrome virus (WSSV).[97] Research projects are now also investigating whether environmental risk factors and other indicators can be identified that would allow early warnings for high disease risk to be developed, and mobile phone technologies are being evaluated as a diagnostic reporting tool.

Currently, few control measures exist for the majority of shrimp diseases, and emergency harvest is one of the only existing measures to ensure farmers retain a profit from a production cohort. Substantial research is therefore focused on developing and evaluating new control and management measures, such as vaccines, probiotics, and chemotherapeutants. However, for management efforts for shrimp disease to work effectively at the area level, it will be critical to:

- Have good coordinating bodies and buy-in from across the industry
- Foster strong working relationships between industry and regulatory bodies
- Establish regular, mandatory testing and reporting of disease incidence
- Develop coordinated disease management plans under both “typical” operations and emergency disease-response plans.

PRAWN PROCESSING FACTORY IN TARAKAN, INDONESIA, PHOTO NORJIPIN SAIDI/SHUTTERSTOCK

97 Bondad-Reantaso et al., *Disease and Health Management in Asian Aquaculture*; Flegel et al., “Shrimp Disease Control.”

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CONSERVATION INTERNATIONAL

Building upon a strong foundation of science, partnership, and field demonstration, CI helps societies responsibly and sustainably care for nature, our global biodiversity, for the wellbeing of humanity. We operationalize this mission through the integration of three key elements: protecting our natural wealth, promoting sustainable production, and fostering effective governance. Founded in 1987, CI has helped support 1,200 protected areas and interventions across 77 countries, safeguarding more than 601 million hectares of land, marine, and coastal areas.

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SFP's mission is to engage and catalyze global seafood supply chains in rebuilding depleted fish stocks and reducing the environmental impacts of fishing and fish farming. Our work is organized around two main principles: making available up-to-date information on fisheries and aquaculture for the benefit of major buyers and other seafood stakeholders; and using that information to engage all stakeholders along the supply chain in fisheries and aquaculture improvements and moving toward sustainability. Founded in 2006, SFP now has a staff of more than 60 globally and projects in more than two dozen countries.

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