Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture
A handbook

**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS/
THE WORLD BANK**

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Cover photograph:

Oyster culture in Chanthaburi, Thailand

Molluscs feed low on the food chain, which make them a relatively cheap source of protein. Culture plots can be established and managed by individual farmers, a cluster of farmers, or the community. This neat and well-managed stretch of oyster culture units in Chantaburi Province, Thailand, reflects some of the advantages of community-based aquaculture management in terms of an equitable and conflict-free access to the water resource, clean culture environment and improved incomes. Off-bottom culture techniques include polyethylene rafts, longlines, racks and cages.

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PREPARATION OF THIS DOCUMENT

The Seventh Session of the Sub-Committee on Aquaculture of the FAO Committee on Fisheries (COFI) acknowledged the growing importance of spatial planning to promote aquaculture growth, and requested the Food and Agriculture Organization of the United Nations (FAO) to develop a step-by-step guide for the implementation of spatial planning tools and continue capacity building in developing countries. Furthermore, environmental, aquatic animal health and socioeconomic issues require an ecosystem approach to management of the sector moving beyond individual farms to the management of spatial units such as aquaculture zones or aquaculture management areas. To this end, FAO in partnership with the World Bank have prepared this publication on aquaculture zoning, site selection and aquaculture management areas under the ecosystem approach to aquaculture. It is aimed primarily at managers and policy-makers, but has relevance to a wide range of stakeholders.

An expert workshop on Site Selection and Carrying Capacities for Inland and Coastal Aquaculture convened on 6–8 December 2010 at the Institute of Aquaculture, University of Stirling, the United Kingdom of Great Britain and Northern Ireland, and proposed the development of a guide for aquaculture site selection and carrying capacity estimation within an ecosystem approach to aquaculture.

This publication builds on the experiences gained in that expert workshop. This document was validated by contributors to this publication and other international experts at a workshop in Izmir, Turkey, on 5–8 July 2015. It was also tested in a few countries such as Angola, Kenya and the United Republic of Tanzania before it was finalized.

The purpose of the publication is to provide practical guidance on spatial planning to managers, policy-makers, technical staff and farmers. The publication reviews spatial planning and management of aquaculture development within the framework of the ecosystem approach to aquaculture development, and also presents suggestions for a strategy for their implementation using an area management approach to ensure greater sustainability for future aquaculture development initiatives by governments. It is based on the FAO Code of Conduct for Responsible Fisheries, which contains principles and provisions in support of sustainable aquaculture development. The publication is global in its reach and is aimed to be of relevance and use in developing countries.

The handbook and Annexes 1, 2, 3 and 4 were edited by FAO/World Bank. However, Annexes 5 (case studies) and 6 (workshop report) have been reproduced as submitted.

ABSTRACT

The ecosystem approach to aquaculture provides the conceptual guideline for spatial planning and management. This publication describes the major steps related to these activities. The rationale for and objectives of each step, the ways (methodologies) to implement it, and the means (tools) that are available to enable a methodology are described in a stepwise fashion. Recommendations to practitioners and policy-makers are provided. A separate policy brief accompanies this paper. The benefits from spatial planning and management are numerous and include higher productivity and returns for investors, and more effective mitigation of environmental, economic and social risks, the details of which are provided in this paper. While the costs are not explicit, the publication describes the resources required–some in broad terms, others in more detail –to apply the methodologies and to acquire and use essential tools.

This publication is organized in two parts. Part one is the "Guidance"; it is the main body of the document and describes the processes and steps for spatial planning, including aquaculture zoning, site selection and area management.

Part two of the publication includes six annexes that present key topics, including: (i) binding and non-legally binding international instruments, which set the context for sustainable national aquaculture; (ii) biosecurity, zoning and compartments, infected zones and disease-free zones; (iii) aquaculture certification and zonal management; (iv) an overview of key tools and models that can be used to facilitate and inform the spatial planning process; (v) case studies from ten countries–Brazil, Chile, China, Indonesia, Mexico, Oman, the Philippines, Turkey, Uganda and the United Kingdom of Great Britain and Northern Ireland; and (vi) a workshop report.

The country case studies illustrate key aspects of the implementation of spatial planning and management at the national level, but mostly within local contexts. Take-home messages include the ways in which institutional, legal and policy issues are addressed to implement the process, or parts of the process. Some of the case studies such as Chile, Turkey and the United Kingdom of Great Britain and Northern Ireland provide examples of the benefits to the aquaculture industry from the application of spatial planning and management.

Aguilar-Manjarrez, J., Soto, D. & Brummett, R. 2017. *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. A handbook.* Report ACS18071. Rome, FAO, and World Bank Group, Washington, DC. 62 pp. Includes a USB card containing the full document (395 pp.).

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A separate policy brief that accompanies this paper was prepared with inputs of Pete Bueno. The authors would also like to thank the Institute of Marine Sciences and Technology, Dokuz Eylul University, for hosting the workshop in Turkey in 2015 where this publication was presented and improved, and in particular Guzel Yucel Gier for her kind assistance in the organization and assistance at the workshop. The authors thank Maria Giannini for proofreading the document, and the participants at the workshop in Turkey for their valuable inputs. The document layout specialist was Koen Ivens.

This publication has been realized with the financial support of the World Bank.

ABBREVIATIONS AND ACRONYMS

AMA	aquaculture management area
COFI	AO Committee on Fisheries
DEPOMOD	computer particle tracking model
DFO	Department of Fisheries and Oceans Canada
EAA	ecosystem approach to aquaculture
EIA	environmental impact assessment
FAO	Food and Agriculture Organization of the United Nations
GIS	geographic information system
IUCN	International Union for Conservation of Nature and Natural Resources
MOM	Modelling–Ongrowing fish farms–Monitoring
BMP	better management practice
EQS	environmental quality standards
FARM	Farm Aquaculture Resource Management
FCR	feed conversion ratio
HAB	harmful algal bloom
HACCP	hazard analysis and critical control point
IMTA	integrated multi-trophic aquaculture
ISA	infectious salmon anemia
SSPO	Scottish Salmon Producers Organisation

FOREWORD

With increasing wealth, health consciousness and global population, coupled with continued reliance of poor coastal communities on fish for protein, demand for seafood is increasing. Current levels of wild capture fisheries are unsustainable and declining. Aquaculture is a key component of closing the distance between demand and supply.

New investment in the order of US$100 billion is needed to grow aquaculture, but the generally small scale and organic growth of the aquaculture industry has made it difficult to plan and regulate, contributing importantly to the high levels of risk perceived by potential new investors. In particular, poor spatial planning can undermine the viability of businesses and the social and economic benefits derived from aquaculture development. Vulnerability to external shocks, the outbreak and spread of disease, environmental impacts, and social conflicts with other resource users are all symptomatic of bad planning. And, of course, the flip side is true: good spatial planning can attract investment while ensuring equitable access to ecosystem services by communities, helping countries achieve the desired social and economic outcomes resulting from aquaculture development and at the same time protecting the environment, all essential elements of the "Blue Economy". It is also a key element in building resilience to climate change and resolving transboundary issues around trade and biosecurity.

The Food and Agriculture Organization of the United Nations (FAO) Fisheries and Aquaculture Proceedings No. 21 on Site selection and carrying capacities for inland and coastal aquaculture, published in 2013, lays out the theoretical underpinnings of an ecosystem approach to aquaculture. This handbook seeks to describe its implementation and ensure that countries and communities can integrate their investments in aquaculture within the wider ecosystem, such that it promotes sustainable development, equity, and resilience of interlinked socio-economic systems.

Good spatial planning and management are absolutely essential if aquaculture is to maximize its potential to reduce poverty and hunger and meet the demand from the growing middle class. The World Bank and FAO together are delighted to have, at last, a comprehensive handbook to help us do just that.

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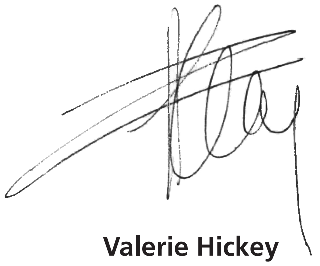

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1. INTRODUCTION

1.1 Objectives and target audience

Generally, the starting point for national aquaculture planning comes from a need for fish, jobs and/or taxable revenues from organized aquaculture development. Unplanned aquaculture development has led to negative environmental and social impacts that can outweigh the benefits of growing more fish or other aquatic products. Some countries with experience in aquaculture have adopted spatial planning[1] based on a balance between environmental carrying capacity, social risks and economic opportunities to minimize negative impacts while permitting the industry to contribute to the national economy. The main objective of this publication is to provide practical guidance on spatial planning to a broad range of stakeholders. These stakeholders are the target audience for this publication and include policy-makers, regulators, developers, farm managers, scientists and providers of extension services, whose relevance is defined in Table 1.

This publication is presented in two parts. Part 1 "Guidance" is the main body of the document and describes the processes and steps for spatial planning, including aquaculture zoning, site selection and area management.[2]

Specific processes and steps are placed in their relevant context to highlight their rationale and how they can be applied within a spatial planning framework. The guidance (Part 1) can be used as a "standalone" section by policy-makers, planners and stakeholders with reference to Part 2 as appropriate. The guidance is necessarily generic because the approaches will vary significantly depending on location and application, but broadly agreed-upon steps and a common framework for more sustainable approaches are described. Possible activities and spatial planning tools are briefly introduced in Part 1 with a few examples of their application.

Part 2 includes "six annexes" that present key topics: (i) binding and non-legally binding international instruments, which set the context for sustainable

TABLE 1. Users of this publication

Users	Relevant processes and activities
Policy-makers	Guide on policies, requirements and processes for responsible aquaculture planning and management
Regulators	All the sections and steps are relevant to improve norms, regulations and enforcement, including zoning, site selection, licencing and permitting, fish health management, area management systems, monitoring and feedback
Farm developers	Relevant guide on farm site selection, carrying capacity and maximum production limits, environmental impact assessments and biosecurity
Farm managers	Management of the farm and coordination with neighbouring farms within the aquaculture management area for biosecurity, health management and environmental management
Scientists	Zone and site selection tools, carrying capacity estimation, and environmental and health monitoring surveys
Extension services	Support zoning processes, aquaculture management area development and servicing, including biosecurity

[1] Spatial planning refers to the methods used by the public sector to influence the distribution of people and activities in spaces of various scales. Spatial planning takes place at the local, regional, national and international levels and often results in the creation of a spatial plan. Spatial planning also entails a system that is not only spatial, but one that also engages processes and secures outcomes that are sustainable, integrated and inclusive (FAO, 2013).

[2] A separate policy brief accompanies this paper. See FAO & World Bank. 2015. Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. Policy brief. Rome, FAO. (also available at www.fao.org/documents/card/en/c/4c777b3a-6afc-4475-bfc2-a51646471b0d/)

national aquaculture; (ii) biosecurity, zoning and compartments, infected zones and disease-free zones; (iii) aquaculture certification and zonal management; (iv) an overview of key activities and relevant tools that can be used to facilitate and inform the spatial planning process; (v) case studies from ten countries –Brazil, Chile, China, Indonesia, Mexico, Oman, the Philippines, Turkey, Uganda and the United Kingdom of Great Britain and Northern Ireland; and (vi) a workshop report. A summary analysis of the ten case studies is provided to highlight the main gaps and issues in the processes of zoning, site selection and design of aquaculture management areas. The ten case studies are presented in detail to describe the processes and steps carried out by each country.

Part 2 should be read in conjunction with Part 1, as the latter provides the context and rationale for the former. The most important activities and tools that can be used to facilitate more integrated planning are reviewed. Where appropriate, the reader is directed to other more comprehensive reviews and other documents.

This publication provides practical advice based on field experience in planning of aquaculture using selected case studies from around the world. Practitioners are encouraged to select, modify and continuously adapt their approaches and tools to their own specific circumstances. It calls for pragmatic and systematic, but flexible planning and management, combined with a good dose of participation, patience, persistence, adequate funding and good governance to create an enabling environment conducive to sustainable aquaculture development.

1.2 Why spatial planning of aquaculture?

Inappropriate spatial arrangement and site selection of aquaculture is a major constraint to sustainable development and expansion of the industry. To create a successful aquaculture business, it is necessary to have farm sites based in locations that are suitable for sustainable production. All aquaculture species have specific biological needs such as oxygen, temperature and good water quality that have to be fulfilled to secure high production and to minimize stress and disease. Location of aquaculture farms require access to land and water where use must also co-exist with other human activities. Access to roads and electricity (infrastructure) is also necessary. A poor location of an aquaculture farm or zone will not only create environmental problems such as localized eutrophication, it may also have a broader impact on environmental, social and economic aspects, such as conflicts with other human activities over the use of inland and coastal zone resources, that can detract from the benefits of a sustainable aquaculture industry.

Common problems arising from the lack of spatial planning and management of aquaculture can be categorized as: (i) fish disease; (ii) environmental issues; (iii) production issues; (iv) social conflict; (v) post-harvest and marketing issues; (vi) risk financing; and (vii) lack of resilience to climatic variability, climate change and other external threats and disasters. Spatial planning and management of aquaculture can be done at several geographical scales to address problems in aquaculture and provide opportunities to enhance development (Table 2).

When spatial planning is within a Blue Growth or Blue Economy Programme, there are additional opportunities to link to other initiatives such as innovative financing and energy efficiencies which can improve social, economic and ecosystem outcomes.[3]

Spatial planning could also be a means to improve negative public perception about potential environmental impacts, especially those associated with marine fish farming, and on access to and use of coastal resources.[4,5]

[3] FAO. 2015. Achieving Blue Growth through implementation of the Code of Conduct for Responsible Fisheries. Policy Brief. Rome, FAO. (also available at www.fao.org/fileadmin/user_upload/newsroom/docs/BlueGrowth_LR.pdf).

[4] Bacher (2015) provides a global overview and synthesis of studies on perceptions of aquaculture in both developed and developing countries. The document also includes recommendations for policy-makers, the industry and other stakeholders on improving public understanding of aquaculture and on the roles various actors can play in this process.

[5] The FAO workshop *"Increasing Public Understanding and Acceptance of Aquaculture – the Role of Truth, Transparency and Transformation"* was held in Vigo, Spain, in October 2015. The workshop covered a number of core topics related to the perceptions of aquaculture, including transparency and ethics, communication, collaboration, responsibilities and new approaches to better management of sector performance and perceptions (FAO, 2016a).

TABLE 2. Problems associated from the lack of spatial planning and opportunities through aquaculture zoning and area management

Problems	Opportunities
Fish disease and lack of effective biosecurity, e.g. when farms are too close to each other and/or do not respect basic rules of farm-level disease prevention.	• Minimize fish disease risks and coordinated response to outbreaks. • Improve access to finance when overcoming biosecurity concerns.
Environmental issues such as eutrophication, biodiversity and ecosystem service losses, e.g. when there are too many farms in a given area or waterbody.	• Better coordinated and integrated approaches to the use and management of natural resources. • Improved animal welfare and growth rates.
Production issues such as lower growth and biomass of filter feeders (e.g. oysters, mussels) due to excessive farming density and overharvesting of common-pool oxygen and microalgae.	• Improved filter-feeders' productivity and yield
Social conflicts, equity issues and lack of public confidence in the sustainability of aquaculture, e.g. when aquaculture is competing with other users for access to water and space use.	• Improved accountability and transparency through relevant stakeholder involvement at all levels and documented environmental management. • improved public perception of aquaculture
Post-harvest and marketing issues, e.g. when individual neighbour farmers do not have access to post-harvest services.	• Clusters of farmers having better access to common post-harvest processes and other services. • Area-based management and certification as a governance and risk-sharing model for sustainable aquaculture.
Risk financing. National governments and financing institutions do not have a good knowledge of where the prospects for aquaculture development are the most promising before committing resources to development.	• National-level information on areas available to invest on aquaculture. • Implementing area-based management strategies (e.g. clusters of farmers) to facilitate access to finance.
Lack of resilience to climatic variability, climate change, and other external threats and disasters, e.g. hurricanes, tsunamis, drought, and industrial pollution of water sources.	• A more resilient sector, better adapted to shocks. • More effective mechanisms for governments and other institutions, including civil society organizations, to deliver services and fulfil their commitments to sustainable aquaculture development.

1.3 The ecosystem approach to aquaculture

One of the major challenges for the sustainable development of aquaculture is the sharing of water, land and other resources with alternative uses, such as fisheries, agriculture and tourism. Spatial planning for aquaculture, including zoning, site selection and the design of aquaculture management areas, should consider the balance between the social, economic, environmental and governance objectives of local communities and sustainable development. It is now widely recognized that further aquaculture development should be a planned activity that is designed in a more responsible manner so as to minimize negative social and environmental impacts as much as possible. One essential step is appropriate spatial planning at the local, regional and national levels, and accounting for transboundary issues where these are relevant. Although many of the social and environmental concerns surrounding impacts derived from aquaculture may be addressed at the individual farm level, most impacts are cumulative. Impacts may be insignificant when an individual farm is considered, but potentially highly significant when multiple farms are located in the same area, or when the entire sector is taken as a whole. The process and steps through which aquaculture is spatially planned and managed, and integrated into the local economy and ecological context is termed the ecosystem approach to aquaculture (EAA). Three principles govern the implementation of the EAA:

(i) Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience.
(ii) Aquaculture should improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of incomes).
(iii) Aquaculture should be developed in the context of other sectors, policies and goals, as appropriate.

The EAA provides a planning and management framework to effectively integrate aquaculture into local planning, and give clear mechanisms for engaging with producers and the government for the effective sustainable management of aquaculture operations by taking into account local and national social, economic, environmental and governance objectives.

The EAA benefits from having a national aquaculture and/or other relevant policy (e.g. food security, coastal zone management) to guide implementation, and depends on legally binding and fair regulation and allocation of user rights. Mandated under the EAA are permanent stakeholder consultations and use of best available knowledge to underpin policy and enforcement (FAO, 2010).

2. IMPLEMENTATION OF AQUACULTURE SPATIAL PLANNING AND MANAGEMENT

2.1 Process

A process for aquaculture site selection and carrying capacity estimation within the framework of an ecosystem approach to aquaculture was initially elaborated by Ross *et al.* (2013). A comprehensive planning process should begin with the formation of an appropriate task team to evaluate the pros and cons of aquaculture and to create a roadmap for its sustainable development. The task team is usually comprised of government policy-makers and technical experts in aquaculture, business development and aquatic ecosystem management.

The first activity of the aquaculture task team is to undertake a national scoping exercise aimed at establishing objectives for aquaculture, reviewing relevant laws, identifying general areas that might be suitable for various types of aquaculture, establishing national priorities for ecosystem conservation and conversion, and determining who might be the relevant stakeholders to engage in decision-making. Scoping is often done within the context of a national aquaculture strategy or policy exercise and influences each subsequent step in the spatial management process.

Once scoping has identified aquaculture as a priority at the national level, detailed plans are elaborated for progressively smaller geographical units at the regional and local levels, as appropriate. The process of spatial planning usually consists of the following three steps:

(i) Aquaculture zoning: bringing together the criteria for locating aquaculture and other activities in order to define broad zones suitable for different activities or mixes of activities.
(ii) Site selection: identifying the most appropriate locations for individual farm development within zones.
(iii) Aquaculture management areas (AMAs): within zones, AMAs contain a number of individual farms that share a common water supply and/or are in such proximity that disease and water quality are best managed collectively rather than by individual farms.

An aquaculture zone can be all or part of any hydrological system that is at least partly suitable for aquaculture, whether it be the open ocean (normally within the exclusive economic zone), a bay, part of a river or estuary, or any inland waterbody (lake or dam). The creation of zones facilitates the integration of aquaculture activities into areas already being exploited by other users. The effectiveness of zoning depends upon its simplicity, clarity and degree of local support.

Site selection is the process by which the biophysical attributes of a prospective site are compared with the needs of cultured organisms and the proper functioning of aquaculture farms. Poor site selection is a major cause of failure in aquaculture development. This process is normally led by the private sector, local landowners and others seeking to embark on an aquaculture business venture. Governments maintain control through clear regulations that define the process and requirements for site licencing.

As all farms within a constrained space contribute to nutrient loading, the spread of diseases and other impacts of aquaculture, some kind of collective management is often needed. AMAs are defined as shared waterbodies, or parts thereof, where all the aquaculture operators agree (coordinate and cooperate) to certain management practices or codes of conduct that act to minimize the overall impacts from their collective activities. Estimation and evaluation of the biological carrying capacity of zones, farm sites and AMAs, and biosecurity considerations are the baseline upon which allowable fish and farm density are based.

Once AMAs have been established with a clear management plan, a system for monitoring the plan is needed to allow for review and iterative adjustment as the need arises. Individual components of the plan such as biosecurity, social and environment measures will need to be periodically adjusted as technology and the local production and socio-economic context evolve. A schematic diagram of the potential steps in the spatial planning and management process is presented in Figure 1.

2.2 Recommended steps

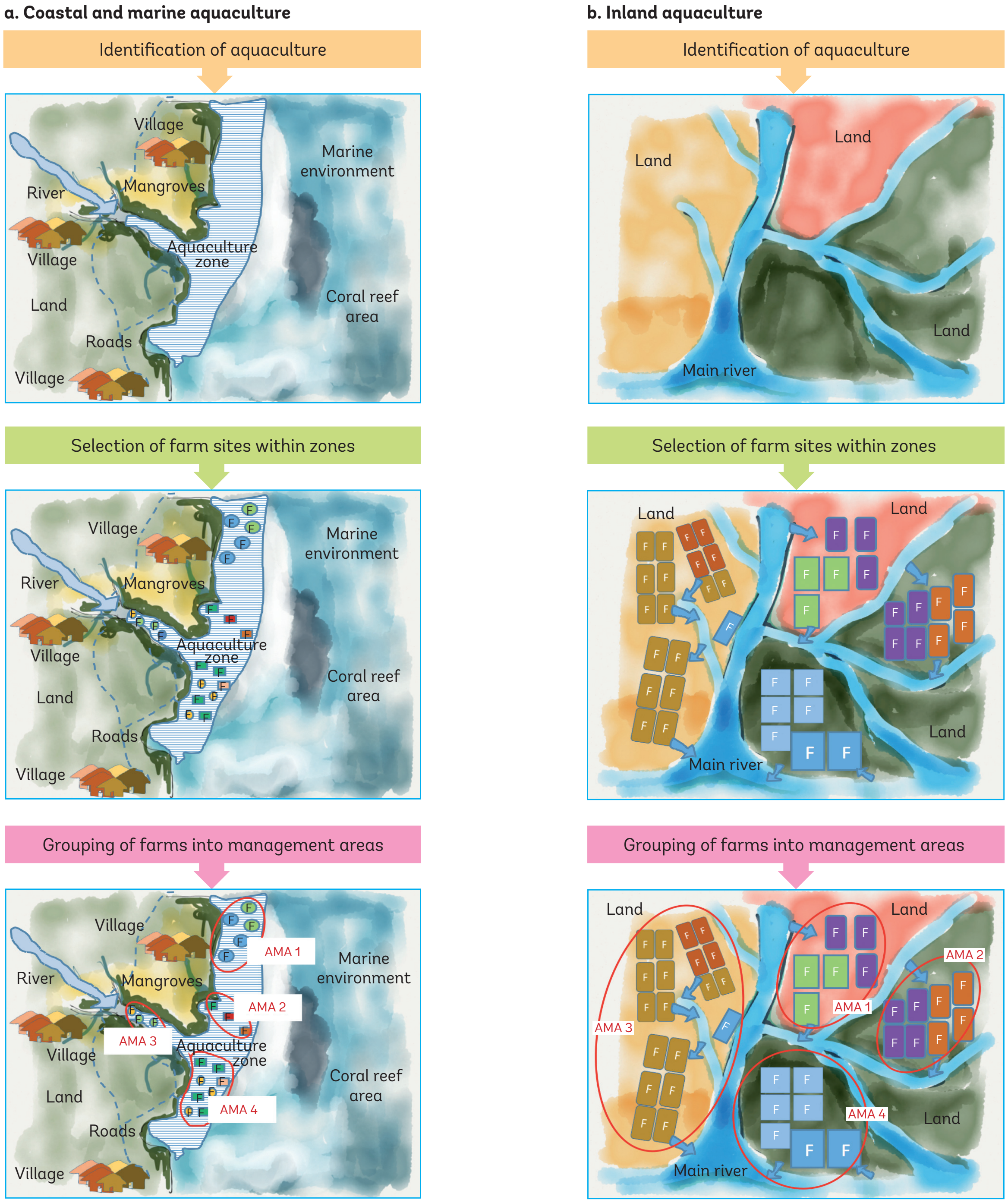
The order in which the main steps shown in Figure 1 and Table 3 are taken depends upon the local situation. For example, when aquaculture is completely new to a country or to a large geographical area, practicioners might want to start with a broad scoping exercise, followed by zoning, site selection, design of aquaculture management areas, and elaboration of the corresponding management plans. In countries or geographical areas where aquaculture farms/structures are well established, however, it may not be possible to relocate farm/structures (e.g. ponds, tanks, raceways) to meet carrying capacity, biosecurity and socially acceptable thresholds. Under these circumstances, there may be an obligation to begin with the definition of AMAs and management plans;

TABLE 3. Main characteristics of the process for scoping, zoning, site selection and area management for aquaculture

Characteristics	Scoping	Zoning	Site selection	Area management
Main purpose	Plan strategically for development and management	Regulate development; minimize conflict; reduce risks; maximize complementary uses of land and water	Reduce risk; optimize production	Protect environment; reduce disease risk; reduce conflict
Spatial scale	Global to national	Subnational	Farm or farm clusters	Farm clusters
Executing entity	Organizations operating globally; national aquaculture departments	National and local governments with aquaculture responsibilities	Commercial entities	Farmer associations; regulating agencies
Data needs	Basic, relating to technical and economic feasibility, growth and other uses	Basic environmental, social and economic sets	All available data	Data for carrying capacity and disease risk models
Required resolution	Low	Moderate	High	High
Results obtained	Broad, indicative	Directed, moderately detailed	Specific, fully detailed	Moderately to fully detailed

Source: Kapetsky and Aguilar-Manjarrez (2013).

FIGURE 1. Potential steps in the spatial planning and management process for coastal, marine and inland aquaculture



Note:

- Schematic figure of a designated aquaculture zone (hatched area in blue colour) representing an estuary and the adjacent coastal marine area. Individual farms/sites (F), owned by different farmers, are presented in different colours and can incorporate different species and farming systems.

Note:

- Schematic figure of an existing aquaculture zone (the whole depicted area) representing individual land-based farms (F), e.g. catfish ponds and/or other species, that may be owned by different farmers (presented in different colours).
- The designation of AMAs depends upon mutual and exclusive use of incoming and outgoing water supplies by a given set of farmers.

The order in which the main steps are taken above depends upon the local situation.

this has been the case in countries where disease outbreaks have forced governments and producers to develop collective response protocols. In some cases, an entire zone might share a common water supply or be configured in such a way that it functions as an AMA. There is no fixed pathway; the steps are flexible and should be adapted to local/national circumstances and capacities as necessary. There are a range of different zoning, site selection and AMA schemes that have been developed worldwide to address different constraints to aquaculture sustainability and local conditions. Selected examples are described in the case studies in Annex 5.

The main steps for spatial planning and area management can be broken down into a more detailed set of processes, each drawing on a range of activities and tools (Table 4). The components, and the associated activities and tools, are briefly described in the sections below. Some of the main tools and their application to aquaculture development and management are reviewed in Annex 4.

The inclusion of all these components in any planning initiative may be a formidable task. However, if the larger goal of long-term sustainable development is to be realized, most of these components will need to be considered. The outcomes of the process will also be more durable if the principles of stakeholder participation and use of best available knowledge are applied at all stages of the process.

Many of the processes and components in Table 3 are repeated in each main step defined in Table 4 (e.g. identification of issues) because each component should serve to inform the scope and focus of others steps, and because some countries may want to focus more on specific aspects without having to follow all the steps in sequence. It is recommended that countries in which aquaculture is a new activity would need to follow all the steps, broadly in sequence.

TABLE 4. Potential framework to guide the implementation of aquaculture spatial planning and area management

Steps	Process	Activities and tools
National/ subnational scoping	• Review national/subnational priorities for aquaculture • Identification of relevant stakeholders for consultation • Review and possible adaptation of laws, policies, regulations and institutional frameworks affecting aquaculture • Identification of general issues and opportunities • Identification of potential for cultured species and farming systems	• Review relevant policy and legal frameworks • Institutional mapping and analysis • Stakeholder mapping and analysis • Aquaculture species/systems review • Issue trees • Geographic information system (GIS), remote sensing and mapping • Google Earth marking of aquaculture areas
Zoning	• Identification of areas suitable for aquaculture • Identification of issues and risks in zoning • Broad carrying capacity estimation for aquaculture zones • Biosecurity and zoning strategies • Legal designation of zones for aquaculture	• Identification of high-level objectives • Description and mapping (GIS-related tools) • Zone selection and modelling • Issue trees • Strategic environmental assessment and other related approaches • Tools/proxies to estimate carrying capacity for large areas • Land use planning maps • Marine spatial planning • Mass balance equation models • Dynamic models • Risk mapping and analysis • Stakeholder consultation to identify issues and potential conflicts • Environmental indicators such as the TRIX index
Site selection	• Assessment of suitability for aquaculture • Detailed estimation of carrying capacity for sites • Biosecurity planning and disease control • Authorization arrangements	• Description and mapping (GIS-related tools) • Site selection modelling • Issue trees • Environmental impact assessment, licences, permits • Environmental management plan • Description and mapping • Nutrient mass balance equation models • Dynamic models for environmental impact • Landscape and seascape analysis • Choice of environmental indicators (e.g. benthic diversity, water quality)
Aquaculture management areas (AMAs)	• Delineation of management area boundaries with appropriate stakeholder consultation • Establishing an area management entity involving local communities as appropriate • Carrying capacity and environmental monitoring of AMAs • Disease control in AMAs • Better management practices • Group certification • Essential steps in the implementation, monitoring and evaluation of a management plan for an AMA	• Agreement on the administration and leadership of the AMA • Description and mapping (GIS-related tools) • Stakeholder identification • Participatory, facilitation tools • Issue trees • Mass balance equation models • Dynamic models for environmental impact • Biosecurity tools • Value chain tools • Farmer organization inclusion and responsibilities • Agreed management plan and management measures • Environmental management tools • Conflict resolution and communication tools • Enforcement measures • Better management practices • Standard operating procedures • Traceability • HACCP and food safety guidelines • Environmental monitoring surveys

Notes:
- Some of the main tools and models are described in Annex 4.
- Scoping is also needed for zoning and the design of management areas.
- Ehler and Douvere (2009) describe marine spatial planning (MSP) as "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process". Meaden *et al.* (2016) provide a comprehensive listing of additional information about MSP, including worldwide examples where MSP has been applied under varied local conditions at highly variable geographic scales.

Fish ponds for culture of Nile tilapia, African catfish and African bonytongue, Cameroon

There is considerable potential to expand inland aquaculture in Africa to improve food security. The first step in aquaculture planning is identifying areas that have potential for aquaculture. In this scoping process, it is important to review any existing coastal zone management plan to establish whether it facilitates aquaculture development. Legal and regulatory frameworks should establish clear mechanisms for aquaculture zoning and site selection in waterbodies considered "common property" and the granting of tenure rights, including aquaculture licences.

Courtesy of José Aguilar-Manjarrez

3. SCOPING

The first step in spatial planning is scoping, which includes as the main tasks: collection of baseline information, definition of priorities for aquaculture, identifying stakeholders, and setting broad objectives. It is important in this step to define the boundaries of both the management unit and the ecosystem, which are often different. Availability of baseline data (through a baseline report) is essential. Not only does a proper baseline report enable a project to measure impact, it also ensures that everyone is clear regarding the challenges, opportunities and issues for sustainable aquaculture development.

Led by the aquaculture task team, scoping is the largely subjective weighing of national and regional development and conservation objectives.
It influences decision-making at all subsequent levels of aquaculture spatial planning and management.
The main processes undertaken in scoping include:

- review of national and subnational priorities for aquaculture;
- identification of relevant stakeholders for consultation;
- review and possible adaptation of laws, policies, regulations and institutional frameworks affecting aquaculture;
- identification of general issues and opportunities; and
- identification of potential for cultured species and farming systems.

3.1 Review of national and subnational priorities for aquaculture

The first step is to understand the priorities that the government attaches to the aquaculture sector relative to other national or subnational priorities for economic development and natural resource conservation. There is a need to understand whether aquaculture is to be undertaken for food and/or food security, income generation, expanding the tax base, local jobs, some other expected benefit, or a combination with differing priorities. The answers to these issues will determine the amount of land, water, institutional resources, types of systems, and aquaculture species that will be targeted for government support and development. For example, government revenues may be higher with a focus on high-value species for export grown in seawater cages by large corporations with relatively few employees, meaning that aquaculture sector planning should focus on coastal areas and on developing strong relationships with the private sector. Pond aquaculture of cheaper species by small- and medium-scale farms employing relatively large numbers of local people could supply more fish to local markets at reasonable prices for consumers, but will require land and freshwater that may or may not be locally available. Acceptable levels of risk to important biodiversity or natural areas are other key considerations to be weighed. Reviewing priorities, therefore, influences the decisions made in relation to the type of aquaculture development that could be undertaken. Consultation with stakeholders is critical in clarifying national priorities.

3.2 Identification of relevant stakeholders for consultation

The identification of relevant stakeholders for consultation is central to the success and durability of aquaculture spatial planning. Box 1 provides guidance for identifying and selecting stakeholders, some of which may be more or less relevant depending upon the step in the process: scoping, zoning, site selection or area management. It may not be necessary or possible to involve all stakeholder groups throughout the whole process, so careful consideration must be given as to who needs to be encouraged and supported to participate, and at what stage of the planning process. To make best use of identified stakeholders, refer to the participatory tools for facilitation of group decision-making described by FAO (2010).

BOX 1
A guide to stakeholder identification in aquaculture planning and management

Criteria for selection of stakeholders:
- those who have sufficient political clout to draw in officials with the public authority to make decisions;
- those who have legal standing and therefore the potential to block a decision;
- those who control resources (or property rights) necessary for implementation of a decision;
- those who may not be sufficiently organizgd to pose a relevant threat today, but may in the near future; and
- those who hold necessary information. The range of necessary types of information can be quite broad, and complex issues often deal with phenomena about which data are limited or privately held. Including parties who may have access to such information may be essential.

According to the criteria above, stakeholders could include:
- fish farmers;
- capture fishers;
- local communities and/or businesses reliant on aquaculture and fisheries value chains;
- authorities (local, regional, national, other): aquaculture, fisheries, environment, animal health etc.
- tourism;
- environmentalists;
- scientists and other technical experts;
- homeowners;
- recreational users;
- enterprises directly using the waterbody concerned (marinas, ports, shipping, wind farms); and
- enterprises indirectly using the coast or waterbody (urban or industrial consumers of water, polluters, etc.).

Source: FAO (2010).

3.3 Review and possible adaptation of laws, policies, regulations and institutional frameworks affecting aquaculture

The collection of relevant information and the review of policy and legal frameworks will need to be undertaken. The need for different levels of planning in order to identify aquaculture zones or sites, to designate aquaculture management areas, and to manage or overcome social conflicts such as competition for space and conflicts of interest and environmental considerations necessitate the following:

- a clear and efficient institutional framework with clearly defined competencies;
- clear policy and legal frameworks and rules and regulations that govern development and management of aquaculture, including, for example, access use rights and duties; and
- encouragement and empowerment of the aquaculture sector to self-regulate where appropriate.

The policy and legal frameworks for sustainable aquaculture must be based on the law of the sea, as reflected in the United Nations Convention on the Law of the Sea of 10 December 1982 (UNCLOS) and international environmental law as well as various soft law instruments (Table 5 and Annex 1). There is also a need for a review of different areas of national law and administration frameworks that may relate to or have an impact on aquaculture activity. For example, spatial and area management requirements may exist in legislation relating to the authorization and conduct of commercial or development activities, public works, zoning and planning, public health and environmental legislation. A review of these legal frameworks in the scoping phase will help determine whether they need to be strengthened to include aquaculture development. In countries where there is no legal framework for aquaculture, which sets out the main requirements for aquaculture management including spatial planning and management in one legislation, appropriate legislation may need to be developed.

There has been an increase in effort in the development of enhanced national policy, legal and institutional frameworks for aquaculture administration in the last decades with the expansion of the sector. A corresponding growth in environmental consciousness is also being noted in the increased number and breadth of environmental considerations in policy, regulations and management. The FAO fisheries National Aquaculture Legislation Overview (NALO) Web page (www.fao.org/fishery/nalo/search/en) includes legal fact sheets for 61 countries. A list of legal issues for sustainable aquaculture planning and management, adapted from the NALO fact sheets are presented in Table 5.

Institutional analysis should cover both formal and informal institutions (FAO, 2010). Formal institutions are those such as government departments or agencies that typically have a legally defined role and structure. Informal institutions are those such as business, social or family networks or associations. The latter in this group also have structure and sets of procedures, although they may have no legal or written basis. In essence, institutional analysis requires that a specific set of questions be addressed, including: What are the rules? Who decides, and how is this done (process and decision criteria)? Who implements what rules, and how? How and when is progress assessed? and What are the relationships between different institutions (both formal and informal)?

3.4 Identification of general issues and opportunities

It is advisable to identify social, economic, environmental, and governance issues and opportunities. In most cases, environmental, social and economic issues have a root cause that needs to be overcome, such as governance and institutional factors, lack of adequate knowledge, lack of training, inappropriate legislation, lack of enforcement, problems with user rights, and so on. It is important that these root causes are investigated, and mitigation or remedial actions proposed. These are not factors that can always be overcome instantaneously and may require investment of time and financial resources. External forcing factors should also be considered to include, for example, catastrophic events, climate change impacts, sudden changes in international markets, and the effects of other users of aquatic ecosystems on aquaculture such as agriculture and urban pollution of aquatic environments that may negatively affect aquaculture.

A large number of issues can be identified, but their importance varies greatly. Consequently, it is necessary to have some way of prioritizing them so that those that require immediate management decisions receive more attention within a plan of action. Examples and more details of issue identification and priorization can be found in FAO (2010), FAO (2003) and APFIC (2009).

The identification of issues also represents an opportunity for the implementation of a spatial planning process under an ecosystem approach to aquaculture, which ensures coordinated, orderly development and promotes sustainability. As an example, if one of the issues is fish disease and the lack of effective biosecurity (e.g. when farms are too close to each other leading to quick infection and reinfection), there is an opportunity to minimize fish disease risks and better respond to outbreaks through good spatial planning.

TABLE 5. Policy, institutional and legal aspects involved in sustainable aquaculture planning and management

Policy, institutional and legal aspects	Instruments, institutions, requirements
International binding and non-binding instruments*	• Binding instruments include, for example, the Ramsar Convention on Wetlands of International Importance (Ramsar, 1971)[1] and the United Nations Convention on the Law of the Sea (Montego Bay, 1982)[2] • Non-binding instruments include the Kyoto Declaration on Aquaculture, Agenda 21, Rio Declaration, and the Code of Conduct for Responsible Fisheries (FAO, 1995)[3], among others
Basic national legislation	• Fisheries and/or aquaculture law • Planning law • Water law • Sanitary law • Tax law • User rights law
Institutions	• Fisheries and aquaculture authorities • Health and sanitary authority • Environmental authority • Forestry and water resources authority • Culture and tourism authority • Indigenous peoples authority • Commerce authority • Local authorities • Trade/farmer associations
Site allocation	• Site allocation criteria and user rights • Required distance between farm sites • Required distance between farm sites and other activities • Interaction with other activities • Indigenous/artisanal fishing community rights
Authorization system	• Leasing or permitting system • Operation licence (duration, renovation, revocation) • New site, change of use, or change of capacity
Environmental impact	• Emission standards • Water quality • Sedimentation models • Waste management
Control mechanisms	• Environmental assessments • Self-monitoring • Citizens' participation • Enforcement and penalties • Conflict resolution procedures
Production system	• Production volume • Species mix • Animal Welfare

Policy, institutional and legal aspects	Instruments, institutions, requirements
Fish movement	• Notification and information • Transport of species • Accidental release of farmed species
Disease control	• Quarantine • Outbreak management • Therapeutants
Feed	• Feed quality • Effect of feed residues on environment
Product safety and traceability	• Certification systems
Education, research and development	• Extension and training • Research and development • Public information and awareness
Aqualculture management areas (AMAs)	• Organization and management of AMAs

*For more details on binding and non-binding agreements, see Annex 1.

[1] United Nations. 1976. *Convention on Wetlands of International Importance especially as Waterfowl Habitat.* United Nations Treaty Series, Vol. 996, I-I-1583. Entered into force 21 December 1975. (also available at https://treaties.un.org/doc/Publication/UNTS/Volume%20996/volume-996-I-14583-English.pdf).

[2] United Nations. 1994. *United Nations Convention on the Law of the Sea. 10 December 1982, Montego Bay, Jamaica.* United Nations Treaty Series, Vol. 1833, 1-31363. Entered into force 16 November 1994. (also available at https://treaties.un.org/doc/Publication/UNTS/Volume%201833/volume-1833-A-31363-English.pdf).

[3] FAO. 1995. *Code of Conduct for Responsible Fisheries.* Rome, FAO. 41 pp. (also available at www.fao.org/docrep/005/v9878e/v9878e00.htm).

Note:

Brugère *et al.*(2010) provide practical guidance on policy formulation and processes. It starts by reviewing governance concepts and international policy agendas relevant to aquaculture development and proceeds by defining "policy", "strategy" and "plan" while explaining common planning terminology. See Brugère, C., Ridler, N., Haylor, G., Macfadyen, G. & Hishamunda, N. 2010. Aquaculture planning: policy formulation and implementation for sustainable development. FAO Fisheries and Aquaculture Technical Paper. No. 542. Rome, FAO. 70 pp. (also available at www.fao.org/docrep/012/i1601e/i1601e00.pdf).

3.5 Identification of potential for cultured species and farming systems

Species should be mainly those with proven culture technologies and with established national or international markets. Some environmental concerns can be overcome by selecting native species depending on the region of interest, the species already cultured, or those undergoing trials. The identification of potential areas for aquaculture should be based on criteria that would be favourable for grow-out of these species. For instance, it is well known that temperature affects the feeding, growth and metabolism of fish and shellfish; thus, water temperature is a common area selection criterion for all species.

Also essential is a broad assessment of areas where it is technologically feasible to place appropriate culture installations. For example, sea cages for fish grow-out and longlines for mussel grow-out are the prevalent culture structures in current offshore mariculture practice. Both sea cages and longlines are tethered to the sea floor, and thus the key assumption is that both sea cages and longlines will, for the time being and until technology develops, be located close to coastlines because of the technical and cost limits related to the depth of tethering. For land-based systems, especially ponds for the growth of relatively cheaper species, costs become an issue, so ready access to a suitable freshwater source is needed on relatively flat land whose soil structure means ponds do not need to be lined.

Shrimp aquaculture ponds in Sinaloa, Mexico

The Mexican National programme for Aquaculture Management was created to: (i) enable an orderly and competitive aquaculture sector that is sustainable; and (ii) regulate and administrate the sector using processes and tools such as the delimitation of aquaculture zones. In this programme, shrimp farming in Sinaloa State is used as one example to illustrate how aquaculture is managed through aquaculture production units or aquaculture zones.

Courtesy of Giovanni Fiore Amaral

4. ZONING

Zoning implies bringing together the criteria for locating aquaculture and other activities in order to define broad zones suitable for different activities or mixes of activities. Zoning is a process that countries can use to sustainably and responsibly identify and allocate areas that are biophysically and socio-economically suitable for aquaculture. In broad terms, zoning can be used to identify potential areas for growth where aquaculture is new, and help regulate the development of aquaculture where it is already established (Table 6). Definition of the legal boundaries of zones demands a consultative process that aligns policy, law, local interests and ecological carrying capacity (more details on carrying capacity are found in Annex 4). More specifically, zoning according to GESAMP (2001) can be used to:

- prevent and control environmental deterioration at the farm and watershed scale;
- implement biosecurity measures and disaster risk management;
- reduce adverse social and environmental interactions; and
- serve as a focus for estimates of environmental capacity.

Additionally, zoning can also be used to:
- increase production and social development;
- serve as a platform for dialogue to reduce conflict among potential resource users;
- help potential developers identify prospective farm sites where long-term investments are possible (user rights);
- establish clear norms/regulations for commercial behaviour within zones; and
- define the area over which planners and regulators set and monitor objectives.

TABLE 6. Examples of zoning initiatives in different countries

Country	Zoning initiatives	Source
Australia	The responsible minister may identify within state waters: • Aquaculture zones, in which specified classes of aquaculture will be permitted. • Prospective aquaculture zones, which are in effect for a specified period not exceeding three years during which investigations are to be completed to determine whether the zone should become an aquaculture zone. • Aquaculture exclusion zones, in which no aquaculture will be permitted. • Aquaculture emergency zones for short-term relocation of aquaculture operations.	South Australia Aquaculture Act (2001, as amended in 2003, 2005 and 2015)[1]
Chile	Twelve regions have been identified so far as authorized areas for the establishment of aquaculture activities (A.A.A.: Areas autorizadas para el ejercicio de la acuicultura); defined as: "geographical areas classified as such by the Sub-Secretariat of Fisheries to be adequate for the establishment of an aquaculture facility". Only areas so classified are eligible for aquaculture investments.	Fisheries and Aquaculture Law[2]
New Zealand	The Resource Management Act establishes that aquaculture activities are restricted to designated coastal marine areas. The regional council develops regional plans and policy statements in order to manage coastal resources, including aquaculture, and the plans are approved by the Department of Conservation.	Resource Management Act 1991 as amended in 2016[3]

[1] South Australia Aquaculture Act. 2001. Consolidated version of Act No. 66 of 2001, as amended 1 July 2015, Australia (South Australia). FAOLEX No. LEX-FAOC044087. (also available at http://faolex.fao.org/docs/pdf/sa44087.pdf).

[2] General Law on Fisheries and Aquaculture (No. 18.892). Ley General de Pesca y Acuicultura (Ley No. 18.892 de 1989). Texto refundido, coordinado y sistematizado ha sido fijado por el Decreto No. 430. Chile. FAOLEX No. LEX-FAOC001227. (also available at http://faolex.fao.org/docs/pdf/chi1227.pdf).

[3] Resource Management Act. 1991. Act No. 69 of 1991. Reprint as at 18 October 2016, New Zealand. (also available at www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html).

The zoning process is normally led by the government at the relevant geographical scale through a consultative interaction with national and local stakeholders, especially those who may invest or set up fish farms, and those who may be affected by aquaculture development (Hambrey *et al*., 2000). Defining and agreeing on broad development objectives for an aquaculture zone is the focus for public involvement and participation. A range of rapid rural appraisal communication techniques are available and can be adapted to local circumstances to facilitate quality dialogue (see tools in Annex 4).

At the zoning stage, it is important to include policy-makers and government planners; scientists (fishery, environment, rural sociology, economics) and farmer leaders; private industry representatives (supply inputs, traders, processors, exporters); and local authorities (agriculture, forestry, industry, tourism) where local development objectives and priorities are reviewed. In some cases, the inclusion of non-governmental organizations (NGOs) and/or consumer groups might also be useful.

When the process of actual boundary definition, zone allocation and identification of possible impacts and mitigation strategies are discussed, it will be important to have representatives of local government; the fishery management agency; other local regulatory bodies (agriculture, forestry, industry, tourism); farmer groups; and relevant local communities, including indigenous groups. Depending upon the nature of the zone, valuable inputs from representatives of private industry, consumer groups and agribusiness associations might also be useful.

The key steps in the zoning process are:

(i) identification of areas suitable for aquaculture;
(ii) identification of issues and risks in zoning;
(iii) broad carrying capacity estimation for aquaculture zones;
(iv) biosecurity and zoning strategies; and
(v) legal designation of zones for aquaculture.

4.1 Identification of areas suitable for aquaculture

Zone boundaries are initially based on hydrographical or hydrological parameters at a scale from a few to hundreds of kilometres, and are usually all or part of a contiguous waterbody or basin such as a fjord, tributary of a river or whole river system, a whole lake, a coastal bay, or an estuary or a semi-enclosed sea.

Geographies with the potential to become an aquaculture zone generally are those that have relatively few existing users, abundant water of a quality adequate for farmed species, have basic production infrastructure (e.g. electricity, roads) and access to input and output markets (including labour), and are not located near ecologically sensitive sites.

At the subnational, national or regional scales, it may only be possible to define in very general terms where aquaculture would most likely prosper. Remote sensing and geographic information systems (GIS) are excellent for this kind of work, and are useful tools to support stakeholder perceptions and insight. Satellite images can show where human settlement and other important land uses could be expected to conflict with aquaculture development; for example, GIS-based flood-zone mapping is commonly used by insurance companies to identify areas prone to inundation and can also provide useful information on such risks.

At the zoning stage, some detail is needed to define good places for aquaculture. In this context, local knowledge, organized data collection, property maps and site visits should be used to focus stakeholder discussion on defining where boundaries for aquaculture zones should be located within the broader regions identified during the scoping exercise.

The fundamental factors that determine the viability of a zone for aquaculture are basic topography/bathymetry (i.e. available flat land or open water), temperature, current velocity, and water quantity and water quality (e.g. salinity, hardness). These determine the species that can be cultured efficiently in a particular area, and give a broad indication of the production system that is best suited. The larger the population, the greater the potential market for aquatic products and the availability of labour and services. Urban market centres are potential locations for on-processing and marketing of the fish. However, there are risks associated with urban centres, including theft and pollution.

Pre-existing aquaculture also has an influence on where new aquaculture should be placed. The presence of successful aquaculture sites is indicative of more general suitability, but should not be automatically assumed. The presence of critical infrastructure, such as roads, power facilities, feed mills, processing facilities and so on, also argue for clustering of aquaculture within zones. This must be balanced with the need to provide sufficient space so that effluents and disease from one farm cannot flow onto another and the carrying capacity of the local environment.

Table 7 outlines the main suitability criteria that apply to most aquaculture farming systems. The various criteria listed in Table 7 will each have their own degree of importance, and it is essential that these can be ranked or measured for specific locations, even if this can only be done crudely. It is also important to determine “thresholds” that pertain to a desired level of suitability for each criterion. The selection of the thresholds involves interpretation of the data selected, and such interpretation should be guided with literature research and opinions from experts and farmers. Thresholds will vary according to location, scale, environment, species and culture systems, and some of the thresholds may change over time. For example, species generally have an optimal range within which they will grow well, suboptimal ranges when stress is induced, and lethal levels above and below this, but will change only slowly or not at all. Social thresholds are likely to me more flexible, as these can change over time. In such cases, it is advisable to operate within optimal ranges where possible to ensure efficiency and cost effectiveness.

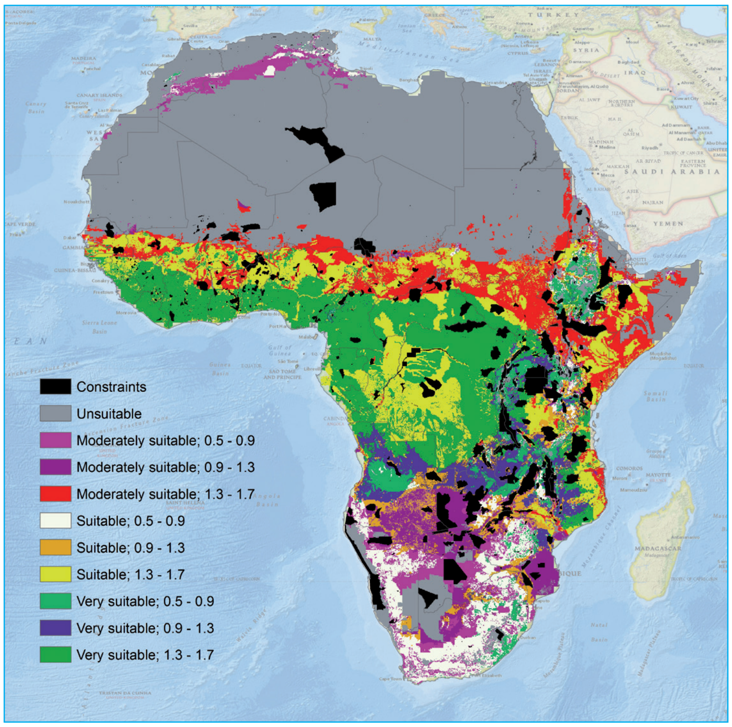
Knowledgeable technicians using the tools listed in Table 4 can identify zones with potential for aquaculture and provide advice on the most suitable species. There is also a myriad of published literature available on criteria for spatial planning and management of aquaculture, many examples of which can be found at:

- The GISFish Global Gateway to Geographic Information Systems, Remote Sensing and Mapping for Fisheries and Aquaculture (www.fao.org/fishery/gisfish).
- GIS and spatial analysis. GIS and remote sensing journal articles from the Institute of Aquaculture, University of Stirling, the United Kingdom of Great Britain and Northern Ireland (www.aqua.stir.ac.uk/GISAP/gis-group/journal-papers).

A good example of the use of GIS to identify potential aquaculture zones is an FAO study by Aguilar-Manjarrez and Nath (1998), who estimated inland fish farming potential at a continental scale. By overlaying the temperature regime, water availability, suitability of topography and soil texture, availability of agricultural by-products, local markets and road density on a map of Africa (Figure 2), they were able to identify in broad terms which areas on the African continent would be suitable for aquaculture.

While at this scale, it is not possible to identify exact locations for aquaculture zones, at the scoping stage this kind of information is useful to identify parks, deserts, flooded areas, cities and other major geographical features that would rule out aquaculture a priori.

FIGURE 2. Suitability for small-scale farming and potential yield (crops/year) of Nile tilapia in Africa



Source: Aguilar-Manjarrez and Nath (1998).

4.2 Identification of issues and risks in zoning

There are a broad range of issues and risks for zoning, and it is advisable to identify, inter alia, those related to environment, biosecurity, climate-related risks, social conflicts and governance. A good approach to identify issues is to focus on the different steps in the aquaculture production process, including upstream (e.g. feed supply) and downstream (e.g. post-harvest) aspects, and understand the impacts on such processes and the likelihood of occurrence. By doing this, it should be possible to determine whether the risk and likelihood of occurrence means a specific zone is unsuitable to become an aquaculture zone. Aquaculture as a production process may require land/sea area as well as water and specific inputs, including labour, to produce expected outputs such as food and income together with unwanted outputs such as nutrients or chemicals. Issues need to be identified within a specific scale and ecosystem boundary, so risks can be defined as local only, or regional, or national. Tranboundary issues should also be addressed where, for example (rivers), water starts within one country, but flows through another and then used for aquaculture development. The converse is also true when water, potentially impacted by nutrients from aquaculture, flows across borders into another country or region.

In most cases, issues such as climate change impacts and urban pollution of aquatic environments have damaging effects on aquaculture. Aquaculture is vulnerable to a number of potentially catastrophic climatic and other disturbances. In addition to wildlife (especially bird) predation, disease and theft, which affect all aquaculture systems, there are likely to be risks that apply only to specific production systems and zone location, such as:

Risks specific for pond/raceway aquaculture:
- floods
- droughts
- severe winters
- earthquakes
- volcanic eruptions
- tidal surges/storm surges/tsunamis

TABLE 7. Essential criteria for scoping, zoning, site selection and aquaculture management areas. Depending upon the species and systems being considered for aquaculture, other criteria deserve consideration

Criteria	Scoping	Zoning	Site selection	Aquaculture management areas
Biophysical (requirements for farmed species and systems)	Water quantity (overall water resources available); Water quality (distance from potential pollution sources); Suitable water temperature ranges; Areas with suitable soil types and slopes for ponds; Suitable depth ranges for culture structures; Exposure to climate disturbances; Land use	Water quantity (amount of surface and groundwater available); Water quality (especially salinity and pollution); Optimal water temperatures; Areas with suitable soil texture and slope for pond construction; Suitable depth ranges for floating structures (e.g. cages, racks); Hydrodynamics (e.g. current velocity); Infrastructure (roads, access, landing sites, etc.)	Water quantity and quality; Soil chemistry and structure (if ponds); Suitable topography for construction pond dykes and farm infrastructure; Land use; Suitable depth for culture structures; Hydrodynamics (e.g. current velocity); Shelter suitable for culture structures; Access/roads landing	Farms are reasonably close; Common waterbody; Common water source; Common species; Common access/roads; Landing sites
Environmental	Avoid protected areas, critical habitats and very exposed areas	Buffer distances to mitigate impacts from sensitive habitats, protected areas, natural biodiversity condition; Distance from other aquaculture zones; Suitable wave heights; Distance from pollution sources	Water depth; Turbidity and suspended solids; Chlorophyll and dissolved nutrients; Hydrodynamics (e.g. current velocity); Sensitive habitats and species; Water quality and condition of the benthos; Presence of predators; Distance from other farms	Water turnover; Nearness of farms; Level of eutrophication; Benthic diversity; Bottom anoxia; Feed conversion rate; Presence of predators; Environmental impact data in general
Social (minimize conflict)	Avoid socially sensitive areas (indigenous peoples' traditional sites, etc.)	Mitigate/reduce visual impact of farm clusters; Potential to integrate with adjacent land and water uses; Population density (availability of inputs, labour, markets, etc.); Access to capital, social services; Potential integration with traditional fisheries	No visual impact of farm; Local labour available; Potential participation of local/indigenous communities, women; Minimal theft, vandalism risks	Farmers are organized locally; There is good potential for cooperation; Potential interest and involvement of local communities
Economic	Distance to urban areas (access, availability of main markets, inputs, etc.)	Distance from other aquaculture zones/ fish farms (for sharing resources); Access to local markets; Access to roads	Access to electricity; Access to markets in close proximity to site; Availability of inputs; Reliable access to roads and ports; Access to services	Access to common market; Common access to inputs and services; Common infrastructure/roads, landing sites
Governance	Legal and regulatory frameworks available; National strategy and development plans	Multisector regulatory frameworks; Sea and coastal access rights	Aquaculture permitting rules and regulations	Extension for the adoption of best management practices available; Available aquaculture certification systems; Compliance with management measures; Available regulations/norms, to address cumulative impacts of resource use
Aquatic animal health	Legal aspects; Existing biosecurity frameworks	Distance from other aquaculture zones; Environmental conditions and other forcing factors that minimize disease risks	Pathogen dissemination pathways; Water flows and hydrodynamics; Water quality	Level of disease outbreak; Water quality; Need for implementation of biosecurity

Risks specific to cage aquaculture include:

- oil spills/chemical spills/chemical runoff
- pollution
- superchill/ice
- storms
- harmful algal blooms and jellyfish
- hypoxia

In addition to these biophysical risks, conflicts with other natural resource users are common. Chief among these are the direct competition for water and space with agriculture and real estate developers; access to traditional sites of indigenous people; and disagreements over visual impact with the tourism sector. Conflict with fishers is also common, given that sea space or lake space can become off limits when structures such as cages are added, which reduces the ability of fishers to exploit such areas.

Risk analysis involves answering the following questions (Bondad-Reantaso, Arthur and Subasinghe, 2008): (i) What can go wrong? How likely is it to go wrong and what are the consequence of its going wrong? and (ii) What can be done to reduce either the likelihood or the consequences of its going wrong?

Risk mapping can help to identify the most important threats. Examples of risk maps for aquaculture zoning include:

- **Fish cage farming and tourism.** Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife, Canary Islands (Pérez, Telfer and Ross, 2003a).
- **Islands and wave strength.** Climate-related wave risk maps for offshore cage culture site selection in Tenerife, Canary Islands (Pérez, Telfer and Ross, 2003b)
- **Floods and aquaculture.** Modelling the flood cycle, aquaculture development potential and risk using MODIS data: a case study for the floodplain of the Rio Paraná, Argentina (Handisyde *et al.*, 2014).
- **Monitoring algal bloom development.** Environmental information system using remote sensing data and modelling to provide advanced warning of potentially harmful algal blooms in Chile so that their impacts can be minimized by the aquaculture industry (Stockwell *et al.*, 2006).

It is also important to assess the environmental and socio-economic risks that aquaculture can pose to other sectors and on itself. These may include biodiversity losses due to organic and chemical pollution, diseases generated by fish farms, and impacts from escaped fish. These risks are evaluated and mitigated through a solid understanding and management of a zone, or AMA location, and carrying capacity. For large industrial farms (e.g. salmon cages), there are models to estimate the spatial distribution of organic matter and related risks and the consequences in terms of water quality and overall carrying capacity (see section 4.3 and Annex 4).

4.3 Broad carrying capacity estimation for aquaculture zones

For purposes of aquaculture zoning, carrying capacity sets an upper limit for the number of farms and their intensity of production that retains environmental and social impacts at manageable and/or acceptable levels, which then implies overall sustainability. At the zone level, carrying capacity will typically be expressed as a level of production (in tonnes) produced through a number of farms located in geographic space, or production in tonnes per hectare or km^2. Within aquaculture zones, carrying capacity has two primary dimensions:

- ecological carrying capacity: the maximum production that does not cause unacceptable impacts on the environment; and
- social carrying capacity: the social licence for the level of farm development that does not disenfranchise people or result in net economic losses to local communities.

At a large zone level, preliminary limits to the number of farms and intensity of production are set based on a large-scale understanding of the area or waterbody proposed to be or already allocated to aquaculture. This contrasts with setting more detailed carrying capacity estimates for AMAs and for individual sites in which more specific assessment is made of local conditions. There are circumstances where an aquaculture zone could become an aquaculture management area if a suitable management plan is developed and implemented. Typically, however, aquaculture zones are broader scale areas that may contain one or more AMAs and numerous sites.

4.3.1 Ecological carrying capacity

To estimate carrying capacity in the context of fish aquaculture, models are usually used to estimate a maximum allowable production, limited primarily by modelling changes to environmental conditions. Nutrient input or extraction and oxygen changes (depending on the species to be cultivated) can be assessed, for example, on a specific catchment area or waterbody for a given number of aquaculture units. For extractive production, such as shellfish, food depletion is the major consideration along with effects on wild species and food availability for them.

The assessment of ecological carrying capacity is based on the capacity of the ecosystem to continue to function through the application of environmental quality standards that cannot be exceeded when aquaculture is included into the system. It is sometimes referred to as assimilative capacity, implying the system is able to assimilate a certain level of nutrients or oxygen uptake without causing detrimental effects such as eutrophication. Aquaculture produces or uses dissolved and particulate matter that enter the environment, uses oxygen and other resources, and adds residues from diseases or parasites and other treatment chemicals. It is the consequences of these on the ecosystem that are used in estimating ecological carrying capacity. The capacity of a particular area also depends on water depth, flushing rates/current velocity, temperature and biological activity in the water column and bottom sediments, and attempting to define the level of ecological resilience. The multifactor nature of ecological capacity is one of the reasons why models are often applied, as models can attempt to integrate the multiplicative and cumulative nature of these factors.

It may also be important to take into account background wastes entering a shared waterbody, coming from other sources such as sewage discharges and diffuse inputs from agriculture, domestic waste and forestry. The basic reasoning is that the collective consequences of all aquaculture farms and background inputs can be compared with the ecological capacity of the ecosystem, which can then determine how much aquaculture can sustainably be conducted within a certain physical space. In reality, diffuse inputs (as opposed to point sources) are difficult to assess and measure, which makes estimating the existing consequences of these background wastes difficult. It may also be that activities such as forestry or agriculture have occurred for millennia already, and therefore current water quality and conditions may already reflect the impacts of such activity.

The negative impacts of exceeding ecological carrying capacity include eutrophication, increases in primary productivity and potential phytoplankton blooms fueled by nutrients discharged from farms, accumulation of noxious sediments in the form of fish faeces and feed wastes, and loss of biodiversity due to declining habitat quality. The consequences for aquaculture farmers can be dramatic, including loss of fish stocks on the farms because of blooms, oxygen stress and disease; and exceeding ecological carrying capacity often aggravates fish health problems and social conflicts. Environmental impacts of aquaculture vary with location, the production system and species being grown. Fish cage culture is an open system that extracts oxygen from water, and discharges faecal and feed and other wastes into the surrounding water and sediments. Pond culture is a closed system, and releases nutrient-rich water and effluents during water exchange and/or pond draining during harvest. Bivalves depend upon natural productivity for their food, but compete with other organisms for food (organic matter, microalgae, etc.) and dissolved oxygen in the water column, and seaweed production can reduce light penetration affecting environmental conditions and species below. The fact that there is no "consequence free" aquaculture means that there is a basic need to determine ecological carrying capacity.

One of the earliest applications of mass-balance modelling in aquaculture was the use of Dillon and Rigler's (1974) modification of a model originally proposed by Vollenweider (1968), which used phosphorus (P) concentration to estimate the ecological carrying capacity of freshwater lakes, assuming that P limits phytoplankton growth and therefore eutrophication (Beveridge, 1984). Inputs to the environment from fish culture are evaluated to determine likely changes in overall water quality. This model has been used widely to estimate carrying capacity of lakes to support fish farming, as in Chile. Further modifications of this model have also been used assuming nitrogen as the limiting factor (Soto, Salazar and Alfaro, 2007).

Ecological carrying capacity models integrate hydrodynamic, biogeochemical and ecological processes in the environment with oxygen consumption, sources, and sinks of organic matter and nutrients derived from farm activity linked to the ecosystem state. There are currently few models that assess carrying capacity fully at the zonal scale; EcoWin (Ferreira, 1995) is one example that combines hydrodynamic models with changes to water biogeochemistry to look at large-scale, multi-year changes under non-aquaculture and aquaculture conditions (Ferreira, 2008a; Sequeira *et al.*, 2008).

On a slightly smaller zonal scale, models such as the Loch Ecosystem State Vector model (Tett *et al.*, 2011) resolve seasonal variations in oxygen and chlorophyll in defined sea areas; and the Modelling—Ongrowing fish farms—Monitoring (MOM) model used for farm level assessment also contains a module for wider scale evaluation of water quality and oxygen concentration (Stigebrandt, 2011).

In Chesapeake Bay and the Puget Sound, United States of America, the EcoWin model has been combined with a farm-level model (FARM) and with other tools into a production, ecological, and social capacity assessment that builds together ecological carrying capacity modelling with a stakeholder engagement process that seeks to reduce social conflicts (see Bricker *et al*., 2013; Saurel *et al.*, 2014). Other similar projects have occurred in Portugal (Ferreira *et al.*, 2014) and Ireland (Nunes *et al.*, 2011). Availability of models to assess freshwater systems is more limited.

Until more precise modelling can be undertaken at the zonal level, it is possible to apply simplistic approaches to limit production to acceptable levels. Examples include the Philippines where a maximum of 5 percent of an aquatic body can be used for aquaculture, although this does not estimate carrying capacity per se. In Norway from 1996 to 2005, feed purchases were used to monitor aquaculture development.
This worked initially as a quota that limited the amount of feed that could be delivered to farms.
As well as serving as an indicator of production (rather than capacity), this system had the benefit of rapidly reducing feed conversion ratio (FCR), as farmers tried to optimize the use of the feed allocated to them while maximizing production, which in turn reduced environmental consequences. This was combined with a limit on the cage volume of 12 000 m^3 per licence together with a maximum fish density in cages. This number of licences with volume limit, along with rules for biomass and feed quota, was the framework used to control production development. Norway's approach has since been updated to now assess carrying capacity directly at site and/or small area scales.

Indices have also been used to assign the status of waterbodies into discrete categories that define typically a specific water status with regards to aquaculture development, or whether or not aquaculture is liable to have an effect (e.g. in the latter case, of eutrophication potential using the TRIX index in Turkey, see Annex 5); or to define areas considered to be the most environmentally sensitive to further fish farming development due to the high predicted levels of nutrient enhancement and/or benthic impact (Gillibrand *et al.*, 2002). Gillibrand *et al*. (2002) scaled model outputs from 0 to 5, and the two scaled values (nutrients and benthic impact) were added together to provide a single combined index. On the basis of this combined index, areas were designated as Category 1 (sensitive to more production, and therefore no more production allowed); Category 2 (production potential, with caution); or Category 3 (least sensitive, and opportunities to increase production).

Overall, the larger the area or zone being evaluated, the more complex and more difficult it is to make reliable estimations of carrying capacity owing to the multiple interacting dynamic factors that affect it and acceptable limits in environmental change.

4.3.2 Social carrying capacity

Social carrying capacity is less tangible than other carrying capacities, but is the amount of aquaculture that can be developed without adverse social impacts (Angel and Freeman, 2009; Byron and Costa-Pierce, 2013). Social licence for aquaculture is affected by cultural norms, and can be affected by social mobility and wealth of people and by the species grown and aquaculture practices undertaken, seen as either polluting (e.g. fed fish) or non-polluting (e.g. non-fed fish or extractive species) whether or not this is explicitly correct. Social capacity for aquaculture is also affected by perceived or actual ecological degradation, the extent to which aquaculture impacts other livelihoods, exclusion of legitimate stakeholders from decision-making, and incompatibility of aquaculture with alternative uses, which are all key sources of social conflict.

Social conflicts can be minimized through good engagement in the development and management of aquaculture zones, adverse impacts on the ecosystem and use of space. Fair business practices and the creation of opportunities for local communities along the aquaculture value chain from manufacture and supply of inputs through to processing, transport and marketing will build alliances among the local population. Proper stakeholder engagement, sharing of information and timely communication in the planning process can help investors avoid social conflicts.

4.4 Biosecurity and zoning strategies

Disease is probably the main threat and cause of disaster to aquaculture everywhere and requires planning at all scales, from individual farms to aquaculture zones and aquaculture management areas. The development and implementation of biosecurity and zoning strategies is increasingly recognized by countries and industries as essential to sustainable growth in aquaculture (Håstein *et al.*, 2008; Hine *et al.*, 2012). The World Organisation for Animal Health defines a zone as a portion of a contiguous water system with a distinct health status with respect to certain diseases; the recognition of zones is thus based on geographical boundaries. A zone may comprise one or more water catchments from the source of a river to an estuary or lake, or only part of a water catchment from the source of a river to a barrier that effectively prevents introduction of specific infectious agents. Coastal areas and estuaries with precise geographic delineation may also comprise a zone. For more detail on zoning and spatial planning from the biosecurity perspective, see Annex 2.

4.5 Legal designation of zones for aquaculture

The allocation of aquaculture zones is the final step in zoning and is the legal and normative process that creates an area(s) dedicated to aquaculture activities, whereby any future development thereof must respect this zone.

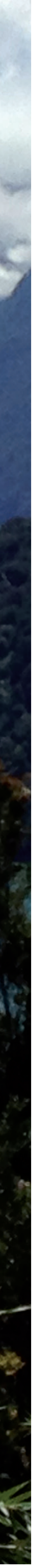
Aquaculture zones should be established within the remit of local or national aquaculture plans and legislative frameworks with the aim of ensuring the sustainability of aquaculture development and of promoting equity and resilience of interlinked social and ecological systems. Regulations and/or restrictions should be assigned to each zone in accordance with their degree of suitability for aquaculture activities and carrying capacity limit. Zones to be allocated to aquaculture activities can be classified, inter alia, as "areas suitable for aquaculture activities", "areas unsuitable for aquaculture activities", and "areas for aquaculture activities with particular regulation and/or restriction". To this end, guidelines should be developed by governments according to the specific location.

Zoning plans guide the granting or denial of individual permits for the use of space. This process includes additional elements of implementation, enforcement, monitoring, evaluation, research, public participation and financing, all of which must be present to carry out effective management over time.

Salmon farming in a remote fjord in southern Chile

The location of a salmon farm must consider the environmental carrying capacity of the recipient waterbody and the local social context in order to be environmentally, socially and economically sustainable.

Courtesy of Doris Soto



5. SITE SELECTION

Site selection ensures that farms are located in a specific location, which has attributes that enable the necessary production with the least possible adverse impact on the environment and society. Site selection is a process that defines what is proposed (species, infrastructure, and so on), estimates the likely outputs and impacts from that proposal, and assesses the biological and social carrying capacities of the site so that the intensity and density of aquaculture do not exceed these capacities and cause environmental degradation or social conflicts. It also provides an assessment for locating farms so that they are not exposed to adverse impacts from other economic sectors and vice versa.

Site selection for individual farms within designated zones is normally led by private-sector stakeholders with direct interest in a specific aquaculture investment. The government assists by defining clear site licencing, environmental impact assessment procedures, and what is acceptable within the zones where the sites will be located. The key steps in the site selection process are:

(i) assessment of suitability for aquaculture;
(ii) detailed estimation of carrying capacity for sites;
(iii) biosecurity planning and disease control; and
(iv) authorization arrangements.

5.1 Assessment of suitability for aquaculture

Table 8 lists the most important criteria to be considered in the selection of individual farm sites within aquaculture zones. Because of the multidisciplinary nature of the criteria and the assessment that needs to be undertaken, it is normal practice to employ professional aquaculture technicians and/or consultants. It is always wise to use conservative estimates (i.e. precautionary principle) in production system planning.

The assessment should thus include a review of local conditions (e.g. temperature, water quantity), historic conditions (such as historical climate data from the local meteorological agency or other sources), and some prediction of impacts from aquaculture activity and measures to be undertaken to minimize impacts (i.e. mitigation). Before finalizing a site suitability assessment, a historical review of external risks should be done, which can include storm, flood and drought frequency, and intensity data from the zoning exercise (section 4.2), that should be made available to individuals or groups seeking permits for aquaculture.

Spacing between the proposed site and other farms and between the proposed fish farm and other economic, cultural or ecological assets is of critical concern in determining where a farm is likely to succeed and how much product a farm can generate (Table 9). This is particularly true in the case of disease transfer, which has proved costly to the aquaculture community. If farms are too close together, diseases can easily spread from one farm to another, and diseases can recirculate leading to persistent problems. This is what happened in the Chilean salmon farming industry prior to zoning and carrying capacity based management, with too many farms crowded into too small a space. When one farm had a disease outbreak, it rapidly spread from one farm to another, resulting in near collapse of the entire industry (see Chile case study in Annex 5). In the Mekong Delta of Viet Nam, farm overcrowding has been identified as a key factor in the inability to manage disease outbreaks (World Bank, 2014).

The choice of an aquaculture site should also take into consideration the location and distance of sensitive habitats, tourist facilities, sites of cultural importance and other service infrastructure, with a consideration of the potential to impact these activities or be impacted by these activities. Table 10 provides an example of distances from aquaculture facilities to other areas or activity in British Columbia, Canada.

Being potential sources of pollution or introduction of disease, human habitation has the potential to be a threat to the viability of a farm and should, where possible, be kept at a safe distance. Potentially, tourism can also be negatively affected, both from a visual perspective (e.g. visual impacts from tourists visiting

TABLE 8. Criteria and data requirements to address production, ecological, and social opportunities and risks

Farming system	Production	Ecological	Social
Coastal marine cages	Temperature Wind, waves, currents Storm and tsunami exposure Depth Salinity Oxygen Diet type Feed regime Infrastructure Investment costs Nearness to other farms Nearness to human settlements Markets Etc.	Feed regime Critical habitats Biodiversity Eutrophication indicators Bottom anoxia indicators Environmental impact assessment (EIA) data in general Visual impact Etc.	Sea and coastal access rights Access to capital Beneficiaries Workforce Etc.
Ponds (inland/ coastal)	Water source Water quantity and quality Soils, slopes Rainfall, evaporation Drought and flood potential Nearness to other farms Temperature Diet type Feed regime Infrastructure Investment costs Markets Etc.	Feed regime Critical habitats Biodiversity Eutrophication indicators Visual impact EIA data in general Etc.	Landownership Water and riparian rights Access to capital Workforce Beneficiaries Etc.
Freshwater cages and pens	Temperature Wind, waves, currents Depth Storm exposure Oxygen Diet type Feed regime Infrastructure Investment, costs Nearness to other farms Nearness to human settlements Markets Etc.	Feed regime Critical habitats Biodiversity Eutrophication indicators Bottom anoxia indicators Visual impact EIA data in general Etc.	Landownership Water and riparian rights Access to capital Beneficiaries Etc.
Hatcheries	Water source Water quantity and quality Temperature Diets Infrastructure Investment, costs Markets Etc.	Critical habitats Biodiversity Eutrophication indicators Visual impact EIA data in general Etc.	Local needs Landownership Water rights Workforce Skills availability Visual impact Etc.
Bivalve culture on the bottom, in plastic trays, in mesh bags, on rafts or on longlines, either in shallow water or in the intertidal zone	Temperature Wind, waves, currents Depth Storm exposure Salinity pH Chlorophyll and productivity Investment, costs Nearness to other farms Nearness to human settlements Markets Etc.	Critical habitats Biodiversity Bottom anoxia indicators Visual impact EIA data in general Etc.	Sea and coastal access rights Access to capital Workforce Beneficiaries Etc.
Seaweed culture on the bottom, or off bottom on rafts or longlines	Temperature Wind, waves, currents Storm exposure Depth Salinity Nutrients availability Investment, costs Markets Etc.	Critical habitats Biodiversity Visual impact EIA data in general Etc.	Sea and coastal access rights Access to capital Workforce Beneficiaries Etc.

Modified from Ross *et al.* (2013).
Notes: Includes social, economic, environmental and governance considerations. Takes into account considerations of carrying capacity for site selection for different farming systems. The list of criteria is indicative rather than exhaustive.

TABLE 9. Some examples of regulated site-to-site minimum distances

Country	Site-to-site distances in national regulations	Source
Chile	Extensive production systems must maintain a minimum distance of 200 metres between them and 400 metres to intensive production systems. Excluded from this requirement are cultures of macroalgae crops fixed to a substrate. Suspended cultures of macroalgae must maintain a minimum distance of 50 metres between them and to other centres.	Art. 11º- 15 Aquaculture environmental regulation, 2001[1]
Norway	The act establishes a licencing system for aquaculture and provides that the Norwegian Ministry of Trade, Industry and Fisheries may, through regulations, prescribe limitations on the number of licences for aquaculture that are allocated. Accordingly, the Norwegian Ministry of Trade, Industry and Fisheries may prescribe: • the number of licences to be allocated; • geographic distribution of licences; • prioritization criteria; • selection of qualified applications in accordance with prioritization criteria; and • licence fees.	The Aquaculture Act (2005)[2]
Turkey	Distance between cage farms is determined by the Central Aquaculture Department, according to criteria such as projected annual production capacity, water depth and current speed. Distance between tuna cage farms and tuna and other fish farms may not be less than 2 kilometres, and less than 1 kilometre between other fish farms.	Aquaculture Regulation No. 25507[3]

[1] Environmental Regulations for Aquaculture. 2001. Reglamento ambiental para la acuicultura (Decreto No. 320), 14 de Diciembre de 2001, Chile. FAOLEX No. LEX-FAOC050323. (also available at http://faolex.fao.org/docs/pdf/chi50323.pdf).

[2] Act of 17 June 2005, No. 79, relating to aquaculture (Aquaculture Act). Lov om Akvakultur (Akvakulturloven), I 2005 hefte 8, Norway. FAOLEX No. LEX-FAOC064840. (English translation by Norwegian Directorate of Fisheries of 24 April 2006 (also available at https://www.regjeringen.no/globalassets/upload/kilde/fkd/reg/2005/0001/ddd/pdfv/255327-l-0525_akvakulturloveneng.pdf).

[3] Aquaculture Regulation No. 25507. Su Ürünleri Yetiştiriciliği Yönetmeliği, T.C Resmî Gazete No. 25507. 29 June 2004, Turkey. FAOLEX No. LEX-FAOC044968. (also available at http://faolex.fao.org/docs/texts/tur44968.doc).

picturesque places that also contain aquaculture) and from an environmental perspective, whereby negative impacts on water quality may impact a tourist's enjoyment of a local area. It is generally desired that fish farming operations be located away from tourist areas. Conversely, biological assets, such as coral reefs, mangroves, seagrass beds, shellfish beds, fish spawning grounds and other biodiversity assets, should be protected by locating aquaculture sites at a safe distance, preferably downstream where effluents cannot cause problems. Sites sacred to indigenous peoples and sites of historical significance should be respected and only developed through consultation with stakeholders and with explicit permission.

5.2 Detailed estimation of carrying capacity for sites

Assessment of carrying capacity at the site level is much more developed than the assessment at the zonal or area scales, especially for the marine environment, but nonetheless still contends with many of the complexities outlined above when considering production impacts on water quality and sediments, and resolving what an acceptable level of production is. In the majority of cases, site-level carrying capacity models estimate nutrient inputs to the environment and assess impacts on sediments, on the water column, or both. More often than not, models assess these impacts against minimum environmental quality standards, often defined

TABLE 10. Distances between salmon aquaculture sites and other areas in British Columbia, Canada

Distance	To
At least 1 km	in all directions from a First Nations reserve (unless consent is received from the First Nations).
At least 1 km	from the mouth of a salmonid bearing stream determined as significant in consultation with the Department of Fisheries and Oceans Canada (DFO) and the province.
At least 1 km	from herring spawning areas designated as having "vital", "major" or "high" importance.
At least 300 m	from intertidal shellfish beds that are exposed to water flow from a salmon farm and which have regular or traditional use by First Nations, recreational or commercial fisheries.
At least 125 m	from all other wild shellfish beds and commercial shellfish-growing operations.
An appropriate distance	from areas of "sensitive fish habitat", as determined by DFO and the province.
An appropriate distance	from the areas used extensively by marine mammals, as determined by DFO and the province.
At least 30 m	from the edge of the approach channel to a small craft harbour, federal wharf or dock.
At least 1 km	from ecological reserves smaller than 1.000 ha, or approved proposals for ecological reserves smaller than 1 000 ha.
Not within a 1 km line	of sight from existing federal, provincial or regional parks, or marine protected areas (or approved proposals for these).
In order to not	infringe on the riparian rights of an upland owner, without consent, for the term of the tenure licence.
Not in areas	that would pre-empt important aboriginal, commercial or recreational fisheries, as determined by the province in consultation with First Nations and DFO.
Not in areas	of cultural or heritage significance, as determined in the Heritage Conservation Act. Consistent with approved local government by laws for land use planning and zoning.
At least 3 km	from any existing finfish aquaculture site, or in accordance with a local area plan or Coastal Zone Management Plan.
Not in areas	that would pre-empt important aboriginal, commercial or recreational fisheries, as determined by the province in consultation with First Nations and DFO.
Not in areas	of cultural or heritage significance, as determined in the Heritage Conservation Act. Consistent with approved local government by laws for land use planning and zoning.
At least 3 km	from any existing finfish aquaculture site, or in accordance with a local area plan or Coastal Zone Management Plan.

Source: Dow (2004).

nationally through scientific endeavour and (in some cases) set specifically by regulators, which then set a maximum production level, often derived through an iterative process. Some models take this further by assessing profitability to ensure the ecological limits defined are profitable for the farmer as well.

Site carrying capacity models can range from simple mathematical calculations to more complex integrated processes that require specialized software. In perhaps the simplest form, model equations produce a mass balance for many different parameters, the most widely used being nitrogen and phosphorus concentrations into and from aquaculture systems. There is a determination of how much of a specific nutrient enters or is removed from a local (site) system and analysis of the consequences of that input/removal for the waterbody.

A relatively simple example of a nutrient-based carrying capacity model was developed by Halide, Brinkman and McKinnon (2008) and is available online at http://epubs.aims.gov.au/handle/11068/7831; it is in part based on the MOM model (see below).

Other models are significantly more complex, and a few only are summarized here to indicate what is possible. The MOM model (Ervik *et al.*, 1997; Stigebrandt, 2011) defines, among other things, changes to sediment oxygen concentration from the deposition of particulate matter for a certain level of production, which is compared with a minimum environmental quality standard. Additionally, the Farm Aquaculture Resource Management (FARM) model assesses species growth and the likely impacts of that growth on environmental conditions (Ferreira, Hawkins and Bricker, 2007; Cubillo *et al.*, 2016).

Another approach to carrying capacity estimation at the farm scale uses depositional models (Cromey, Nickell and Black, 2002; Corner *et al.*, 2006; Ferreira, Hawkins and Bricker, 2007; Ferreira *et al.*, 2008a, 2008b; Cubillo *et al.*, 2016), which predict the accumulation of particulate outputs from fish cage aquaculture in the sediments below fish cages (Figure 3) or other aquaculture systems, and can be used in local-scale assessment of the effects of fish cages on sensitive demersal flora and fauna. The DEPOMOD model (Cromey, Nickell and Black, 2002) is a particle tracking model for predicting flux and resuspension of particulate waste material and assesses the associated benthic community, the outcome of which can be a definition of an allowable zone of effect; see Cromey (2008). The ORGANIX model (Cubillo *et al.*, 2016) can be used to evaluate settlement of wastes, and combined with the FARM model can assess the local impacts of multiple species, individually, and in combination in an integrated multi-trophic aquaculture (IMTA) system.

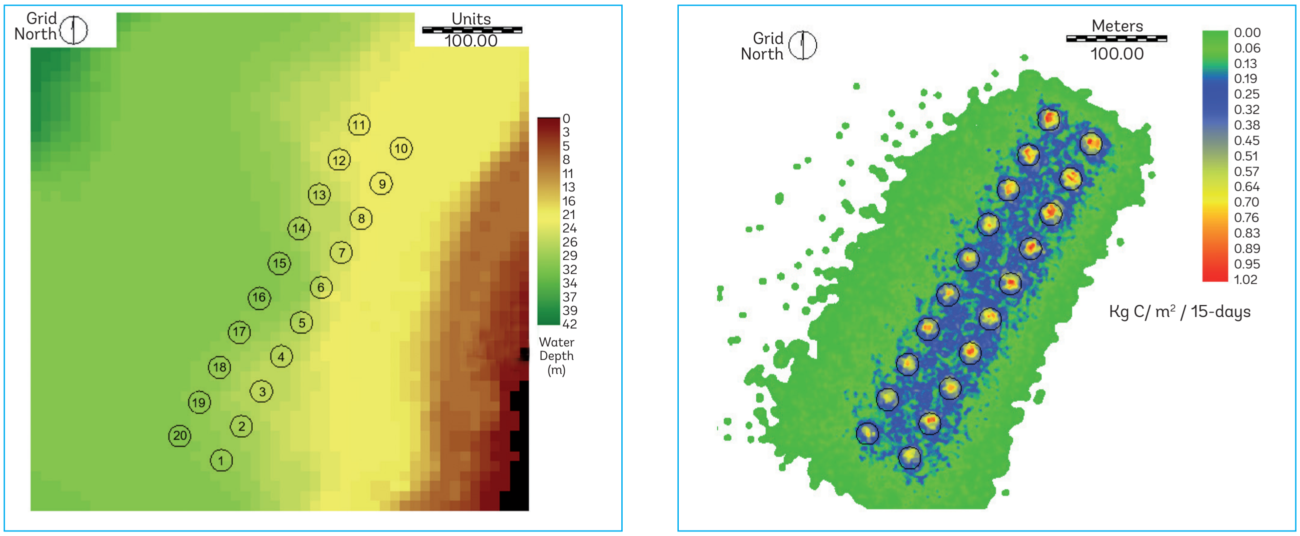
To estimate carrying capacity of shellfish and seaweeds, which do not pollute through nutrient outfall, but do compete with wild organisms for food, nutrients and oxygen, models should calculate the amount of shellfish that can be grown in a particular site without starving either the cultured or wild animals in the area. Ferreira (1995), Nobre *et al.* (2005, 2011), and Ferreira *et al.* (2008a) describe a carrying capacity model applicable for such systems. EcoWin is based on hydrodynamics, suspended matter transport, nitrogen cycle, phytoplankton and detrital dynamics, shellfish growth and human interaction and has been field tested in a number of locations, notably in Ireland (Ferreira, Hawkins and Bricker, 2007) and China (Ferreira *et al.*, 2008b).

An efficient production plan for aquaculture needs to consider carrying capacity and site characteristics to determine how much production can be accommodated in a particular location and, consequently, the amount of money that could be generated in order to achieve sustainability. Crowded production units mean that the stock can suffer from crowding stress, which lowers productivity (Figure 4), in addition to the disease transfer risks outlined previously. Figure 4 shows the evolution of productivity for three fish species in Chile over time, with dips in productivity associated with overcrowding, particularly of Atlantic salmon (*Salmo salar*). The decrease was critical in 2008 and 2009, and at this time saw the introduction of new regulations that established area management and coordinated fallowing periods, which resulted in improved productivity for all three species. Achieving production within the carrying capacity of the local system means managing for maximum productivity rather than maximum standing stock (e.g. the number of fish in the water at any one time), which will reduce pollution and costs while ensuring the welfare and maximizing the growth rate of the stock.

Carrying capacity estimation for individual farm sites is usually undertaken as part of the environmental impact assessment (EIA) and the licencing procedure (FAO, 2009). A fair and equitable licencing procedure, an EIA and an assessment of carrying capacity enable the setting of limits on farm size, including permits to discharge nutrients or other wastes to a waterbody, to ensure that there is no deterioration of water quality. This is particularly important for fed culture systems that generate wastes, but also for extractive species where wild stocks also need to be maintained.

For project planners at all levels, estimating carrying capacity is crucial to ensure overall sustainability of farms, and a number of modelling tools are available

FIGURE 3. Output from a particulate waste distribution model developed for fish culture in Huangdun Bay, China, using GIS, which provides a footprint of organic enrichment beneath fish farms



Source: Corner *et al.* (2006).

to be able to better understand what the limits are (see Annex 4). Models are generally the domain of knowledgeable specialists, and it is recommended that a suitable consultant conversant with appropriate models be engaged to develop systems relevant to specific circumstances.

5.3 Biosecurity planning and disease control

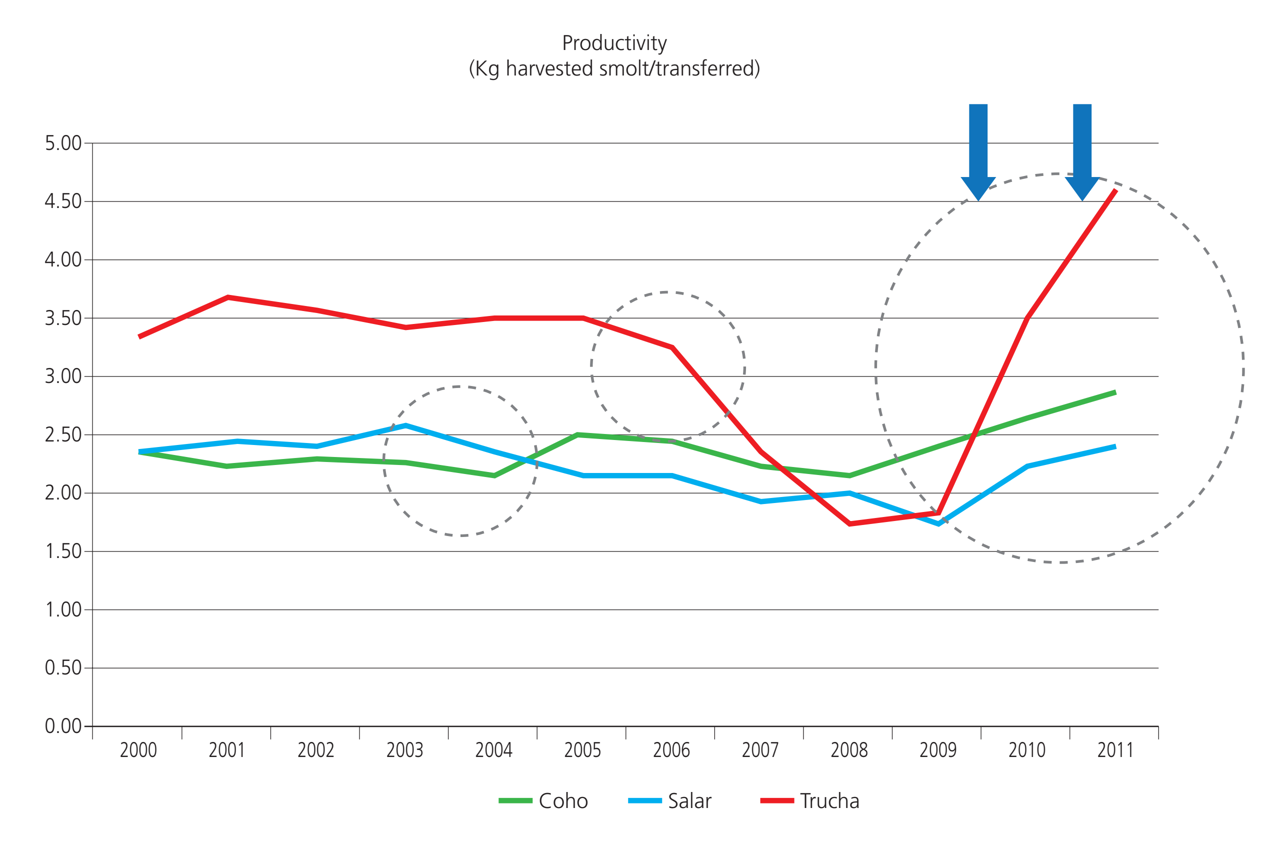
Diseases cause up to 40 percent of all losses in aquaculture systems, so biosecurity is an essential component of proper farm management at the site level. Diseases can spread to and from wild animals in the water surrounding a farm and through the water to other farms, and thus they are of concern to all stakeholders locally and within an aquaculture zone. Individual farms must maintain strict measures to prevent diseases coming into the farm (e.g. using certified disease-free stock), and maintain healthy and unstressed stocks and implement good hygiene practices so that diseases cannot gain a foothold and spread.

Most diseases affecting aquaculture organisms are more or less ubiquitous, present in low numbers in wild populations or in the environment. In most populations, some individuals will be resistant to a disease, but could still be a carrier. The onset of a disease outbreak not only requires the pathogen to be present, but stocks will also need to be in a vulnerable state, typically induced by some kind of stress. Common stressors in aquaculture include rough handling, low dissolved oxygen, inadequate feeding, and temperatures being either too high or too low or fluctuating. The combination of stressed fish and pathogen presence can lead to a disease outbreak.

The World Organisation for Animal Health is the leading international authority on disease management, including fish and shellfish. It proposes guidelines, published as the Aquatic Animal Health Code (available at www.oie.int/international-standard-setting/aquatic-code/access-online). Additionally, the fundamentals of aquaculture animal disease management have been reviewed by Scarfe *et al.* (2009). The basic components of a farm- or site-level biosecurity plan are:

- Screening and quarantine—all animals coming onto the farm should be certified disease free and tested for disease on arrival, and be maintained in separate holding facilities for a period of time to ensure that they are not infected.
- Isolation—nets, tanks and other equipment should be routinely disinfected, and farm workers should

FIGURE 4. Changes in productivity for three species of fish (kg harvest per smolt) under overcrowded (pre-2009) and properly spaced (post-2008) farm density



Source: Data from Alvial (2011).

maintain good hygiene, including handwashing and foot or boot washing. The amount of vehicular traffic (cars, boats) between the farm and the surrounding area should be kept to a minimum and disinfected upon return when possible.

- Proper handling—to avoid stress, fish should be kept in well-oxygenated water at an optimum temperature during holding and transport, and handled as little as possible during transport and when on site.
- Proper stocking density—in addition to causing stress, high-density conditions increase the frequency of contact among individual fish, leading to increased rates of disease transmission and infection.
- Regular monitoring—one of the first signs of disease is loss of appetite. Fish should be monitored closely during routine feeding to ensure that the fish are eating well and are healthy. Suspect animals should be removed immediately.
- Veterinary services—a licenced veterinarian should sample the farmed stock at regular intervals to ensure that any latent problem is detected as early as possible. If a government veterinarian is not available, farmers should call on a local specialist.

A more detailed analysis of the biosecurity implications for spatial planning and management can be found in Annex 2. Overall, a well-managed site, with maintained and healthy, well-fed stock along with appropriate and implemented hygiene procedures, reduces the likelihood of a disease outbreak and transmission between sites.

5.4 Authorization arrangements

The aquaculture leasing, licencing or permitting system is normally established through legislation or aquaculture-specific regulations. Implementation of these legislative or regulatory instruments and any protocols that define the procedures to be followed leads to the issuance of authorization to conduct aquaculture, usually containing specific terms and conditions that bind the lease, licence or permit holder.

The leasing, licencing or permitting system provides the authorities with the means to verify the legality of an aquaculture operation at a proposed site, and can be used as a basis for controlling and monitoring the potential environmental and social impacts of the operation. These authorizations/licences/permits typically outline what the holder is permitted to do by establishing the permitted physical dimensions of the site, the species that can be grown, acceptable operating conditions in relation to production and nutrient load limits, and the period over which permission to operate is valid.

A proper leasing, licencing or permitting system provides a legally secure right to conduct aquaculture operations in a specific location for a specified period of time. It provides exclusivity and ownership over the farmed organisms to the holder of the authorization, and protects investors from interference and from political vagaries in order to provide investor confidence. The authorization also allows the holder of such authorization to enforce the right accorded under the authorization against third parties, if the right is frustrated or denied or cancelled without good or legal reason for such cancellation.

Regulations governing the issuance of leases, licences and permits should consider the different stages of aquaculture development in a particular locale:

- New site—a proposal for a new previously undeveloped site for aquaculture. Most countries have specific rules for the location of a new farm to avoid locating it near habitats of special interest (recreation, wildlife, fishing zones) or near industries and sewage outfall. In many cases, site selection decisions are made in response to singular applications.
- Change of use—proposals that involve a change in the species that will be farmed on site, new or modified production practices, or requests to increase production. A new EIA and carrying capacity estimation could be needed to make an appropriate decision.

All leasing, licencing and permitting systems should include consideration of distances among aquaculture sites existing and planned, and between aquaculture and other, potentially conflicting, uses. Safe minimum site distance depends on many factors, including, but not necessarily limited to, wind direction and speed, water currents and direction, visibility of installations, wildlife corridors and nature reserves, and transportation routes.

5.4.1 Aquaculture licences or permits

Each separate company or legal entity operating within an aquaculture zone should be required to have an aquaculture licence or permit that defines:

- species to be cultured;
- maximum permitted annual production or peak biomass;
- culture method;
- site marking for navigation safety; and
- any special conditions such as regular environmental surveys and other monitoring.

There should be penalties or measures taken for contravening a condition of an aquaculture licence. In addition, a licence should also contain a provision giving the licensor the right to cancel, suspend or not renew a licence where the holder fails to adhere to the required standards, or where new information means the site is no longer acceptable or sustainable.

5.4.2 Aquaculture leases

Each separate company or legal entity operating within the zone should be granted legal tenure by way of an aquaculture lease issued by the competent authority. The aquaculture lease would include terms and conditions that specify:

- the terms or duration of the lease and its renewal options;
- perimeter location (latitude and longitude);
- lease fees; and
- other specific criteria such as what happens if there is no operation of the site within a specified time, or penalties for non-payment of fees or abandonment.

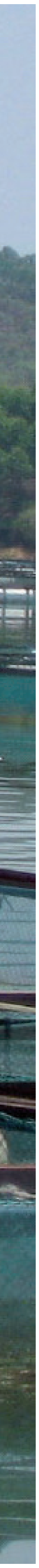
For both licences and permits, there should be regular surveys to monitor social and environmental impacts to ensure that they remain within acceptable levels. In cases where problems are occurring, flexibility in the licencing, permitting and/or lease terms should provide the farmer/owner with sufficient time to enable mitigation measures to be put in place and changes to be made before more drastic action is taken (such as removal of the licence).

Tilapia cage culture in Beihai, China

When there are several farms in an enclosed or well contained waterbody, it is essential to develop and implement an area management plan to minimize risks of disease and environmental risks.

Tilapia is cultured in many types of production systems. This flexibility makes the fish attractive to farmers in many parts of the world for subsistence and commercial production. Tilapia is also a favourite for many consumers. Fish from this farm in China is destined for the American market, although consumption is increasing locally. This strong demand is supporting increased production around the world in ponds and cages, in fresh and brackish water. However, as the industry grows, the risks also grow. Farmers must do their part to reduce environmental and disease risks on each farm as part of a larger resource management system that will protect the quality of water resources and the livelihoods for producers. Standardizing production practices and coordinating disease risks through area management strategies are key aspects for ensuring sustainable growth of the industry.

Courtesy of Jack Morales



6. AQUACULTURE MANAGEMENT AREAS

The designation and operation of an aquaculture management area (AMA) lies at the heart of the ecosystem approach to aquaculture. It is at this level of organization that collective farm and environmental management decisions are made that can more broadly protect the environment, reduce risk for aquaculture investors, and minimize conflict with other natural resource users.

There are activities that are amenable to area management that often fail to be effective when implemented at the individual farm level. Examples include the coordination of cropping cycles for sales and marketing purposes; synchronicity of treatments in disease management; environmental monitoring that ensures the cumulative effects of multiple farms are not unduly harming the environment; waste treatment and management; collective negotiation of input (e.g. feed supply) and service (e.g. monitoring) contracts; collective certification and marketing of products; the ability to implement a comprehensive biosecurity and veterinary plan; and provision of collective representation to the government and with other stakeholders. The key steps in the definition and management of AMAs are:

(i) delineation of management area boundaries with appropriate stakeholder consultation;
(ii) establishing an area management entity involving local communities as appropriate;
(iii) carrying capacity and environmental monitoring of AMAs;
(iv) disease control in AMAs;
(v) better management practices;
(vi) group certification; and
(vii) essential steps in the implementation, monitoring and evaluation of a management plan for an AMA.

6.1 Delineation of management area boundaries with appropriate stakeholder consultation

Within a defined aquaculture zone, AMA boundaries can be based on biophysical, environmental, socioeconomic and/or governance based criteria that, by overlapping, result in one geographical area with an identifiable physical/ecosystem base. For ease of regulation, AMAs should ideally be within one governance administrative unit (e.g. municipal, state, district, region). The AMA should be large enough to make a real difference in the ability of the components to increase their operating efficiency, but small enough to be functional and easily managed. Without specific governmental interference, farms and farmers will often self-organize around areas that are good for aquaculture. Their designation as aquaculture management areas simply allows for more formal and better overall management.

The most common means to delineate an AMA is related to disease, in particular disease transfer, which is spread through a common water source. Since diseases move through water and environmental loading is a function of the outflow of nutrients and wastes from all farms within a given area, it would be typical for the AMA to be delineated by the water surface/supply that is shared by all farms within it. Ensuring that all users of a common water source are in the same AMA creates incentives for cooperation in maintaining good water quality and in coordinated disease management. In cases where it is not obvious how water flow and diseases move from farm to farm, it may be necessary to develop a hydrological (freshwater) or hydrodynamic (marine water) map of the area. Such a map would identify major water sources, or tides and currents, that effect water movement or flows, and will assist in determining where the AMA boundaries should be located.

It is important that all farms within a designated AMA cooperate. Failure by one or a few farms to participate fully and to find solutions to problems when they occur may result in farmers who do participate becoming discouraged with a resultant loss of interest in cooperating. This is potentially wasteful in terms of time and energy on the part of the government seeking to sustainably develop aquaculture.

It is not always the case that farms in close physical proximity necessarily share a common water supply. In these circumstances, due to their close proximity, it may increase the likelihood of a disease transfer through other means (e.g. sharing workers, predation of diseased stock by birds that are then dropped into the neighbouring farm), and these farms should be extra vigilant in managing how they interact to minimize the overall risks.

Broadly, designating physical boundaries for cage aquaculture in a lake or embayment is relatively straightforward (Figure 5a). Pond aquaculture systems are more complex, as it is often difficult to spatially arrange ponds in any meaningful way; for example, in a river delta where the catchment (and therefore the water source) may be significantly larger and more dispersed than the aquaculture activity using that water. Nonetheless, attempts should be made to delineate AMAs for freshwater pond systems (e.g. Figure 5b), and then to undertake periodic assessments to ensure they function correctly. It is much easier to organize AMAs before aquaculture becomes well established, and therefore difficult to move, rather than later when farms are already operating and unable to relocate. Nonetheless, the rewards from better management, perhaps increased production, better coordination of shared resources and reduction of risk, mean that even where farms are long established the development of an AMA system is worth the time and effort.

It is not necessary that an AMA is specific to a single kind of aquaculture system or to a single species. For example, IMTA provides the by-products, including waste, from one aquatic species as inputs (fertilizers, food) to another. Farmers combine fed aquaculture monitoring (e.g. fish, shrimp) with inorganic extractive (e.g. seaweed) and organic extractive (e.g. shellfish) aquaculture to create balanced systems for environment remediation (biomitigation), economic stability (improved output, lower cost, product diversification and risk reduction), and social acceptability (better management practices). IMTA is most appropriate at the landscape level, and it is thus very relevant for an AMA. The delineation of management area boundaries should be done in consultation with all relevant stakeholders.
A consultation process is an opportunity for stakeholders to obtain information as well as give feedback. Stakeholders can use the opportunity to educate about the local context, raise issues and concerns, ask questions, and potentially make suggestions for the delineation of the management area. Therefore, a planned participatory process with consultation with all relevant stakeholders needs to be in place, commencing with clear objectives about what is to be achieved.

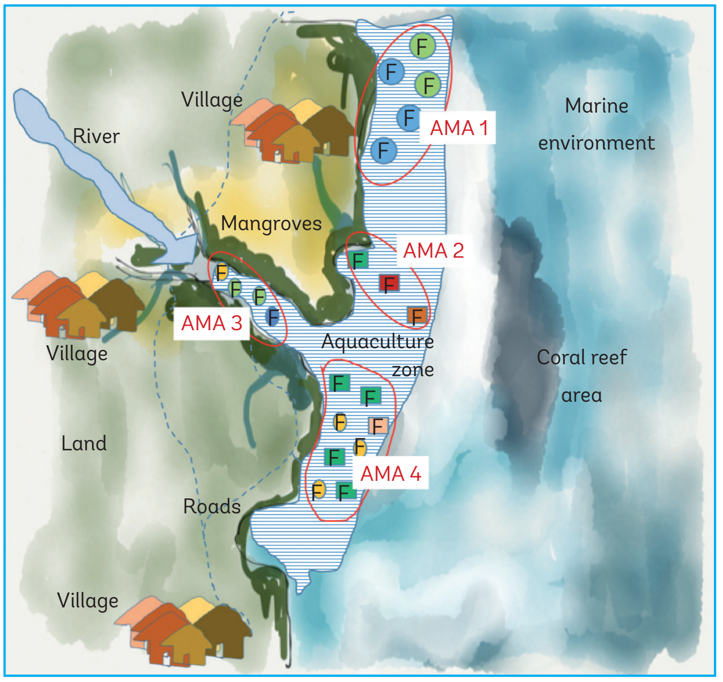
6.2 Establishing an area management entity involving local communities as appropriate

In any specific farm, it is imperative that the farmer operates to the highest standards in managing the site. It may not, however, be possible to influence everything that happens in the wider area, especially when other farms are in operation. Added to this, the impacts of disease and environmental loading to a waterbody or watershed are the result of all farms operating in that waterbody or watershed; and control cannot be managed by any single farm working alone, and collective activity becomes important in these circumstances. Where possible, all operating farms within an AMA should be members of a farmers' or producers' association as a means to allow representation in an area management entity, and which can set and enforce among members the norms of responsible behaviour, including, for example, the development of codes of conduct.
There is more than one way to develop an entity for an AMA, given that the legal, regulatory and institutional framework will vary at the national, regional and local levels. While the main impetus for the establishment of a farmers' or producers' association must come from the farmers themselves, there is nonetheless a significant role for the government as a convening body and, ultimately, the government has specific responsibility as the regulator and can place a high degree of impetus on the farmers to coordinate.
The government could help by providing basic services (e.g. veterinary, environmental impact monitoring, conflict resolution) through the farmers' association, which will encourage cooperation by all farmers.

Importantly, the government may also need to create a formal structure through which it engages with the farmers' associations that develop.

FIGURE 5a and 5b. Conceptual arrangement of aquaculture farming sites clustered within management areas designated within aquaculture zones

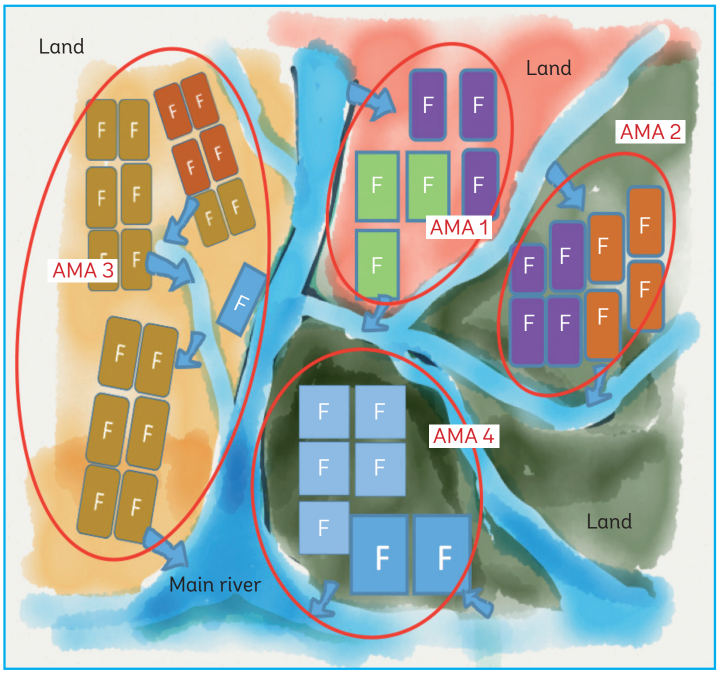
a. Coastal and marine aquaculture



Note:

Schematic figure of a designated aquaculture zone (hatched area in blue colour) representing an estuary and the adjacent coastal marine area. Individual farms/sites (F), owned by different farmers, are presented in different colours and can incorporate different species and farming systems. Four clusters of farms illustrate examples of AMAs, grouped according to a set of criteria that include risks and opportunities and that account for tides and water movement.

b. Inland aquaculture



Note:

Schematic figure of an existing aquaculture zone (the whole depicted area) representing individual land-based farms (F), e.g. catfish ponds and/or other species, that may be owned by different farmers (presented in different colours). In this example, there are four AMAs. The commonality in the AMA is the water sources and water flow (arrows) as the priority criteria (e.g. addressing fish health and environmental risks) used to set boundaries of the AMAs.

The number of individual farmers to be included in an AMA should be carefully planned and discussed to make the AMA operational. Some good examples of farmer associations include those in Chile, Hainan Island (China), India and the United Kingdom of Great Britain and Northern Ireland.

In Chile, there are approximately 17 corporate entities in the main producer's association, Salmon Chile, and when a significant disease outbreak occurred, aquaculture area management was used to overcome and manage the outbreak, with Salmon Chile developing and implementing some of the response measures.

The Scottish Salmon Producers Organisation (SSPO) incorporates 10 commercial decision-making entities, all of whom adhere to common principles of behaviour, adopt best practices, and share important disease and market information for the benefit of all members. In Scotland, the United Kingdom of Great Britain and Northern Ireland, AMAs were also developed out of a need to contain a disease outbreak, infectious salmon anemia (ISA), and which included control measures to eliminate transfer of stock between AMAs.

The Sustainable Fisheries Partnership (SFP) organizes farmers' associations into groups of approximately 20 on Hainan Island (China) and continues to support the Hainan Tilapia Sustainability Alliance. It is driven by a group of leading local companies who support the associations with seed, feed, technical support, farming and processing, and increasingly involving more of the local industry.

Cluster management, used to implement appropriate better management practices in Andhra Pradesh, India, can be an effective tool for improving aquaculture governance and management in the small-scale farming sector, enabling farmers to work together, improve production, develop sufficient economies of scale and knowledge to participate in modern market chains, increase their ability to join certification schemes, improve their reliability of production, and reduce risks such as disease (Kassam, Subasinghe and Phillips, 2011).

To be effective, it is important that all or nearly all of the farmers are part of the management plan, so as to avoid cheating on best practices that can lead to disaster for all. The SSPO in Scotland, the United Kingdom of Great Britain and Northern Ireland, and Salmon Chile in Chile represent ~90 percent of production in their respective management areas, and have been successful in coordinating and expanding production.

Where there is already a well-established aquaculture industry, it may be practically difficult to reorganize farms into defined aquaculture areas, in which case it may be necessary to adopt a strategic approach that establishes a working area management entity around a core of interested farmers, and gradually expanding to incorporate as many other farmers in the watershed as possible. If a serious problem occurs, such as a disease outbreak or pollution problems that affect an aquaculture area, and a sizeable number of farmers refuse to cooperate with the area management entity, it may be necessary for the government to impose regulations that require participation in an AMA as part of the permitting/leasing process to force the process.

The different scales of farmer groups will have a different internal governance and management system. Any system developed must formally identify how decisions will be made, have clear leadership and hierarchy within the group, and determine how the costs and any profits will be managed. In small farmer groups, it is easy for all members to be involved in day-to-day decision-making, but as farmer groups become larger, representatives are usually chosen to manage the group on behalf of members. In some cases, group members may not have sufficient business and management skills and experience to manage the AMA effectively and could employ professional managers from outside the group to manage their organization until sufficient experience is gained. Management of larger, more complex AMAs can be a time-consuming task, leaving little time for people to focus on their own individual farm management and production, and is another reason why a professional manager may be useful.

The structure of the AMA entity will vary depending on whether parties are the same size. AMA entities should be inclusive, as appropriate, for identification of issues, and stakeholder participation is essential. Under these circumstances, undue dominance by one or more larger commercial entities within an AMA can lead to disagreement on a course of action (e.g. affordable by some but not all), which might place a burden on the larger companies in providing the needed financial and other support to smaller farmers within the AMA. Conversely, there are instances where larger companies that support small farmers facilitate overall development and support to small farmers who have less capacity to take action. Some AMAs will make more sense for large-scale commercial aquaculture, while other AMAs could include a mix of producer sizes and types or could be designed just for small-scale farmers.

6.2.1 What does the area management entity do?

The purpose of the area management entity is the setting and implementation of general management goals and objectives for the AMA, developing common practices that ensure commonality in operations to the best and highest standards possible, and focusing on the activity that cannot be achieved by each farmer alone. In doing so, the entity is able to develop a management plan for the AMA.

A range of issues that could be best addressed at the level of the farmer's association are listed in Table 11. What is important is that the activity is of direct relevance and benefit to farmers, and that it leads to effective management of the AMA. The entity is not there specifically to resolve individual disputes between farmers, although the management entity can of course play a conciliation role where this does occur.

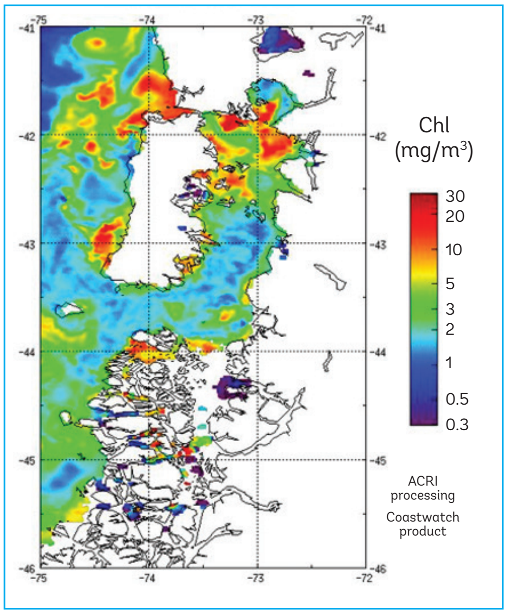
A major justification for collective action on the part of fish farmers is the reduction of risk to the farming system and to natural and social systems. To guide the creation of an area management plan, a thorough risk assessment should be considered to prioritize the most important risks that should be addressed, and identify actions to be implemented to overcome or otherwise mitigate the risks.

The majority of relevant threats "from and to" aquaculture have a spatial dimension and can be mapped. Risk mapping of AMAs should include those risks associated with the clustering of a number of farms within the same water resource, as well as external impacts that can affect the farm cluster, for example:

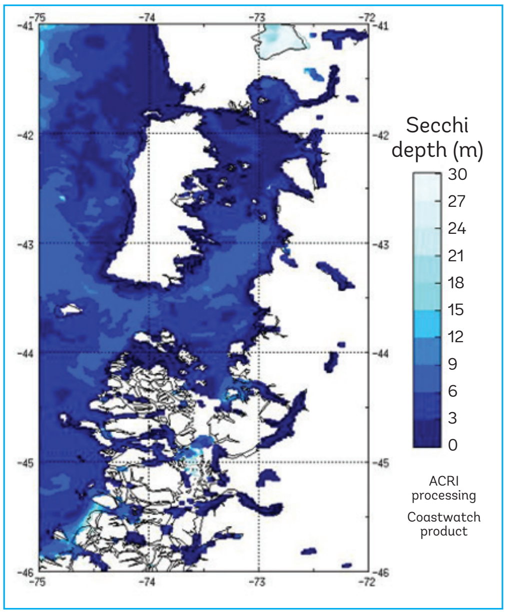
- eutrophication or low dissolved oxygen levels;
- impact on sensitive habitats;
- impact on sensitive flora (e.g. posidonia beds) or fauna;
- predators (e.g. diving birds, otters, seals);
- epizootics/fish disease outbreaks (e.g. ISA);
- social impact and conflict with local communities and other users of the resource, including, for example, theft;
- storms and storm surge;
- flooding; and
- algal blooms.

A variety of data and tools exist to support risk mapping analysis. Some GIS-capable systems are specifically targeted at risk mapping, and many general-use GIS systems have sufficient capability to be incorporated into risk management strategies. Remote sensing is a useful tool for the capture of data subsequently to be incorporated into a GIS, and for real-time monitoring of environmental conditions for operational management of aquaculture facilities. Satellite imagery has an important role to play in the early detection of harmful algal blooms (HABs). For example, in Chile, an early warning service based on Earth observation data delivers forecasts of potential HABs to aquaculture companies via a customized Internet portal (Figure 6). This Chilean case was led by Hatfield Consultants Ltd (Hatfield, UK), using funding from the European Space Agency-funded Chilean Aquaculture Project.

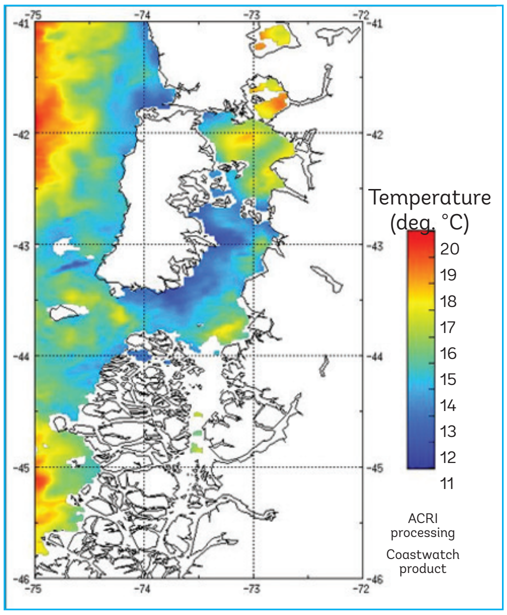
FIGURE 6. Monitoring and modelling of bloom events in the Gulf of Ancud and Corcovado, south of Puerto Montt in Chile



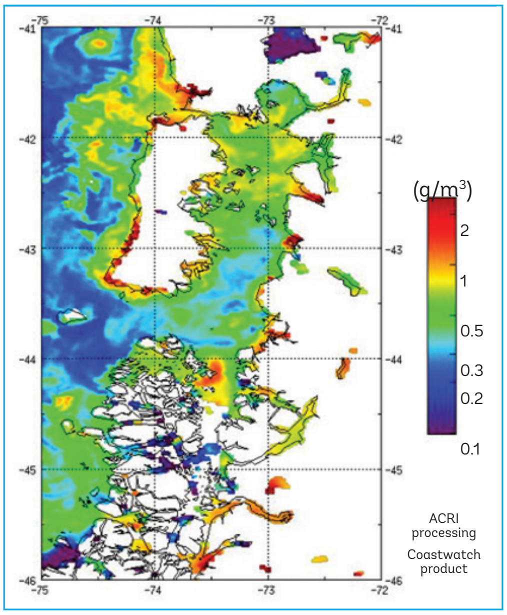
Chlorophyll-a pigment concentration
Time period: 2005-02-23 to 2005-03-02



Secchi disk transparency
Precision of ± 2m.
Time period: 2005-02-16 to 2005-03-02



Sea surface temperature
Precision of ± 0.5°C.
Time period: 2005-02-23 to 2005-03-02



Suspended particulate matter
Time period: 2005-03-02

Notes:

- Data extracted from Moderate Resolution Imaging Spectroradiometer (or MODIS), presented in a composite image showing data over a period of 15 days. Data distributed daily to the end users.
- MODIS is a key instrument aboard the Terra and Aqua satellites. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days. These data improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.

Source: Stockwell *et al.* (2006).

Another example of early warning for aquaculture is in Europe: the project Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms (ASIMUTH) funded by the European Union (www.asimuth.eu) used a collection of satellite and modelling data to construct a HAB forecasting tool. They incorporated ocean, geophysical, biological and toxicity data to build a near-real-time warning system, which took the form of a Web portal, an SMS alert system for farmers, and a smartphone app. The Web portal is curated and maintained by scientists in each country participating in ASIMUTH (France, Ireland, Portugal, Spain and the United Kingdom of Great Britain and Northern Ireland).

Over and above the issues listed in Table 11 are the key management measures that have been taken to address the key issues listed above where collective action is better than singular action, namely:

Improving aquatic animal health management and biosecurity

- Develop a common aquatic animal health and biosecurity plan for the area. Defines the approach to mitigate against disease risks for the area.
- Implementation of single year classes of stock (e.g. fish) where juvenile inputs are coordinated and managed in order to ensure there is no disease transfer through mixing stocks and to allow for a fallow period to break disease cycles.
- Disease control through regular disease surveillance and synchronized disease and parasite treatments. Treatment with the same medication is useful, and use of only authorized medication is expected.
- Vaccination of stock for specific diseases, where vaccines are available, with vaccination of all juveniles prior to stocking.

TABLE 11. Common issues to be addressed in aquaculture management areas

Social	Economic	Environmental	Governance
User rights conflicts	Production losses due to fish diseases and fish kills	Eutrophication of the common area	Weak management body
Resource use conflicts (e.g. water use, space, etc.)	Production losses due to thievery and general security	Poor discard of solid wastes (feed sacs, dead fish, etc.)	Non-compliance by farmers
Lack of training	Poor access to markets/low selling prices, etc.	Disease and parasite transfer to wild stocks	Inadequate monitoring and control
Lack of adequate services	Limited access to inputs (seed, feed, capital, etc.)	Escapes impacting biodiversity	Poor or slow conflict resolution
Lack of employment and poor labour conditions	Lack of post-harvest facilities	Use of chemicals impacting biodiversity	Lack of institutional capacity
Lack of opportunities for women		Use of fish as feed with negative impacts on local fisheries	Lack of political will towards aquaculture
Food safety problems		Poor management of water use	Absence of biosecurity frameworks
		Habitat disturbance (on mangroves, coral reefs, seagrasses, etc.)	Damage to the farms caused by climatic variability, climate change or other external forcing factors

- Coordination for fallowing and restocking dates. Synchronized fallowing, leaving the whole area empty of cultured fish for a specified time, and subsequent coordinated restocking supports biosecurity. Dates should be agreed upon between all parties and should be obligatory.
- Monitor the health status of newly stocked juveniles. There should be agreement on the quality of the juveniles to be stocked into a management area, which may include: physiological status of juveniles; use of vaccines; sourcing juveniles from specific pathogen free sources; and tests for specific pathogens on arrival.
- Control of movement of gametes/eggs/stock between the farms within the AMA and into the AMA from external sources.
- Disinfection of equipment, well boats, and so on at farms, and following any movements between different farms by defining the expected disinfection protocols.
- Regular monitoring and reporting of aquatic animal health status, regular monitoring of disease criteria, and other management measures within the AMA. This should include measures to be taken against non-conforming or non-complying farmers.
- Reconsidering the AMA boundaries to control a disease; for example, following the definition of epidemiological units in order to limit spread and impact of disease outbreaks within the common area.

For more information on biosecurity, see Annex 2.

Control of environmental impact, particularly cumulative impact

- Establishing the carrying capacity for the area to receive nutrients. In most cases, this is one of the first measures needed to adjust production and plan for the future of the AMA.
- Protecting natural genetic resources. Preparation of containment and contingency plans to minimize escapes and to control the input of alien (non-native) species introduction.
- Improving water quality by reducing contribution to eutrophication. This will involve an improvement in FCR so that excess nutrient wastes are also reduced. May involve re-siting farming structures (e.g. in the case of cages) where a new layout for the AMA could improve nutrient flows. This is also related to the first bullet point above.
- Environmental monitoring and implementation of regular environmental monitoring surveys and reporting and sharing of results.
- Fallowing of aquaculture areas. Synchronized fallowing of aquaculture areas, which leaves the whole area empty of cultured fish for a specified time. This is a biosecurity as well as an environmental management measure. It helps to break the disease and parasite cycle and allows the sediments and water quality to partially recover.

Improved economic performance of member farms

- Negotiation of supply and service contracts, whereby effective economies of scale and better terms can be achieved by negotiating contracts for common services (such as environmental monitoring), as well as for technology, fertilizer and feed supplies, among others.
- Marketing. Sharing post-harvest facilities (ice machines, packing facilities, refrigeration facilities, etc.). Establishing a common marketing platform.
- Sharing of infrastructure, such as jetties, boat ramps, feed storage facilities, sorting, grading and marketing areas, and ice production plants.
- Sharing of services, such as net-making, net-washing and net-repair facilities.
- Data collection, reporting, analysis and information exchange. Information exchange may include: veterinary reports; mortality rates; timing and types of medicines used; and mutual inspections for assurance purposes, both within the AMA entity and with external stakeholders, such as government departments.
- Coordinated harvesting and marketing that allows farms within the AMA to have a larger and continuous sales and marketing platform from which to sell products.

Social management measures and minimizing conflict with other resource users

- Facilitating and strengthening clusters and farmer associations.
- Identifying relevant social issues generated by aquaculture in the coastal communities.
- Social impact monitoring by agreeing on and setting indicators of impacts and regular monitoring of the impacts on local communities and other users of the water and other resources.
- Management of labour by monitoring workers' health and that of their families, implementing safety standards, providing appropriate wages and benefits, and identifying additional employment opportunities along the value chain. This will also include developing and implementing training activities to upgrade the skills of workers.
- Implement conflict resolution and measures to avoid conflict. If conflict does occur between farmers and between the management area and local interests (with fishers, for example), then resolution procedures should be fair, uncomplicated and inexpensive.

Once key issues are identified and agreed upon by the group, the management entity should develop management measures to address the key issues. These will then be incorporated into an area management agreement or plan that can guide future action for implementation.[6] The measures should be the most cost-effective set of management arrangements designed to generate acceptable performance in pursuit of the objectives.

Without a clear set of objectives and time frame for their achievement, the area management entity can turn into a "talk shop" and lose credibility among farmers, reducing its effectiveness and influence. Some elements of an area management agreement or plan that should be considered are as follows:

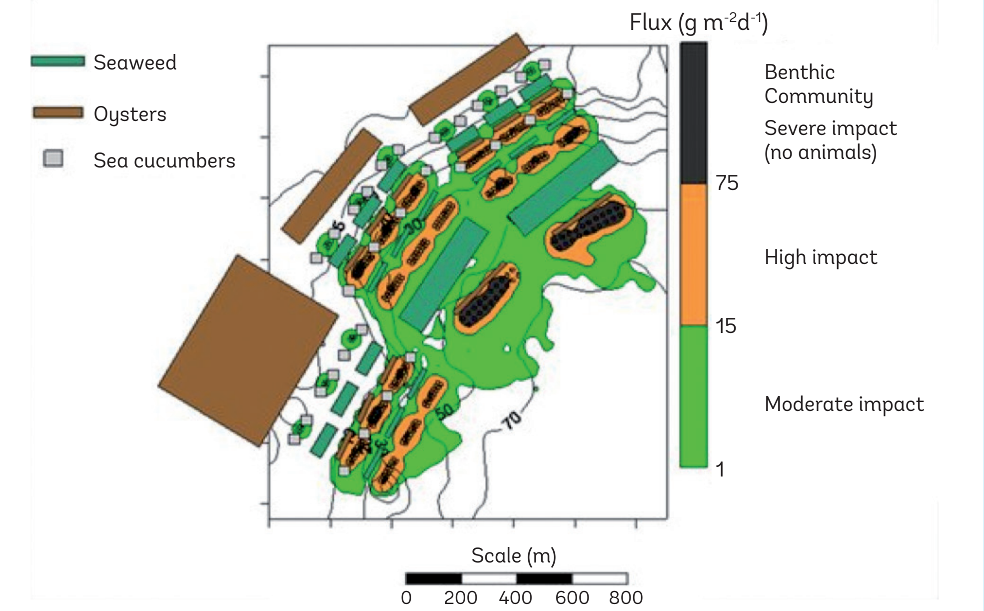
- agreement on the participants;
- clear statements on the objectives and expected outcomes;
- definition of the area and the farms included;
- agreement on the management measures;
- a management structure must have a mechanism to engage with public agencies and organizations, representatives from stakeholders, NGOs and other sectors that use the aquatic resource;
- responsibilities for implementation of the management plan must be clearly allocated to particular institutions and individuals;
- all farmers within the AMA must agree to conform to the management plan;
- the management structure must be able, willing, and allowed to implement or administer the incentives and disincentives to farmers who do not conform to the management plan;
- an agreed upon timetable;
- the roles and responsibilities and desired competencies for the key persons participating in key management positions within the zone; and
- financial arrangements supporting the management plan and area management entity.

6.3 Carrying capacity and environmental monitoring of AMAs

Estimates of environmental carrying capacity of the area should be made and regular surveys conducted to reassess the area. Carrying capacity at the AMA scale could be undertaken, for example, using depositional models (particle tracking) that predict the particulate outputs from fish cage aquaculture and that can be used in local-scale assessment of the effects of fish cages on the organic footprint impact on the sediment and sensitive demersal flora and fauna. Particulate tracking models use the output from a spatially explicit hydrodynamic-dependent particle tracking model to predict (organic) flux from culture sites to the bottom. At the local scale, screening models may be used to look at aquaculture yields,local impacts of fish farming and water quality. Figure 7 shows the modelled sediment impact below a cluster of fish farms in Panabo Mariculture Park, the Philippines, based on the existing situation (2012) and proposed rearrangement of the layout to increase production while trying to minimize impact.

[6] For more information on EAA management plans, see FAO (2010); FAO (2012); Gumy, Soto and Morales (2014); and FAO (2016b).

FIGURE 7. Output from a particulate waste distribution model (TROPOMOD) developed for fish cage culture, which provides a footprint of organic enrichment beneath clusters of fish farms (Panabo Mariculture Park, the Philippines)



Source: Lopez and White. Case study of the Philippines; Annex 5 of this publication.

Regular environmental monitoring surveys of individual farms for local impact and aquaculture area monitoring for clusters of farms are needed. In Turkey, aquaculture zones are monitored using the TRIX index, which is a measure of eutrophication, and is a tool for the regulation of Turkish marine finfish aquaculture to protect coastal waters, especially those of enclosed bays and gulfs from pollution by fish farming. Environmental monitoring systems are essential to address climatic variability and climate change (Box 2).

BOX 2

Area-based environmental monitoring systems to address climatic variability and climate change

Even though each farmer may collect some information and may have access to meteorological forecasts, these may not be enough for early warning on local extreme events. Simple information collected and shared on a permanent basis (e.g. water temperature, oxygen, transparency, water level, fish behaviour, salinity) can be highly relevant for decision-making, especially when changes can produce dramatic consequences. For example, temperatures above or below average can trigger diseases, or can bring anoxic water to the surface or trigger algal blooms that kill fish. The monitoring of environmental variables such as oxygen and water transparency can also indicate excessive nutrient output from farms, etc. The sharing of monitoring information in common areas combined with early warning systems can assist rapid response to diseases and other threats such as algal blooms and anoxic bouts. In general, environmental monitoring systems should follow a risk-based approach that recognizes that increased risk requires increased monitoring efforts. The involvement and value of locally collected information should be seen as very relevant to farmers to better understand the biophysical processes and become part of the solution, e.g. rapid adaptation measures and early warning, long-term behavioural and investment changes. Key activities include training of local stakeholders on the value of the information, monitoring, and use of the feedback for decision-making. It is also advisable to provide/implement some simple network/platform to receive and analyse the information, to coordinate and connect with broader forecasts and monitoring systems, and to provide timely feedback that is useful to local stakeholders. In such cases, well organized AMAs can generate information and facilitate feedback for faster responses.

A recent consultation on developing an environmental monitoring system to strengthen fisheries and aquaculture resilience and improve early warning in the Lower Mekong Basin took place in Bangkok, Thailand, in 2015 (FAO, 2017).

Capacity building

The FAO-INPESCA workshop on estimating carrying capacity for shrimp farming in Estero Real, Gulf of Fonseca, Nicaragua, targeted 25 stakeholder representatives, including national and local government aquaculture technical personnel, shrimp farmer companies, shrimp farming cooperatives, local communities, and representatives of fishers from Estero Real. The workshop focused on the process and steps to assess carrying capacity for shrimp farming in a Ramsar area and review current aquaculture zoning and management measures to ensure a sustainable shrimp farming sector.

Courtesy of Doris Soto

6.3.1 Some key actions to establish ecological carrying capacity and maximum allowable aquaculture production in aquaculture zones and aquaculture management areas

1. **Define the boundaries of the aquaculture zone or aquaculture management area, considering it as an ecosystem unit.** In freshwater systems boundaries are generally physical boundaries such as a river basin, a water catchment, a lake or oxbow lake. Boundaries in marine systems for enclosed bays or Fjordic systems can be defined as the point at which they connect with the open sea, and are easier to define than an open coastal zone or offshore area. The latter marine cases may require operational boundaries such as a current border or a sharp change in hydrography, oceanographic conditions or benthic morphometry.

2. **Establish baseline conditions for the aquaculture zone or AMA**. This requires data collection (either remotely or directly) to establish the pre-existing conditions. Here, satellite remote sensing is useful to define physio-chemical properties such as temperature in marine systems, and land use in freshwater systems. Direct data collection can include samples for water quality and benthic conditions.

3. **Agree a set of standards or thresholds that determine environmental, ecological and social limits of change to the zone/area through stakeholder consultations, scientific research and local knowledge.** All aquaculture has "impact", whether this is change to conditions in the immediate vicinity of fishpond outlets or further down river systems, under or surrounding fish cages and mussel rafts, or changes to water flows, where there may be temporary deterioration of some environmental conditions. Standards account for the baseline conditions and determine acceptable changes in those conditions, leading to definitions of maximum acceptable criteria. What is important is to ensure resilience in the overall area or ecosystem unit to ensure sufficient sustainability in the long term, so that there remain areas without aquaculture, with buffers and where no other human interventions are permitted. Environmental standards tend to be related to biological and chemical parameters such as maximum chlorophyll (eutrophication). Ecological standards could include the presence and abundance of indicator species such as a fish, crab, marine grass, or maximum water abstraction. Social limits might involve ensuring fishing rights/areas are maintained, or minimising visibility from urban or tourism areas.

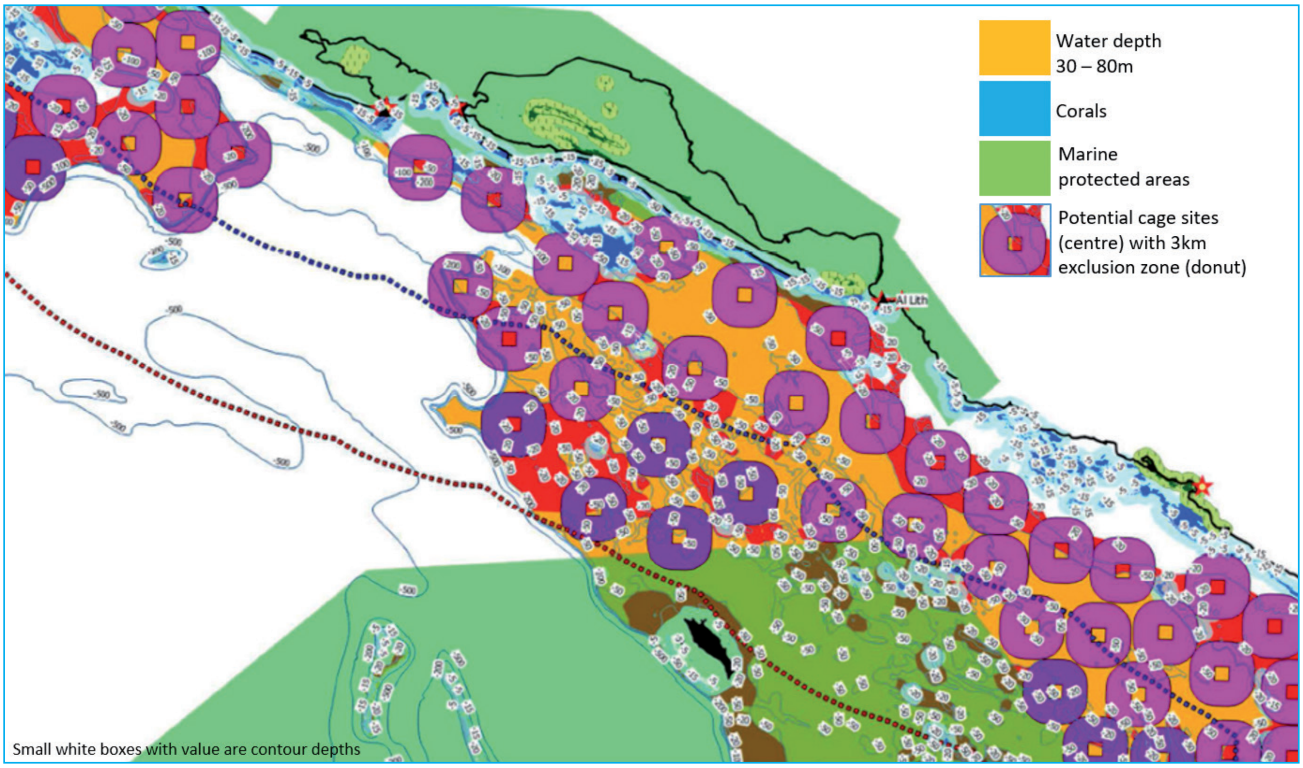
4. **Estimate the maximum ecological carrying capacity of the ecosystem unit to include the maximum aquaculture production permitted; estimated using the best available models (see Annex 4) and application of the standards and thresholds agreed.** There are some classical models for assessing lakes and contained water bodies (e.g. modifications of Vollenweider, 1968; Beveridge, 1984) to estimate likely changes in phosphorus and nitrogen according to the known inputs from aquaculture and certain thresholds for chlorophyll concentration, as an indicator of ecosystem response (i.e. eutrophication effects). Establishing carrying capacity in coastal ecosystems or open water systems is much more challenging due to complex oceanographic and biological conditions and the lack of clear boundaries. Some models can estimate likely changes over large areas, others assess impact of individual fish farms or mussel farms that could be extrapolated to larger areas. The application of GIS is also useful in determining physical limits on location through the application of basic criteria such as water depth and buffers from existing activities. This could also include minimum distances between aquaculture sites and other areas (see distance ranges in Tables 9 and 10 in Chapter 5 on site selection) along with sufficient distance from each other, adequate water depth, and circulation. Figure 8 provides an example of the application of GIS to estimate possible locations of farms and broad evaluation of overall capacity in Saudi Arabia based on physical limits.

5. **Invest in appropriate research** to address carrying capacity estimation of complex systems or open systems for aquaculture development.

6. **Permit production to commence through a set application and licencing system.** Increase production slowly at first, applying a conservative approach, and increase production when it is clear the current production is not having undue environmental and social impacts. It is better to be able to increase production slowly as ecosystem indicators show that there is no or minimal harm to the ecosystem and/or the farming system, instead of starting big and being forced to reduce production due to serious environmental and/or fish health damage.

7. **Establish an integrated environmental monitoring system at the farm scale and/or at the system scale.** Integrated monitoring is required since monitoring individual farms is not sufficient on its own to establish multiplicative effects of many farms in a zone/area. The monitoring of reference areas, away from farms but in key positions in the AMA or aquaculture zone, can provide the reference conditions to evaluate and compare ecosystem change. Also, permanent monitoring of other similar habitats, such as aquatic reserves, marine reserves and protected areas, can be useful to compare with areas being used by aquaculture.

FIGURE 8. Example output from GIS to identify potential sites for cage aquaculture within a zone along the Red Sea coast of Saudi Arabia



Note:

Basic criteria has bee applied to delimit suitable locations (i.e. maximum distance from coast, water depth, protected species and areas, and basic criteria for distance between sites. This does not define ecological capacity, which requires investigation of ecosystem quality and use of models to assess actual capacity.

Source: Saunders *et al.* (2016).

6.4 Disease control in AMAs

Disease outbreaks pose one of the most significant risks to the sustainability of aquaculture. There are many examples of how the introduction of a disease or diseases has brought large aquaculture industries to the verge of collapse with serious economic and socio-economic consequences. Biosecurity can be broadly described as a strategic and integrated approach that encompasses both policy and regulatory frameworks aimed at analysing and managing risks relevant to human, animal and plant life, and health, as well as associated environmental risks (FAO, 2007a; 2007b). As such, it has direct relevance to the sustainability of aquaculture, protection of public health, the environment, and biodiversity.

In the context of aquatic animal health, the term biosecurity is used to describe the measures used to prevent the introduction of unwanted biological agents, particularly infectious pathogens, and to manage the adverse effects associated with contagious agents. It encompasses both farmed and wild aquatic animals; exotic, endemic and emerging diseases; and is applied from the farm to the ecosystem, and at the national and international levels (Scarfe *et al.*, 2009). Farmers should be encouraged or possibly mandated to follow sound biosecurity practices that provide the framework for disease management on the farm and that are implemented through documented standard operating procedures. At the farm level, the owner or operator is responsible for ensuring implementation of biosecurity. Auditing and certification of the efficacy of a biosecurity programme is provided by the attending veterinarian and competent government officer.

Biosecurity planning, applied from the farm to the national level, provides an effective means of implementing disease control at multiple levels and for preventing catastrophic disease events. At the zone, compartment or AMA level, the biosecurity plan provides an auditable process of management procedures that can be evaluated by hazard analysis and critical control point (HACCP) methodologies (Zepeda, Jones and Zagmutt, 2008). Control measures designed to mitigate the impact of aquatic animal diseases may include containment, eradication, disinfection and fallowing. Control measures should be based on the ability to define epidemiological units. Depending on the infection pathway of an aquatic animal disease, the epidemiological unit may need to encompass the entire AMA, or a subpopulation within the AMA, for instance, one of a group of farm sites within an AMA. Well-defined subpopulations of aquatic animals can then be managed according to realistic outcomes. The identification and prioritization of hazards represents the first step justifying implementation of a biosecurity scheme. This is followed by assessment of the risk posed by these hazards and the evaluation of critical control points whereby the risk can be remediated. Establishment of appropriate measures against a defined hazard or disease, including appropriate contingency planning, allows the risk to be mitigated. A programme of disease surveillance is instituted for the AMA to monitor occurrence or absence of a disease. Where a hazard or disease is detected or has been introduced, eradication and disinfection provides a method of managing the impact of disease with the possibility of reinstating a disease-free status. One of the outcomes of a biosecurity scheme is audited third-party certification. In order for a third party to provide disease status assurances, transparent and credible written records must demonstrate the effectiveness of the biosecurity scheme in preventing, controlling and eradicating disease within an AMA.

The devastation of the Chilean salmon farming industry by the ISA disease in 2007 provides an example of how AMAs have been implemented in this country to help rehabilitate the farming of salmon and to create an environment conducive to the sustainable growth of the industry (Ibieta *et al.*, 2011). Establishment of AMAs appropriate for aquaculture has been legislated in Chile through the so-called "neighbourhood system". These areas represent suitable zones for aquaculture activities according to appropriate epidemiological, oceanographic, operational or geographic characteristics, and incorporate complementary environmental, sanitary and licencing regulations. Epidemiological, operational and logistical characteristics of the AMAs are aimed to address the ISA virus infection and control. These site regulations include movement of all aquaculture concessions to AMAs, limiting the life span of a concession to 25 years (renewable), and banning the movement of fish from and between sea sites. This limits the movement of broodstock from sea sites to freshwater facilities, as well as the temporary use of estuarine sites. Fish inputs, disease prophylaxis, therapeutic interventions, sanitary issues, harvesting and fallowing are coordinated among the farms within the AMAs (neighbourhoods). The distance between neighbourhoods has been established at a minimum of 3 nautical miles (about 5.6 km), and aquaculture sites must be spaced out by at least 1.5 nautical miles (about 2.8 km) from each other and from marine protected areas (natural parks and reserves) (Ibieta *et al.*, 2011).

6.5 Better management practices

Better management practices (BMPs) are a set of guidelines that promote improved farming practices to increase production through responsible and sustainable aquaculture. There is a significant level of variation in BMPs for different commodities, culture systems and locations. In India, BMPs implemented by farmer clusters have resulted in improved yields, fewer disease occurrences and higher profitability, as well as other private and public benefits.

In the Philippines, each mariculture park has an operations manual containing production guidelines and management measures following the principles of good aquaculture practices, and serves as the guideline for all activities within the parks. The guideline covers zone and farm location, layout and design, biosecurity sanitation and hygiene, waste storage and removal, good farm management measures, including feeds and feeding, farm effluent treatment, worker health and safety, disease diagnosis, treatment and chemical use, harvesting, post-harvest, traceability and food safety.

In Scotland, the United Kingdom of Great Britain and Northern Ireland, area management agreements follow the Code of Good Practice for Scottish Finfish Aquaculture. The code, developed in 2006, is an evolving document that is regularly reviewed to incorporate essential changes in legislation and emerging priorities in environmental management and the sustainable development of the industry. It brings the standard of practice of every participating farmer up to a specified acceptable level, and is based on science and experience, reflecting the industry's desire to remain at the forefront of good practice.

6.6 Group certification

The ability to provide third-party auditing and certification through an effective and justifiable biosecurity plan, when applied at the farm or compartment level, can allow farmers to access markets that require disease-status assurances that may not be available on a national level. This allows trade from a suitably certified AMA, even where a region or country is not certified free from a disease and cannot provide relevant disease-status guarantees.

If the environmental or social indicator threshold was breached, there would be need for measures to reduce the impact. For instance, these could include improved feeding strategies to reduce FCR, longer fallowing periods, synchronization of grow-out calendars to minimize excessive biomass at any one time, and other measures. If these fail to reduce the impact to the acceptable level, a drastic step may be needed, including reductions in the total production or maximum standing biomass levels within the AMA.

6.7 Essential steps in the implementation, monitoring and evaluation of a management plan for an AMA

The implementation of the management plan should be time bound. Two aspects are important relative to a time frame. The first is to decide on a base year for the management system. This will represent a year (or period) against which progress can be measured. The second time aspect relates to target years or periods by which various aspects of the work plan can be achieved, or by which any quantitative programme output should be attained. Overall, it is likely that the management system should be envisaged as spanning

TABLE 12. Examples of indicators for aquaculture management areas

Social	Economic	Environmental	Governance
• Quality of labour conditions • Socio-economic benefit to the local community • Positive perception by local community • % of local people employed • % of local women employed	• Average farm profitability • Level of disease outbreak • % of losses during production period • Market demand • Product quality and safety • % certified	• Average food conversion rate • Level of eutrophication (e.g. TRIX index) • Benthic diversity at edge of area (cages) • Water quality at outfall (ponds)	• Adoption of Code of Conduct or good aquaculture practices • AMA certification • Compliance of farmers to management measures • Level of transparency

a 5- to 10-year time frame, but during this period the system will need periodic reviews over shorter time scales.

The management plan must address all the relevant issues, have very clear and achievable operational objectives for each issue, and a clear timeline for completion with targets and indicators (Table 12).

The management plan must have responsible people/institutions/entities and requires adequate funding for each management approach and also must have resources to implement the measures as appropriate. Since it will generally be the central government that will be implementing the work, financing will mainly come from general tax revenues, though other sources of funding include stakeholder contributions, funding from external donors, international and multinational organizations, grant funding, foundations and the private sector. Since many of the activities that stand to gain from a management system will be in the private sector, it would not be unreasonable to expect that a range of business associations might be willing to help with financing. For example, an alternative source of funding tried in China is that all users of the sea must pay a "marine user fee" if they intend to carry out production and other economic activities.

It is almost certain that the eventual financial support will be delivered from more than one source. Clearly, funding will need careful planning ahead of the systems implementation.

Performance indicators must be set to inform whether set targets are being achieved, while efficiency indicators would show if there has been any improvement. The indicators that are selected should cover sustainability dimensions–social, economic, environmental, and overarching governance–at the aquaculture area scale. For each objective, an indicator and its associated performance measures should be selected so that the performance of each objective can be measured and verified (Table 12 and Table 13). The choice of indicators to be measured should reflect the cumulative impacts within the management area.

A monitoring programme to keep track of implementation must be put in place. In the context of an AMA, monitoring keeps track of the progress of the management plan based on indicators. Just as important, it provides an indication of compliance by AMA members with the agreed plan. Monitoring involves: (i) continuous or ongoing collection and analysis of information about implementation to review progress; and (ii) compares actual progress with what had been planned so that adjustments can be made in implementation.

Corrective measures can be implemented, an important part of which are sanctions to non-conforming members. The result of monitoring gives a factual, objective basis for a sanction. Should non-compliers persist, a defined conflict-resolution mechanism has to be agreed on and firmly applied.

TABLE 13. Examples of management plan objectives and indicators to address the prioritized issues

	Issues	Operational objectives	Indicators	Target (e.g. in 1 year)	Management measures
Social	Limited access to inputs (seed, feed, capital, etc.)	Increase access to seeds by 20% (all farmers in the area) in two years	Average seed (biomass, numbers, etc.) being bought by farmer per growing cycle	10% increase first year	Build a hatchery for the AMA
Economic	Production losses due to fish diseases	Diminish losses by 30% in two years	Mortality index	20% reduction by second year; continual reduction thereafter	Establish a biosecuirity framework in the area with all relevant procedures
Environmental	Eutrophication of the common area	Diminish eutrophication by 40% in three years	Oxygen, fish kills, chlorophyll-a (Chl-a)	Diminish eutrophication by 20% in the first year	Establish the carrying capacity for nutrients in the area; Reduce total production until meeting maximum allowable according to carrying capacity
	Use of chemicals impacting biodiversity	Use only authorized medication; All medication used under guidance of health specialist	Use of (extent, percentage, biomass, etc.) banned chemicals and medication	Zero use of banned chemicals and medication by year 2	Designation of a common veterinarian; All medication given under supervision and coordinated
Governance	Inadequate monitoring and control	Regular monitoring of performance indicators and compliance of farmers; All farmers in the area management complying to management plan	Number of performance indicators and related th-resholds being recorded	Thorough annual monito-ring of indicators and full report after year 2	Regular monitoring survey with standard analysis and regular reporting and eva-luation
	Lack of institutional capacity	Designated management committee members are knowledgeable, efficient and well trained	Number of key posts filled	All area management posts filled in first year	Training and standard operating procedures on key management measures

That said, the use of incentives for compliance can be a more effective measure than a sanction.

The regular monitoring of management performance may show that the area management plan needs to be adjusted. If current management measures do not seem to be working or are deemed inappropriate, alternative measures need to be introduced. In some cases, some measures may be rendered unnecessary if the issue has been solved. In other cases, changes in issues or priorities could end the relevance of a measure. The management plan should in any case be reviewed periodically, e.g. once a year or every two years according to needs. This underlines the importance of monitoring and evaluation.

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GLOSSARY

Aquaculture licence	A legal document giving officialauthorization to carry out aquaculture. This authorization may take different forms: an aquaculture permit, allowing the activity itself to take place; or an authorization or concession, allowing occupation and/or for aquaculture of an area in the public domain so long as the applicant or holder of the authorization complies with the environmental and aquaculture regulations and other conditions of the authorization (IUCN, 2009).
Aquaculture zone	An aquaculture zone is an area dedicated to aquaculture, recognized by physical or spatial planning authorities, that would be considered as a priority for local aquaculture development (GESAMP, 2001; Sanchez-Jerez, *et al.*, 2016).
Area management plan	A plan for the management of a defined area for aquaculture where the farmers undertake aquaculture in accordance with agreed strategies, management practices and codes of conduct, and manage production in order to reduce and manage risks posed by disease and parasites, including cumulative environmental impacts and social conflict.
Biosecurity	Mitigating the risks and impacts on the economy, the environment, social amenity or human health associated with pests and diseases.
Carrying capacity	Carrying capacity is the amount of a given activity that can be accommodated within the environmental capacity of a defined area. In aquaculture, it is usually considered to be the maximum quantity of fish that any particular body of water can support over a long period without negative effects to the fish and to the environment (FAO, 2009; Ross *et al.*, 2013).
Coastal zone management	The management of coastal and marine areas and resources for the purposes of sustainable use, development and protection (IUCN, 2009).
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their nonliving environment interacting as a functional unit (Millennium Ecosystem Assessment, 2005).
Ecosystem boundaries	The boundaries of a system of complex interactions of ecosystem-linked populations (including humans) between themselves and with their environment.
Evaluation	Evaluation is the systematic examination of a project in order to determine its efficiency, effectiveness, impact, sustainability and relevance of its objectives.

Fallowing	This refers to leaving an aquaculture site empty of fish stock and all removable production structures for a certain period of time. It can be done for environmental or sanitary reasons. For an aquaculture company, fallowing implies having several sites in order to maintain production capacity year-round (IUCN, 2009).
Indicator	Indicator is a parameter, or a value derived from parameters, which points to, provides information about, and describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value (OECD, 2003).
Issue tree	An issue tree, also called a logic tree, is a graphical breakdown of an issue that dissects it into its different components vertically.
Management areas	Management areas are defined geographical waterbody areas where all the operators in the management area agree (coordinate and cooperate) to certain management practices or codes of conduct.
Monitoring	Monitoring is the continuous or periodic surveillance of the physical implementation of a project to ensure that inputs, activities, outputs and external factors are proceeding as planned.
Operational objectives	Operational objectives are measurable production, environmental and additional socioeconomic targets to be achieved within immediate and long-term scales.
Risk assessment	Risk assessment focusing on a variety of ecological attributes in order to protect the environmental, economic, social and cultural values identified by society.
Site selection	Site selection is the process by which various factors indicated are considered to enable one to decide on the right site for a specific culture system, or alternatively, to decide on a culture system that suits the available site (Kutty, 1987; Ross *et al.*, 2013).
Site management	Refers to all the actions involved in maintaining the activity on the site, including the environmental, legal, administrative and managerial aspects of the activity (IUCN, 2009).
Spatial planning	Refers to the methods used by the public sector to influence the distribution of people and activities in spaces of various scales. Spatial planning takes place at local, regional, national and international levels and often results in the creation of a spatial plan. Spatial planning also entails a system that is not only spatial, but one that also engages processes and secures outcomes that are sustainable, integrated and inclusive (FAO, 2013).
Social carrying capacity	Social carrying capacity is the level of development above which unacceptable social impacts would occur.
Stakeholder	Person, group or organization that has a direct or indirect interest in an activity normally initiated by a management authority or other stakeholders or is affected or has an interest in an objective or policies established by such management authority (IUCN, 2009).
Surveillance	Means a systematic series of investigations of a given population

	of aquatic animals to detect the occurrence of disease for control purposes, and which may involve testing samples of a population.
Surveillance zone	Means a zone in which a systematic series of investigations of a given population of aquatic animals takes place.
Targeted surveillance	Means surveillance targeted at a specific disease or infection.
Zone	Means a portion of one or more countries comprising an entire catchment area from the source of a waterway to the estuary, more than one catchment area, part of a catchment area from the source of a waterway to a barrier, or a part of the coastal area, or an estuary with a precise geographical delimitation that consists of a homogeneous hydrological system.
Zoning	Means identifying zones for disease control purposes. (aquatic animal health)
Zoning	Zoning implies bringing together the criteria for locating aquaculture and other activities in order to define broad zones suitable for different activities or mixes of activities. Zoning may be used either as a source of information for potential developers (for example, by identifying those areas most suited to a particular activity); or as a planning and regulating tool, in which different zones are identified and characterized as meeting certain objectives (GESAMP, 2001).

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The ecosystem approach to aquaculture provides the conceptual guideline for spatial planning and management. This publication describes the major steps related to these activities. The rationale for and objectives of each step, the ways (methodologies) to implement it, and the means (tools) that are available to enable a methodology are described in a stepwise fashion. Recommendations to practitioners and policy-makers are provided. A separate policy brief accompanies this paper. The benefits from spatial planning and management are numerous and include higher productivity and returns for investors, and more effective mitigation of environmental, economic and social risks, the details of which are provided in this paper.

This publication is organized in two parts. Part one is the "Guidance"; it is the main body of the document and describes the processes and steps for spatial planning, including aquaculture zoning, site selection and area management. Part two of the publication includes six annexes that present key topics, including: (i) binding and non-legally binding international instruments, which set the context for sustainable national aquaculture; (ii) biosecurity zoning; (iii) aquaculture certification and zonal management; (iv) an overview of key tools and models that can be used to facilitate and inform the spatial planning process; (v) case studies from ten countries – Brazil, Chile, China, Indonesia, Mexico, Oman, the Philippines, Turkey, Uganda and the United Kingdom of Great Britain and Northern Ireland; and (vi) a workshop report.

The country case studies illustrate key aspects of the implementation of spatial planning and management at the national level, but mostly within local contexts. Take-home messages include the ways in which institutional, legal and policy issues are addressed to implement the process, or parts of the process.

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