Key drivers and issues surrounding carrying capacity and site selection, with emphasis on environmental components

Joao Gomes Ferreira
Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, the Portuguese Republic

Laudemira Ramos
Administração de Região Hidrográfica – Tejo, Lisboa, the Portuguese Republic

Barry A. Costa-Pierce
Rhode Island Sea Grant College Program, University of Rhode Island, R.I. 02882–1197, United States of America

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Abstract

Historically, site selection has been based largely on available space and constraints to productivity (e.g. circulation or food availability). However, in order to ensure sustainable development: (a) carrying capacity and site selection can no longer be viewed in such a limited way, and requires an analysis of trade-offs among production, ecology, governance, and social aspects; and (b) a system-wide assessment of carrying capacity should precede licensing at the farm-scale. This is in keeping with the three core principles of the Ecosystem Approach to Aquaculture that promote ecological balance, social equity, and multi-sectorial planning. This review considers the relevant legislation and regulations in the major world producers of aquaculture goods, and highlights the variable requirements for licensing, particularly with respect to the environmental component. Additionally, different countries and economic blocks view carrying capacity in different ways. In Southeast Asia and the People's Republic of China, production is generally the limiting factor, whereas in Europe and North America, social constraints are of paramount importance. Both aspects present a challenge for a common assessment platform with respect to carrying capacity and site selection.

Virtual technologies such as GIS, satellite remote sensing, and dynamic models, can play a huge role in addressing the physical, production, and environmental pillars of site selection and carrying capacity. However, models need to be more production- and management-oriented, and adapt to local realities and conditions. Research

into improved models for social aspects, and for the connection to environmental assessment models, needs a much greater effort. This will establish a more quantitative basis for discussion and for decision-making, enabling a better understanding of trade-offs. Distributed computing (e.g. smartphones) has great potential in bridging the information gap in many thematic areas, and should certainly be used to improve the understanding of aquaculture-environment interactions, simulate local conditions in real time, and interpret the outputs of sensors.

Aquaculture is particularly important to developing countries, where it is not only critical in supporting healthy food provision but is also an important source of income for local communities. It is important however that production in developing countries should not translate into negative environmental externalities considered unacceptable in the developed world.

Introduction

In the field of aquaculture, carrying capacity has been variously defined through its original meaning (Krebs, 1972; Kashiwai, 1995) which may be

$$\sum_{i=1}^{n} \frac{dB_i}{dt} = 0 \qquad \text{(Eq. 1)}$$

where: B_i = biomass of species i of n and t = time.

Eq. 1 suggests that in a stable community the *average* biomass of component species is asymptotic over the time period of interest, and corresponds to the logistic growth curve in population ecology.

The specific demands of aquaculture, an activity based on the interaction between humans and other elements of the natural system, converting the latter (at least in part) into a *managed* system, led to the definition of carrying capacity as "the standing stock at which the annual production of the marketable cohort is maximised" (Bacher *et al.*, 1998; Smaal *et al.*, 1998). Although this definition was proposed in the context of organically extractive open water culture (for bivalve shellfish), it is sufficiently broad to be relevant for production both in open off-the-coast and offshore environments and in land-based systems using ponds or raceways.

However, even from the point of view of sustainable production this definition needs to be qualified, because in economic terms the maximisation of annual production is not the objective function. This function seeks to achieve optimal *profit*, well before the inflexion point in the production function, where total physical product (TPP) maximises *income* (e.g. Jolly and Clonts, 1993; Ferreira, Hawkins and Bricker, 2007).

This simplistic view of carrying capacity for aquaculture based solely on production has developed over the last decade into a four pillar approach based on physical, production, ecological, and social carrying capacity (Inglis, Hayden, B.J. & Ross, 2000; McKindsey *et al.*, 2006). In large part these pillars encompass the three elements of sustainability, viz. planet, people, and profit. Recent legislative instruments such as the European Union's Marine Strategy Framework Directive (EU MSFD – EC, 2008), together with guidelines for an Ecosystem Approach to Aquaculture (EAA – Soto, Aguilar-Manjarrez and Hishamunda, 2008), highlight the ecological component and aim to optimize production without compromising ecosystem services. Part of the challenge of determining carrying capacity is the quantification of negative externalities as a first step towards improved management.

The social[1] pillar is at the forefront of decision-making in the EU, US, and Canada,

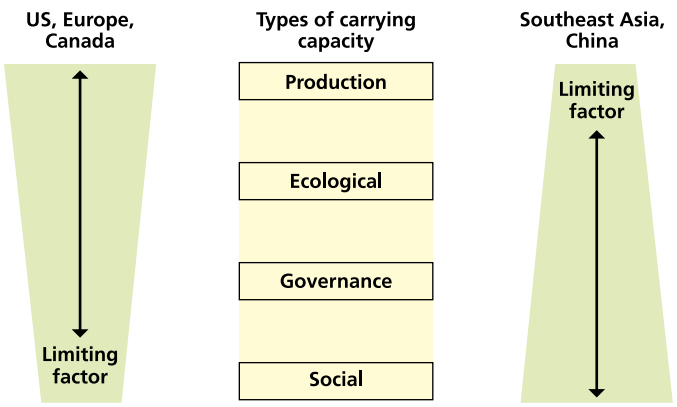
[1] Here used in the context of social opposition to visual or other impacts of aquaculture development, such as conflict with leisure areas.

and can frequently be identified as the single most important criterion for carrying capacity assessment and site selection (Figure 1). By contrast, in Asia and other parts of the world where food production is the paramount concern, licensing criteria are more frequently based on the physical and production pillars, with ecological and social considerations assuming less relevance.

Virtual tools, including various types of mathematical models, are fundamental in analysing these various components of carrying capacity, and therefore in assisting sound decision-making on sustainable development of aquaculture without the costs of social experimentation. Ferreira *et al.* (2010) have defined virtual technology in this context as:

Virtual Technology is defined as any artificial representation of ecosystems that support aquaculture, whether directly or indirectly. Such representations, exemplified by mathematical models, are designed to help measure, understand, and predict the underlying variables and processes, in order to inform an Ecosystem Approach to Aquaculture.

FIGURE 1
The relative importance of the four pillars of carrying capacity



Source: Adapted from Carrie J. Byron and Barry A. Costa-Pierce (2012).
Note: The narrowest segment for the regional areas corresponds to the greatest constraint to carrying capacity.

This review focuses on the key drivers and issues surrounding carrying capacity and site selection, with an emphasis on the environmental components, and aims to:

1. Examine current practice for site selection worldwide, both for inland (freshwater) and coastal (onshore, off-the-coast, and offshore) aquaculture;
2. Contextualise the existing approach in the light of environmental legislation in different parts of the world;
3. Analyse how carrying capacity and site selection can benefit from virtual technologies, and identify areas for development;
4. Recommend actions to promote an Ecosystem Approach to Aquaculture from an environmental perspective.

Worldwide perspective

Current global criteria and approaches for site selection

The establishment of aquaculture activities in different geographical areas has traditionally been a bottom up process, without a particular concern about overall definition of a zoning framework. This has been the case globally, from the development of salmon cage culture in Scottish lochs to the incremental destruction of mangroves in Nicaragua for construction of shrimp farms (Figure 2).

This approach to licensing (or in many cases just to development), based mainly on space availability and limits to production rather than on any environmental criteria led to a number of undesirable ecosystem effects, including habitat destruction both on land and in open waters, coastal eutrophication through increased nutrient loading from land, and organic enrichment of sediments and loss of benthic biodiversity.

Changes in the regulatory framework have in the last decades led to a more stringent approach to licensing, most notably in the European Union, United States, and Canada. Nevertheless, only in a few cases (e.g. Ferreira *et al.*, 2008b) has

FIGURE 2
Expansion of shrimp ponds over a 13 year period in Estero Real, Nicaragua

November 19, 1999

January 6, 1987

Source: Adapted from Byron and Costa-Pierce (2008).

there been a concern with the assessment of carrying capacity at the system scale, i.e. defining and quantifying potential *aquaculture zones*, as an initial step prior to local-scale licensing of aquaculture operations.

Mathematical models such as DEPOMOD Cromey, Nickell and Black, 2002; Cromey *et al.*, 2002) and others (Nath *et al.*, 2000, Corner *et al.*, 2006) have become increasingly important in supporting the local-scale assessment of effects on the environment, and are used e.g. in Scotland by the regulator in order to screen for environmental impact of new lease applications for salmon farms, i.e. to support *site selection* at the local scale.

The international legal framework

On a global scale, the Convention on Biological Diversity (CBD) is one of the most important documents concerning environment and biodiversity. Loss or alteration of habitats as a result of aquaculture operations can become a biodiversity concern when it changes the living conditions of other species, for instance through:

(i) seed collection for aquaculture from benthic habitats using destructive gear causes habitat destruction and/or alteration;
(ii) Spatial conflicts: aquaculture takes up space, often very large areas, not only in bays and oceans, but also on nearby foreshore areas as a result of development of aquaculture infrastructures;
(iii) destruction of tidal marshes and mangroves that serve as important nursery grounds for populations of fish and shellfish

However, the CBD has also recognized that aquaculture may have some positive effects, for instance by helping preserve biodiversity when, as a successful economic activity, it can provide a release to the predation pressure over commonly harvested aquatic species. Best site selection (including optimal flushing and dispersal of nutrients) could actually promote an increase of local and total productivity, especially in oligotrophic and mesotrophic systems, particularly when additional substrate heterogeneity, such as building of artificial reefs to soft bottom areas, is provided. Additionally, some forms of aquaculture, such as shellfish and macroalgal production, could contribute to biodiversity enhancement by providing habitat structure and food.

Several international conventions include provisions related to aquaculture e.g. the Oslo-Paris Convention (OSPAR), Bern Convention, and Helsingfors Convention (HELCOM). In addition, the European Community is committed to the principles of the Precautionary Approach, the guidelines for aquaculture in the FAO Code of Conduct for Responsible Fisheries (Article 9 of which covers Aquaculture Development) and other international arrangements or guidelines such as the ICES Code of Practice on the Introductions and Transfers of Marine Organisms.

The legal framework in the People's Republic of China and southeast Asia

Asia as a whole currently produces 90 percent of the world's aquaculture (Sorgeloos, 2010). It is estimated that the current annual production of 68 million metric tonnes (MMT) (De Silva, 2010) will need to be substantially increased to meet the world demand for aquatic products by 2050. This increase, of the order of 30 MMT/year (Swaminathan, 2010), will rely on aquaculture, and will not be provided by Europe or North America. In both cases, production is limited by stringent environmental regulation and social concerns. Growth in the European Union will be very limited, and the United States of America expects an annual increase of about 0.5 MMT (Olin *et al.*, 2010). This is a 30 percent increase of current United States of America production, but hardly registers on the scale of world food requirements. By contrast, the production of Vietnamese catfish in the Mekong Delta has increased exponentially over the last three years, with a current production of 1.2 MMT/year, and successful placement in the Europen and United States of America markets (De Silva, 2010).

As a consequence, it is important to review environmental legislation in the framework of aquaculture for the main Asian producers, to understand to what extent comparable constraints exist to aquaculture production in various parts of the world.

The European Union legal framework

Specific European legislation relevant to limiting the effects of aquaculture on biodiversity is less well established than for capture fisheries. Among the relevant legislation is that on aquatic animal health, and the Environmental Impact Assessment (EIA) legislation.

Most aquaculture concerns are regulated by national legislation which is influenced by a number of horizontal EU Directives governing water, habitat and bird life. Following from these directives it is required that developing projects, including new fish[2] farms, should be subjected to prior assessment if they are likely to have significant effect on the environment. In the framework of the reform of the Common Fisheries Policy (CFP) the European Commission recognized the importance of aquaculture and the necessity to develop a Strategy for the Sustainable Development of European Aquaculture (COM 2002 511 final). The Strategy set out a wide range of policy principles on which the future development of aquaculture in the EU would be based, including the necessity to assure that aquaculture becomes an environmentally sound activity. Additionally in the framework of the CFP a biodiversity action plan was developed which includes a chapter dedicated to impacts of aquaculture.

The second generation EU water directives, which presently consist of the Water Framework Directive (WFD 2000/60/EC) and MSFD, do not address aquaculture in a meaningful way. The WFD explicitly excludes the fisheries component, and only considers fish populations as a Biological Quality Element (BQE) in transitional waters.

The approach itself, with an emphasis on a *one out, all out* classification for quality elements in the determination of Good Ecological Status (GE_cS), has been described

[2] Although finfish are referred in the EU directive on environmental impact, the national authorities are free to interpret this as appropriate, so some Member States consider the legislation to apply to other types of aquaculture, based on areal occupation and production.

as a "deconstructing structural approach" (Borja *et al.*, 2010). The MSFD is developed in a holistic manner, defining eleven quality descriptors (QD) that should in some (as yet unknown) way be combined to establish Good Environmental status (GE_nS). QD3 is the Fish and Shellfish quality descriptor, but contrary to what might be expected, the guidance produced for this descriptor focused only on capture fisheries. It is disappointing that aquaculture is considered in the MSFD only as a pressure; discounting for instance the role that organically extractive aquaculture plays in top-down control of eutrophication symptoms in many European coastal areas.

Since the WFD mandates GE_cS by 2015 and the MSFD requires GE_nS by 2020, the latter for very large marine areas, extending to the Exclusive Economic Zone (EEZ) of the EU, aquaculture development in Europe is clearly under significant pressure with respect to environmental regulation.

The United States legal framework

This brief review of the legal framework in the United States of America has been largely drawn from Duff, Getchis and Hoagland (2003), Pittenger *et al.* (2007), Upton and Buck (2008), and from Peterson *et al.* (2010) in what concerns shellfish aquaculture.

In United States of America coastal waters the legal framework delegates jurisdiction to individual states, leading to complex results and inconsistencies. A comprehensive review of aquaculture regulations across the United States of America (the "Aspen Report" sponsored by the United States of America Fish and Wildlife Service) was carried out in 1981, and identified at least 120 federal laws directly (50 laws) or indirectly (70 laws) affecting aquaculture, together with over 1,200 state statutes regulating aquaculture in 32 states. According to this report, in some states aquaculture operations must obtain at least 30 permits to site and operate their businesses. Regulatory jurisdiction over bivalve mariculture typically requires approval by several local, state, and federal agencies.

Public land management typically falls under the authority of the state department responsible for environmental protection. Regulatory complexity is further increased when towns or counties are given jurisdiction over local waters. The consequences of this complexity on shellfish growers have often been an expensive, time-consuming, and sometimes unsuccessful process for obtaining permits (Duff, Getchis and Hoagland, 2003).

In response to concerns over real or perceived regulatory complexity, many states have designated a particular state agency as the "lead" and starting point for mariculture permit applications. Many coastal states also have created inter-agency coordinating committees or task forces to facilitate the mariculture permit process. Some states produce written guidance to help permit applicants understand the requirements for different mariculture operations and the process and sequence for obtaining them.

Offshore mariculture policy

Regulatory complexity, use conflicts, and (in some cases) water quality issues in nearshore waters have led to greater interest in offshore or open ocean mariculture.

The regulation of offshore mariculture in the United States remains unsettled. At present, there is no federal policy pertaining specifically to the permitting of mariculture in waters under federal jurisdiction, typically 3–200 nautical miles offshore, known as the exclusive economic zone. At a minimum, a Section permit is required from the United States Army Corps of Engineers (USACE), and in some cases, approval from fisheries management councils may be required. In the absence of a settled and transparent regulatory framework, not only is expansion of the existing industry hampered, but potential future growth and research in this area is discouraged (Barr, 1997; Brennan, 1999; National Oceanic and Atmospheric Administration, 1999).

TABLE 1
Synthesis table of legislation and other framework elements

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
China	- Fisheries Law and Regulation for the Implementation of the Fisheries Law (1987). - Local laws and regulations	Numerous guidelines have been issued, on various topics, for instance the operation of hatcheries and the use of antibiotics and chemicals in aquaculture.	- Party to the Convention on Biological Diversity (CBD). Signed Biosafety Protocol (BP), but not yet a party. - Party to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).	The people´s governments may grant licences to use state-owned water surfaces and tidal flats. After the 2000 amendment, those wishing to use designated areas must apply for an aquaculture permit.	EIA requirements in various environmental laws, but none of which specifically refer to aquaculture. The EIA Law (2002) expands EIA requirements from individual construction projects to government planning for the development of aquaculture, etc.
India	- Indian Fisheries Act (1897); - Environment Act (1986); - Water (Prevention and Control of Pollution) Act (1974); - Wild Life Protection Act (1972).	- Guidelines for Sustainable Development and Management of Brackish Water Aquaculture; - Guidelines for optimizing yield levels and improving the management of shrimp aquaculture.	- Party to the CBD and signed the BP. - Party to the CITES	The Aquaculture Authority is responsible for the authorization system approval. The approval form, given for a period of 3 years, will specify the conditions to the activity.	EIA Notification, in accordance with the Environmental Act, specifies the projects that require an EIA. The list does not include aquaculture, but the Guidelines for Sustainable Development and Management of Brackish Water Aquaculture recommend to carry out a site selection process, which should include proper EIA.
Thailand	- Fisheries Act (1947, amended in 1953 and 1985); - Royal Decree on Administration (1994); - Development Policy; - National Fisheries.	Code of conduct standards for the marine shrimp culture industry; - Good Aquaculture Practice guidelines for hygienic shrimp production with no environmental impacts.	- Party to the CBD but not to the BP. - Party to the CITES	Fisheries Act classifies fisheries into four categories. Anyone that wants to cultivate aquatic animals will need a permission obtained from the Director-General for Fisheries.	Aquaculture is currently not among the range of projects for which an EIA is required.
Indonesia	Fisheries Law n.º 31/2004, which underscores the importance of sustainable use of aquatic resources in the development of fisheries.	Being a member of ASEAN, Indonesia embraces the codes of conduct adopted by the Association, which includes, among others, the Manual of ASEAN Good Shrimp Farm Management Practices Guidelines.	- Party to the CBD and to the BP. - Party to the CITES - Member of Southeast Asian Fisheries Development Center (SEAFDEC)	Fisheries Law requires a specific licence to engage in fisheries business, including aquaculture. Small producers are exempt from such requirement. When required, the EIA is part of the licensing procedure.	Environment Management Act (1997) requires an EIA for any business or activity likely to have a major and significant impact on the environment. The conduct of aquaculture is subject to EIA procedure, as established by Decree of the State Minister of the Environmental Affairs n.º 3/2000.
Bangladesh	- Protection and Conservation of Fish Act (1950) as amended by the Protection and Conservation Ordinance (1982) - Marine Fisheries Ordinance (1983 - Marine Fisheries rules (1983).	There are no guidelines or codes of conduct for aquaculture activities	- Party to the CBD and to the BP. - Party to the CITES	There is no authorization or registration system of aquaculture facilities.	The Environment Protection Act (1995) aims to protect the environment and to control and mitigate environmental pollution. Aquaculture projects are not included.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Japan	- Fisheries Law (1949, as revised in 1962) - Law to Ensure Sustainable Aquaculture Production (1999).	Basic Guidelines to Ensure Sustainable Aquaculture Production (1999)	- Party to the CBD and to the BP. - Party to the CITES - Member of SEAFDEC	Fisheries Law recognizes three principal categories of fisheries rights, from which the demarcated rights are granted for aquaculture in specific areas.	EIA Law (1997) sets procedures and contains provisions designed to ensure that EIA are conducted properly with respect to large-scale projects that could have a serious impact on the environment. The Law does not specifically refer to aquaculture.
Philippines	- Philippine Environment Code (1988) integrates all relevant laws to these issues. Part of Chapter II of the Code deals with aquaculture.	Code of Practice for Aquaculture, for environmentally-sound design and operation to promote the sustainable development of aquaculture industry	- Party to the CBD and signed the BP, but not yet a party. - Party to the CITES - Member of SEAFDEC	Authorizations are granted by the body that has jurisdiction over the venue of the aquaculture operation.	Fisheries Code requires that activities or projects which will affect the quality of the environment need to prepare a prior detailed Environment Impact Statement. Fishery projects are included in the list of the Environmental Critical Projects.
European Union (EU)	• Water Framework Directive 2000/60/EEC of 23 October; • Marine Strategy Framework Directive 2008/56/CE of 17 June; • Regulation (CE) n.° 710/2009 of 5 August; • Regulation (CE) n.° 535/2008 of 13 June; • Regulation (CE) n.° 708/2007 of 11 June; • Regulation (CE) n.° 506/2008 of 6 June; • Strategy for Sustainable Development of European Aquaculture COM(2002)511, of 19 February 2002 (Communication from the Commission to the Council and the European Parliament)	The Federation of European Aquaculture Producers(FEAP) is open to all national aquaculture associations. FEAP members adopt the 2000 Code of Conduct for European Aquaculture.	EU is a member of several international arrangements, namely: • Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Agreement); • Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Convention for the Marine Environment Protection and of the Mediterranean Coastal Area (Barcelona Agreement 1995). • North Atlantic Salmon Conservation Organization (NASCO). • Convention on Biological Diversity (CBD); • Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM); • International Baltic Sea Fishery Convention (IBSFC); • North Atlantic Fishery Organization (NAFO); • North East Atlantic Fishery Convention (NEAFC);	No specific legislation	Directive 85/377/EEC of 27 June 1985, modified by Directive 97/11/CE of 3 March 1997.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
USA	Aquaculture is regulated at the federal and state level: • National Aquaculture Act (1980), establishes a National Aquaculture Development Plan and requires federal coordination of aquaculture; • Clean Water Act, the major federal law regulating environmental aspects of marine aquaculture; • Coastal Zone Management Act (1972) requires federal activities to be consistent with State Coastal Management Plans.	The EPA Effluent Limitations Guidelines and New Source Performance Standards for Concentrated Aquatic Animal Production Point Source; Draft Guidance for Aquatic Animal Production Facilities to Assist in Reducing the Discharge of Pollutants, EPA; Code of Conduct for Responsible Aquaculture Development in the United States of America Exclusive Economic Zone (NOOA 2003).	- Party of the CBD - Party to the CITES among others with implications for the regulation of aquaculture	In principle, it is unlawful to conduct aquaculture operations or to culture approved species of aquatic plants and animals unless registered with state authorities. However, this may vary from state to state; The clean Water Act establishes pollution discharge permits and ocean discharge criteria; Open ocean aquaculture requires approval of United States of America Environmental Protection Agency, United States of America Army Corps of Engineers and National Marine Fisheries Service.	The requirement of an environment impact assessment before an aquaculture facility is registered may vary from state to state.
Canada	The aquaculture industry is overseen by a combination of federal, provincial and local authorities.	- National Code System for Responsible Aquaculture. - Another codes of conduct targeted specifically to the aquaculture industry have also been developed at the provincial level.	- Party of the CBD - Party to the CITES, among others with implications for the regulation of aquaculture	Both the federal and provincial governments are authorized to issue licences to engage in and set up an aquaculture facility in Canada.	The Canadian Environmental Act (1992) and its regulations are the legislative basis for the federal practice of environmental assessment. Under the CEAA a marine aquaculture project is subject to an environmental assessment.
Norway	- The Aquaculture Act (2005). - The agreement on the European Economic Area (EEA) imposes several obligations on Norwegian legislation.	There are no guidelines or codes of conduct for aquaculture activities	- Party to the CBD and to the BP. - Party to the CITES	The Aquaculture Act establishes an obligatory licensing system for aquaculture, and provides that the Ministry may, through regulations, prescribe limitations in the number of licences.	Any aquaculture licence may, as a general rule, only be granted if it is "environmentally responsible". The Regulation relative to impact assessment (2005), establishes that an EIA is to be carried out for large aquaculture installations,
Chile	- Fisheries and Aquaculture Law (1989, as amended up to 2006) regulates the conservation of living aquatic resources, capture fisheries, aquaculture and scientific and recreational fisheries.	There are no guidelines or codes of conduct for aquaculture activities	- Party to the CBD but has not yet ratified the BP. - Party to the CITES	The authorization/ concession system to set up aquaculture facilities is regulated by the General Fisheries and Aquaculture Law.	According to the General Law on Environment, the conduct of aquaculture is subject to an environmental impact assessment, with the exception of minor scale aquaculture.
New Zealand	- Resources Management Act (RMA) as amended in 2004. - Freshwater aquaculture activities regulated by the Freshwater Fish Farm Regulations of 1983, under the statutory guidance of the Fisheries Act as amended in 2004.	New Zealand as not adopted a specific code of conduct for fisheries or aquaculture. However, it "fully supports" the FAO Code of Conduct for Responsible Fisheries	- Party of the CBD - Party to the CITES, among others with implications for the regulation of aquaculture	In coastal zones, rules and plans will determine whether resource consents are required to carry out aquaculture related activities Inland fish farming is also subject to an approval, in the form of a resource consent or certificate compliance	The RMA requires that any application for a resource consent must contain an adverse effects assessment, which details the scale and significance of the effects of aquaculture and other activities, upon the environment.

A bill defining federal policy and permit processes for mariculture in the exclusive economic zone, the National Offshore Aquaculture Act, has been introduced several times, most recently in 2007 as H.R. 2010 and S. 1609 in the 111th Congress (NOAA, 2008). The 2007 bill would address the current gaps in United States of America offshore mariculture regulation by:

- authorizing the Secretary of Commerce to issue offshore mariculture permits;
- requiring the Secretary of Commerce to establish environmental requirements for offshore mariculture;
- requiring the Secretary of Commerce to work with other federal agencies to develop and implement a coordinated permitting process for offshore mariculture;
- exempting permitted offshore mariculture from fishing regulations that restrict size, season, and harvest methods;
- authorizing a research and development program for all types of mariculture.

This asymmetry in regulatory instruments and requirements for environmental compliance on a global scale has been an important factor in the delocalisation of aquaculture from Europe and the US to other parts of the world, where there is little concern for the negative externalities that result from unsustainable aquaculture practices.

Main gaps and key elements

Main global carrying capacity and site selection issues and gaps

Table 2 presents a summary of the main issues that are presently considered in carrying capacity and site selection, together with what may constitute future components for assessment.

Feed-based aquaculture taking place in cages (open water) or ponds (inland or fringing) is mainly constrained by holding capacity and wastewater reduction criteria. In Southeast Asia and People's Republic of China there is a greater preoccupation with holding capacity, whereas e.g. in the European and the United States of America legislation drives a greater emphasis on negative externalities.

TABLE 2
Novel management approaches (adapted from Ferrreira et al., 2010)

Topic	Now	Tomorrow
Feed-based (cage, pond)	Site selection based on holding capacity (cages), wastewater minimization (ponds)	Integrated model systems, risks, welfare, disease. Holistic indicators LCA: inefficiencies and eco-labelling Mechanistic and statistical models Data assimilation models
Shellfish farming	Large areas Focus on production and social carrying capacity NIMBY[3], NIMTO[4]	Economic sustainability, ecology and economics Coupled GIS expert systems including xenobiotics HAB, etc Model uncertainties in yield Early warning
Integrated Multi-Trophic Aquaculture	Optimize production Reduce negative externalities	Integrated Coastal Zone Management. Simulate species combinations Full economic assessment. Combine GIS, remote sensing, and modelling
Ecosystem Approach to Aquaculture (EAA)	Development of concept and practical implementation	Ecological aquaculture, balancing multisectorial requirements, ecosystem equilibrium, and social equity. Many of the tools that will be used in IMTA are applicable, much more will emerge on social components where "hard" models are a challenge. Achievement of more equitable global balance.

[3] Not in my backyard
[4] Not in my term in office

More intensive aquaculture and volume of production tends to occur in nations that are currently developing regulation, and where there is weak enforcement, and /or low consideration to environmental effects. On the other hand in some of these countries food security and social needs are higher ranked than environment (Figure 1) particularly in consideration to high population density in coastal zones. This could be the case in some Asian countries such as it is shown in Figure 3 that illustrates aquaculture production normalised to coastline length and area.

However, in some cases such in the People's Republic of China the intensity of cultivation in coastal bays, may often constitute a positive environmental impact (see below).

As an example of potential aquaculture pressure on coastal ecosystems, Figure 4 shows a mass balance for shrimp cultivation, simulated by means of the POND model (Ferreira *et al.*, 2010) that estimates an environmental discharge of over 60 kg (i.e. total output) of nitrogen (mostly dissolved, but also as algae), roughly 20 population-equivalents per year for the 110 day cultivation cycle. This corresponds to an abatement cost of about US$800 (Lindahl *et al.*, 2005). Frequently these waste costs are not internalized, but would need to be determined in the scope of EAA, and are increasingly required for product certification in western markets. Currently, pond production in the United States already requires a National Pollutant Discharge Elimination System (NPDES) permit (Boyd, 2009). In practice this means that large agri-industrial companies from developed nations

FIGURE 3
Intensity of aquaculture per unit coastline and per total (marine + land) area

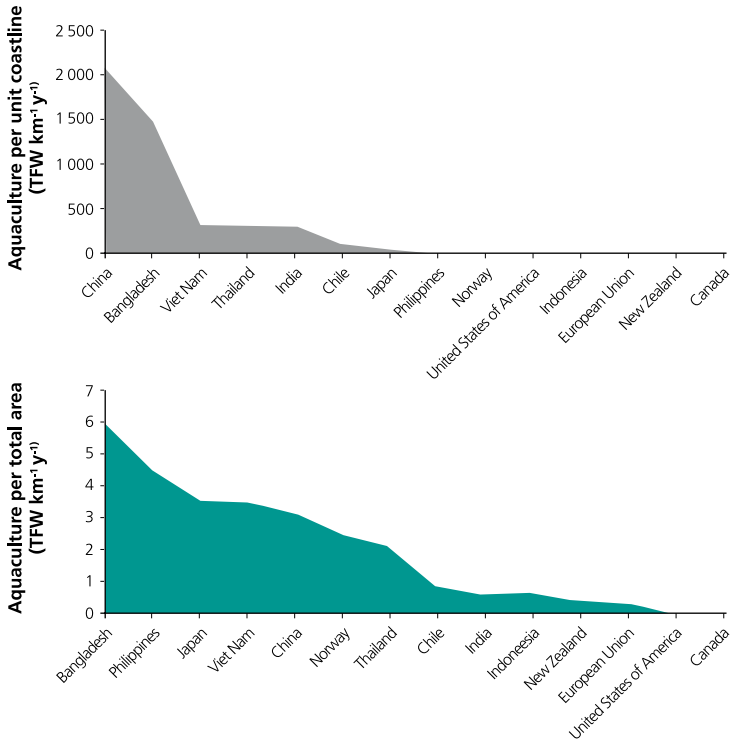
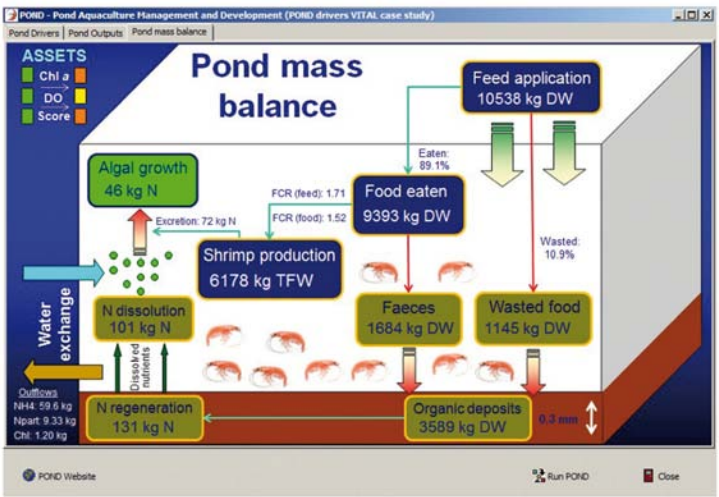
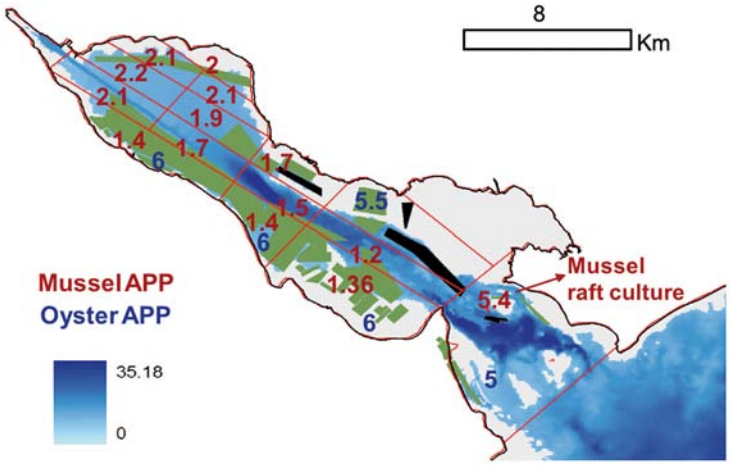


FIGURE 4
POND mass balance output for a 1 ha farm, including Feed Conversion Ratio (FCR), diagenesis, primary production, effluent discharge, and ASSETS eutrophication rating



Source: Ferreira *et al.* (2010).

FIGURE 5
Average physical product (APP = output/input) for bottom culture of blue mussel *Mytilus edulis* (in red), and *Pacific oyster* (in blue) in Carlingford Lough, Ireland, determined in the SMILE project with the EcoWin2000 ecological model



Source: Ferreira *et al*. (2008).

price-leverage the lack of environmental regulation and/or implementation in the developing world.

Organically extractive aquaculture takes place on a very different spatial scale, due to the nature of the food supply, and results in the occupation of relatively large areas, often including shorefront leases. The issues that have emerged with respect to carrying capacity have been largely (i) production-related, such as the reduced growth and harvest size of the Pacific oyster *Crassostrea gigas* in the Marennes-Oléron area of the French Republic in the mid-1990's, largely due to overstocking (Raillard and Ménesguen, 1994), or (ii) social concerns in developed nations on the use of waterfront areas (e.g. the geoduck industry in Puget Sound, Cheney *et al*., 2010), landscape values etc.

In the few system-scale carrying capacity studies that have taken place (e.g. Ferreira *et al.*, 2008b) it is clear that even from a production perspective (Figure 5) there appears to be room for improvement in terms of site selection. With respect to environmental issues, there is a debate on the impacts due to biodeposits and consequent sediment organic enrichment.

Appropriately dimensioned shellfish culture seems to have little effect on the benthos (e.g. Fabi, Manoukian and Spagnolo, 2009), even when large areas are occupied (Zhang *et al.*, 2009). On the other hand, the positive externalities of bioextraction for top-down control of eutrophication symptoms have been documented in many parts of the world (e.g. Xiao *et al.*, 2007), and it is clear that the existence of significant shellfish aquaculture e.g. in the People's Republic of China has been instrumental in controlling coastal eutrophication, probably on a national scale (Sorgeloos, 2010), as industrial and urban pressure on coastal zones has mounted in the last decades.

An additional issue for shellfish cultivation is the interaction with the development, frequency, and duration of harmful algal blooms (HAB). This is presently in debate, given both the lack of clarity in many cases as to the drivers and processes that trigger HAB, and the effects on human health. There are significant areas of the coastal ocean where carrying capacity is limited by such HAB events, often unrelated to human-originated nutrient loading.

Integrated multi-trophic aquaculture (IMTA) has long been practiced in Asia, and is a mainstay e.g. of aquaculture in the People's Republic of China. Presently the interest in co-cultivation across trophic levels is growing in the EU and the United States of America. The focus once again is more on optimal production in developing countries, whereas in developed countries the emphasis is on reduction of emissions. There is a clear link between the two since for instance hypoxic pond water is not only an external environmental liability but also an internal factor of increased mortality.

Two important issues that are not often considered and constitute potential liabilities of IMTA are:

[5] The higher value for raft culture of mussels is due to much better survival, particularly of seed

(i) The potential for disease vectors to "jump" across trophic levels, thereby impacting the whole co-cultivation system. Conversely, it has been pointed out (Chopin *et al.*, 2010) that blue mussels in IMTA with Atlantic salmon may be instrumental through filtration in reducing the incidence of salmon lice in finfish cages; and

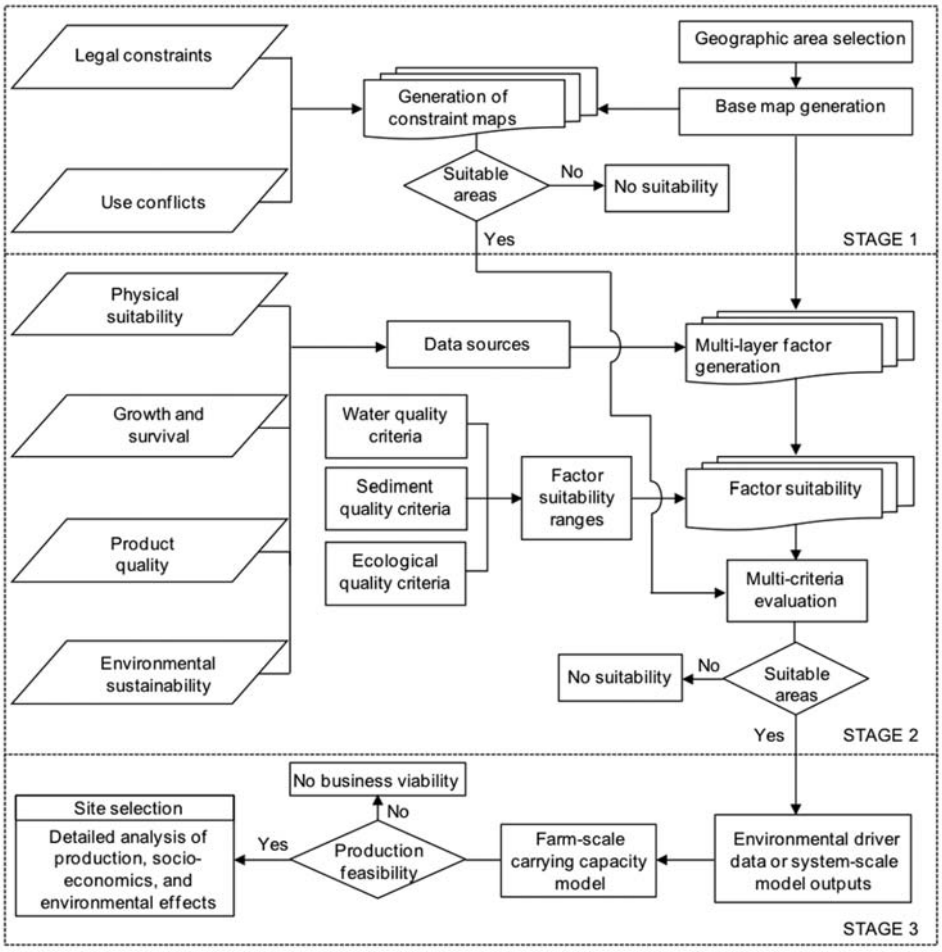
(ii) Any fluctuation in yield for one component of an IMTA system can potentially have serious consequences with respect to the environmental balance of the whole. This can occur through a disease outbreak in one or more trophic levels, but also if parts of the culture become economically unattractive, leading to an equilibrium shift. For example, an offshore area of 5 km² along the 30m bathymetric line is currently being developed in southern Portugal, planned for 60 leases, of which 70 percent for finfish and 30 percent for shellfish; these leases are independently contracted, and if market shifts determine changes to production, this may lead to unexpected environmental effects.

Use of surrogates and models for decision support

Recommended selection criteria and tools

Decision-support for future expansion and optimization of aquaculture operations can make use of a wide range of indicators, indices, and models, drawing from a considerable volume of work (see e.g. www.ecasatoolbox.org.uk/).

FIGURE 6
General top down approach for carrying capacity assessment combining GIS and dynamic modelling



Source: adapted from Silva *et al.* (2011).

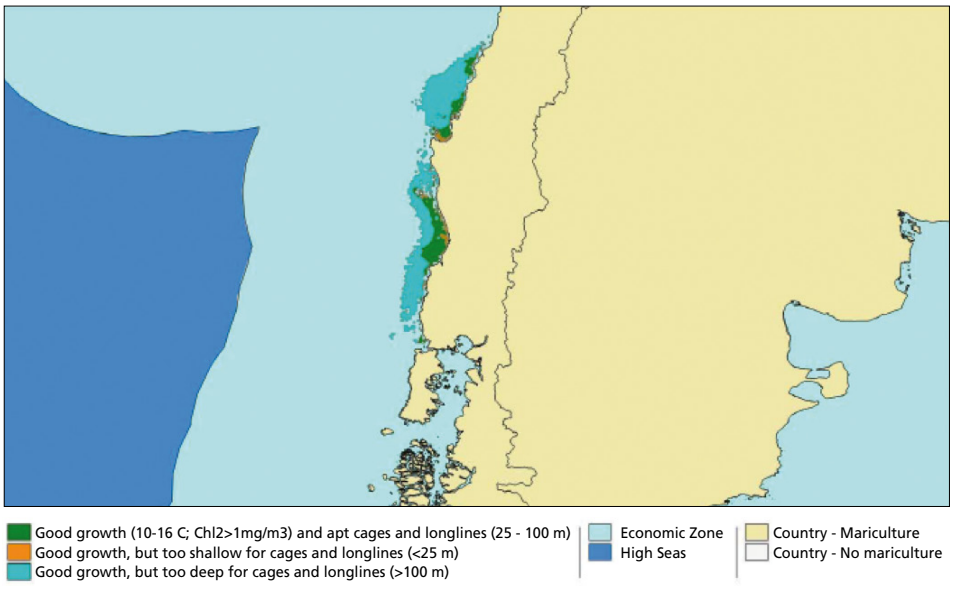
While carrying capacity has a multipolar focus, and should be assessed accordingly, site selection is herein considered to be essentially spatial in nature.

By definition, the general suitability of an area (at the scale of an embayment, offshore coastal zone, or land region) is an issue of carrying capacity rather than site selection, and should be the object of an initial assessment that determines (i) overall suitability; and (ii) limits to cultivation. The latter may include protection of biodiversity (Sequeira *et al.*, 2008), environmental effects (Ferreira *et al.*, 2008a; Ferreira *et al.*, 2008b), and identification of spatial usage conflicts (Ferreira *et al.*, 2010).

Within this wider context, there are clear distinctions between open water and land-based areas, the former being the object of marine spatial planning exercises presently occurring in various parts of the world, whereas the latter are already heavily regulated, particularly in developed nations. Nevertheless, the planning process should flow from a broad assessment of carrying capacity to detailed site selection, focused on a narrower spatial scale and supporting specific licensing procedures. A general approach, adapted from Silva *et al.* (2011) is presented in Figure 6. At all stages of the process virtual technologies are valuable for decision support, providing a means to evaluate tradeoffs among social, environmental, and economic components of sustainability. The type of approach shown in Figure 6 draws heavily on Geographic Information Systems (GIS), a valuable modelling tool both in prospective studies and in assimilating and presenting results of other kinds of models.

GIS is limited in its capacity to represent time-varying phenomena, and these are usually of importance, but it can be combined for instance with remote sensing data (Figure 9) to provide a spatial image of site suitability. This type of approach is applicable also for land-based aquaculture, drawing on spatial information on water resources, land cover, and other thematic data. The extension of GIS approaches such as those reported by Corner *et al.* (2006) and Radiarta, Saitoh and Miyazono (2008) to include dynamic growth models is a promising area of research (Kapetsky, Aguilar-Manjarrez and Jenness, 2012; Silva *et al.*, submitted), since it allows decision-makers to examine the temporal variation of local production and environmental effects within a wider

FIGURE 7
GIS combined with satellite remote sensing: identification of potential areas for IMTA of salmon and mussels in Chile, based on remotely sensed sea surface temperature and chlorophyll data



Source: Kapetsky *et al*. (2010).

spatial context. GIS is relatively inexpensive by comparison to dynamic models, and a combination of both tools optimizes resource use with respect to potential benefits.

For off-the-coast or offshore areas, the review by Ferreira *et al.* (2010) provides three different illustrations (Table 3) of the application of virtual technologies for carrying capacity and site selection. These range from (i) simple ecological models (Nº1) focusing on primary production and mussel growth (Filgueira and Grant, 2009); to (ii) integrated catchment and bay-scale modelling (Nº2) of multiple finfish and shellfish species, including some economic aspects (Nobre *et al.*, 2010); and (iii) management systems (Nº3) combining GIS with dynamic models for circulation, and seeking to incorporate novel aspects such as simulations of salmon lice propagation (Ervik *et al.*, 2008). These approaches are not directly transferrable to land-based culture, although some of their components, such as growth models for cultivated species, or models of biogeochemical cycles, may be re-used.

TABLE 3
Case study examples for carrying capacity and site selection

	Case Study Nº 1 Prince Edward Island	Case Study Nº 2 SPEAR	Case Study Nº 3 AkvaVis
Main management issue(s)	Ecological carrying capacity	Carrying capacity for Integrated Multi-Trophic Aquaculture	GIS for site selection, carrying capacity, and management monitoring in aquaculture
Stakeholders	Water managers, aquaculturists	Water managers	Water managers, aquaculturists
Location	Prince Edward Island, Canada	Sanggou Bay, China	Hardangerfjord, Norway
Scale	Bay	Bay	Bay, local
Cultured species	Blue mussel	Finfish, shellfish and seaweeds	Finfish and shellfish
Data and information types	Field, experimental	Field, experimental, GIS, remote sensing	Field, GIS, desk-based
Tools and model types	GIS, dynamic system-scale models	Dynamic system-scale models, catchment models etc (multilayered)	GIS, socioeconomic instruments, models
Platform	Console	console/Web	Web
Decision-support	Licensing, production, and environmental effects	Licensing, species combinations, production, and environmental effects	Management monitoring, site selection, and licensing

One of the main challenges for production and environmental sustainability in pond culture is optimization, i.e. EAA in this context means optimal yields without imposing the externality costs on the environment. Models can provide valuable information on different options, as illustrated in Table 4.for monoculture of the white shrimp *Litopenaeus vannamei* when compared to co-cultivation with the Pacific oyster *Crassostrea gigas*.

The two simulations illustrate the value of adding filter feeders to the shrimp ponds. In this example for a large farm, typical of some of the industrial scale shrimp production operations, co-cultivation of oysters adds about 25 percent to the top line (income), but doubles the bottom line (profit) due to the low costs of shellfish production. The filter feeders also account for a 60 percent reduction in the chlorophyll concentration in the pond effluent, although oyster excretion increases the output of ammonia.

The Assessment of Estuarine Trophic Status (ASSETS) grade (Bricker, Ferreira and Simas, 2003; Ferreira, Hawkins and Bricker, 2007) changes from Moderate to Good status due to the removal of phytoplankton by the oysters. Screening models such as ASSETS are valuable from a management point of view because they combine indicators into indices,

providing an aggregated image of the environmental status of different management options. Figure 10 illustrates another example of optimization, for mussel culture in Killary Harbour, Ireland, comparing two models at differing scales (Nunes *et al.*, 2011).

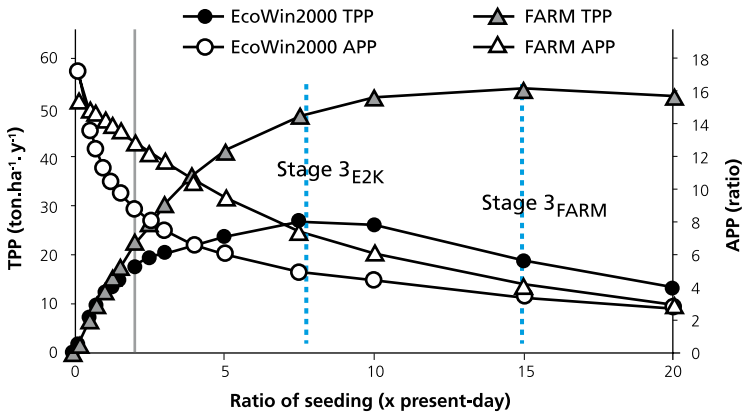
TABLE 4
Application of the POND model to simulate production and environmental effects of shrimp cultivation in monoculture and IMTA with oysters. Cultivation layout: 106 m^2, 90 day cultivation period, water renewal of 15 X 103 m^3/day (3 percent of pond volume) throughout the culture cycle.

Variable	Shrimp monoculture	IMTA of shrimp and oysters	
Model inputs			
Seeding density (kg TFW[3])	35,000	35 000	14 000
Seed weight (g)	0.7	0.7	10
Harvest weight (g)	16	16	30
Natural mortality (percent culture/cycle)	30	30	5
Model outputs			
Production			
Total Physical Product (TPP) (kg TFW)	619 226	619 226	83 320
Average Physical Product (APP)	17.7	17.7	5.95
Feed application (kg DW)	788 200	788 200	-
Feed Conversion Ratio	1.27	1.27	-
Environmental impact in the ponds			
Faeces (kg DW)	129 400	129 400	1 298
Excretion (kg N)	5,400	5 400	258
Organic deposits (kg DW)	250,400		220 200
Nitrogen regeneration in sediment (kg N)	8,500		11 500
Nitrogen dissolution from sediment (kg N)	6,200		8 300
Net primary production (kg N)	2,400		1 200
Nitrogen removal (kg N/year)			
Phytoplankton (kg N/year)	-		-1 349
Detritus (kg N/year)	-		-7
Faeces (kg N/year)	6710		273
Mortality (kg N/year)	2560		7
Mass balance	-		-818
Population equivalents (PEQ/year)	-		248
ASSETS chlorophyll score	in ■ → ■ out	in ■ → ■ out	
ASSETS dissolved oxygen score	in ■ → ■ out	in ■ → ■ out	
ASSETS overall score	in ■ → ■ out	in ■ → ■ out	
Environmental externalities			
Outflow of NH4+ (kg N)	4 410		6 840
Outflow of particulate nitrogen (kg N)	510		230
Outflow of chlorophyll (kg chl)	70		30
Profit and loss			
Aquaculture products (US$)	3 096 132	3 096 132	833 196
Total income (US$)	**3 096 132**	**3 096 132**	**833 196**
Feed (US$)	788 164		788 164
Seed (US$)	1 000 000	1 000 000	7 000
Energy (US$)	69 363		69 804
Total expenditure (US$)	**1 857 527**	**2 257 968**	**7 000**
Income-Expenditure (US$)	**1 238 605**	**1 238 164**	**826 196**
Farm profit (US$)	**1 238 605**	**2 064 360**	

EcoWin2000 (E2K) is an ecological model applied at the system scale, whereas FARM simulates production and environmental carrying capacity at the local scale. Any model of this type, as well the type of pond-scale model described previously, can be used to perform a marginal analysis (Ferreira, Hawkins and Bricker, 2007) to determine stocking densities that lead to optimal profitability.

[6] TFW: total fresh weight (with shell)

FIGURE 8
Impacts of different mussel stocking densities on Total Physical Product (TPP) and Average Physical Product (APP, the ratio between seeded and harvested biomass) as simulated by EcoWin2000 (system scale, per unit of cultivated area) and FARM (single farm) for Killary Harbour, Ireland



Source: Nunes (2011).

This is extremely useful for licensing purposes, since farms often maximise income rather than profit (i.e. aim for the highest TPP). It can be seen that for a coastal or semi-enclosed system there appear to be significant differences between the results for the system-scale model, where the dotted line indicating highest TPP (which exceeds the seeding density of maximum profit) occurs at a density 7-8 times greater than the current situation. FARM however, which deals only with the local scale, determines the end of Stage 2, i.e. highest TPP, as around X15 density. This reflects the fact that (i) the ecosystem model data reports what is actually harvested, since E2K runs multiple production cycles, typically for periods of 10-20 years, whereas FARM reports what is harvestable over one cycle; and (ii) FARM does not account for interactions among farms, whereas E2K considers all the farms in a particular waterbody. Figure 5 illustrates how E2K model boxes are distributed in a system (Carlingford Lough, Ireland), and how this kind of dynamic model is combined with GIS to provide the bathymetry, location of aquaculture leases, and other features.

In fed aquaculture the law of diminishing returns does not apply directly with respect to the food supply, at least on a local scale, given that there is no depletion of natural food resources as occurs for instance in bivalve shellfish culture. However, the increase in stocking density has other consequences, for instance in the increased competition for space and for other factors such as dissolved oxygen. The TPP and APP curves (Figure 9) are obtained by progressively increasing the stocking density of *Litopenaeus vannamei* in ponds, using the POND model. At higher densities growth is constrained by the reduction in dissolved oxygen, due to increased respiration and diagenesis of faeces and uneaten food. The first derivative of the production curve is the marginal physical product i.e.:

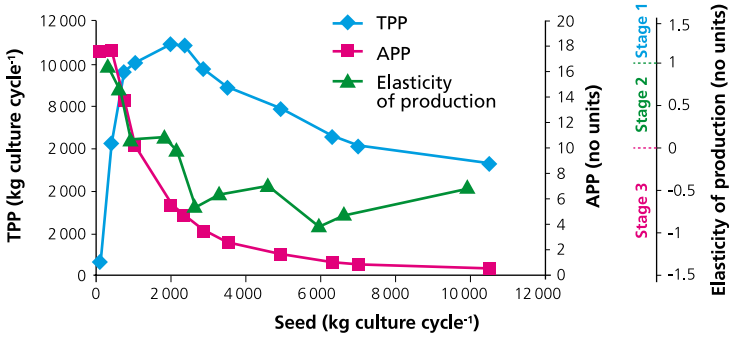
$$MPP = \frac{d(TPP)}{dS} \qquad \text{(Eq. 2)}$$

where: S = stocking density of seed and the elasticity of production E_p is defined (Eq. 3) as the percentage change in output (Y) with respect to percentage change in input (X):

$$E_p = \frac{\frac{\Delta Y}{Y}}{\frac{\Delta X}{X}} = \frac{\Delta Y}{\Delta X} * \frac{X}{Y} = \frac{MPP}{APP} \qquad \text{(Eq. 3)}$$

The model outputs can be used to calculate elasticity of production for a particular culture situation (Figure 11), and show that production becomes progressively more inelastic as the stocking density increases, i.e. relative changes in seed input have progressively smaller effects on production, until they lead to an effective decrease in output.

FIGURE 9
Production function with oxygen limitation for fed aquaculture of penaeid shrimp, simulated using the POND model



Source: Ferreira *et al.* (in press).

The issue of disease is another important area for development of carrying capacity models. The potential disease interactions of IMTA (both positive and negative), have already been discussed, but there is very little work on combining production and animal welfare models, although there is substantial empirical evidence on the association of disease with water quality degradation, overstocking, relaying, and inappropriate feeds. The risks of disease outbreaks can to some extent be spatially mapped, and although the models are stochastic, scenarios can be developed that may allow for proactive management. An example of this type of risk is the exponential growth of *Pangasius* culture in the Mekong delta, driven by European and US imports, and which if uncontrolled will not only have significant effects on product quality and market perception, but will also potentially lead to a collapse of the local industry in the Socialist Republic of Viet Nam, with serious social consequences.

The level at which carrying capacity and site selection models may be applied depends on various factors. In the first instance it is driven by legislation, best practice agreements, and by public pressure, usually routed through NGO's or citizens' groups. Secondly, some models are harder to apply than others, in terms of data requirements, cost, and technical expertize. Thirdly, some areas are less amenable to modelling, but equally important in decision-making. Foremost is the social component, which as previously stated is a key limit to aquaculture expansion in Europe, the US, and Canada, and where decisions are largely based on belief. A better integration of models for the natural and social systems is an important research area for EAA. Some steps (e.g. Nobre *et al.*, 2009) have been taken in that direction, but it is critical for economic models to provide feedback to ecological models, to potentially incorporate aspects such as employment or market dynamics.

Integration with regulation and governance

Regulation and governance standards in aquaculture vary widely throughout the world, which to an extent reflects the prevailing social conditions and priorities. Other texts that form part of this volume address these aspects in more detail; we limit ourselves herein to highlighting the role that simulation models of various types can play in supporting those societal choices.

Current and future issues and bottlenecks

The application of the EAA on a worldwide scale requires the harmonization of (i) environmental; (ii) social; and (iii) multi-sectorial planning objectives (Soto, Aguilar-Manjarrez and Hishamunda, 2008). These three principles and their relative weights are by definition different across world regions, making it socially and politically impractical to define a standard for uniform compliance with respect to limits and thresholds.

Rather, it is important to establish appropriate approaches, such that within a particular world region a gradient can be defined in relative terms, assessing EAA in terms of the principles stated above. The three principles of EAA can be mapped onto the four pillars of carrying capacity, and illustrated as the overlap of these (Figure 10).

The importance (size) of each of the circles represented will vary regionally, and will develop through time based on the natural feedbacks society provides.

The practical use of models for addressing some of the aspects represented in Figure 12 depends on various constraints (Table 5).

The regulatory level provides the initial impetus for an EAA approach; thereafter two other hurdles must be overcome. The first is the scientific and technological barrier to entry with respect to model application which includes financial access, data-poor environments, and lack of expertize. The second has already been mentioned, i.e. the social aspects that are challenging to model but form a significant part of the EAA.

FIGURE 10
Harmonisation of the four pillars (in blue) of carrying capacity to arrive at an ecosystem approach to aquaculture (in green)

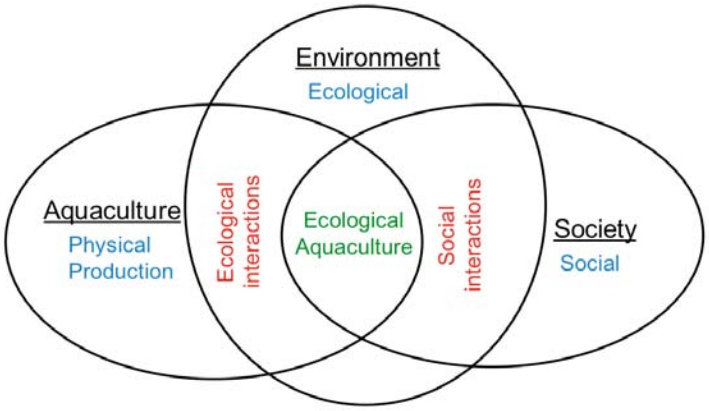


TABLE 5
Application of carrying capacity and site selection models

Regulatory level	
Legislation (internal, international, or external, such as import regulations)	
Best practice agreements (certification etc)	*Drivers*
Public pressure (NGOs, citizens' groups…)	
Scientific and technical level	
Difficulty in model implementation	*Feasibility*
Data requirements, cost, expertize	
Some areas less amenable to modelling	
Social component	*Inclusion*
Belief-driven, but equally important	

Some of these can be addressed using GIS approaches that consider multi-sectorial planning (Figure 12), but others are belief-driven and must be included through a participative approach.

A 50 percent annual increase in aquatic production is required by 2050 to accommodate the needs of the global human population. This increase of 30 MMT (Swaminathan, 2010) translates to a net production area of 30,000 km^2, for an annual yield of 1 kg/m^2. The gross area would be equivalent to 100-150 X 10^3 km^2, taking into account facilities and processing infrastructure; this is roughly twice the area currently under cultivation in the People's Republic of China. As discussed previously, this expansion will not take place in Europe, the United States of America, or Canada, but in developing nations. In many Asian countries, the proportion of available land occupied by aquaculture is nearing capacity, together with a good deal of the coastline. More efficient cultivation methods will increase yields of existing farms, but greater environmental awareness will tend to reduce production.

Africa is one of the world regions with the lowest aquaculture production, and simultaneously suffers from massive food security problems. It appears therefore to have the potential for development of aquaculture as a means to alleviate poverty

FIGURE 11
Cage culture of yellow croaker in Sandu Bay, China (260 000 cages)

Source: Image @2012 Digital Globe

and increase the food supply to local populations. However due to restrictions in access to water, land-based aquaculture would need to be confined to areas with adequate rainfall, whereas other areas, particularly in the Indian Ocean, are suitable for offshore aquaculture. The challenge is to ensure this development follows an ecosystem approach, rather than one that neglects the protection of natural and human capital.

Recommendations

It is clear that virtual technologies, whether they be GIS, satellite remote sensing, dynamic models, or others, can play a huge role in addressing the physical, production, and environmental pillars of site selection and carrying capacity. From the environmental perspective, which is the focus of this review, the examples provided illustrate the value of such tools. However, models need to be more production- and management-oriented, and adapt to local realities and conditions. This requires a more effective linkage between industry and research to create objective-led demand for virtual technology-driven RTD, and a clear view of the business models that might support it.

In parallel, research into improved models for social aspects, and for the connection to environmental aspects, needs a much greater effort. This will establish a more quantitative basis for discussion and for decision-making, enabling a better understanding of trade-offs.

Distributed computing, and in particular the use of smartphone technology to combine location data, Web communication, and computational applications, is a paradigm shift at least as important as the appearance of the world wide web in the 1990's. It has great potential in bridging the information gap in many thematic areas, and should certainly be used to improve the understanding of aquaculture-environment interactions, simulate local conditions in real time, and interpret the outputs of sensors.

Aquaculture is particularly important to developing countries, where it is not only critical in supporting healthy food provision but is also an important source of income for local communities. These nations often have a comparative advantage, i.e. it makes sense economically for resources to be used in aquaculture production, because it can be done at a lower cost than in developed countries. It is important however that production in developing countries should not translate into negative environmental externalities

considered unacceptable in the developed world. The modelling approaches discussed in this review and in Ferreira *et al.* (2010), together with currently emerging work, promise exciting times ahead for the role that virtual technologies will increasingly play in implementing an ecosystem approach to aquaculture.

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TABLE 6
Relevant legislation – Asia

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
China	The Fisheries Law (1986, amended in 2000) seeks to enhance the production, development and reasonable utilization of fisheries resources. It requires the state to adopt a policy that calls for simultaneous development of aquaculture, fishing and processing, with special emphasis on aquaculture. The Law is implemented by the Regulation for the Implementation of the Fisheries Law (1987). The Bureau of Fisheries, falling under the Ministry of Agriculture, is the main administrative body governing aquaculture sector. Over last decades, many local laws and regulations with relevance for aquaculture have been adopted.	Numerous guidelines have been issued, at both the national and the provincial level, on various topics, for instance the operation of hatcheries and the use of antibiotics and chemicals in aquaculture.	China is a party to the Convention on Biological Diversity (CBD). It has signed the Biosafety Protocol, but is not yet a party to the protocol. China is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES).	According to the Fisheries Law and its implementing Regulation, the people´s governments may grant licences to use state-owned water surfaces and tidal flats to develop aquaculture. After the 2000 amendment, the State draws plans for the use of water surface areas and defines those for aquaculture purpose. Units or individuals wishing to use those designated areas must apply for an aquaculture permit.	Provisions on EIA requirements can be found in various environmental laws, none of which, however, specifically refer to aquaculture. The Law on the Prevention and Control of Water Pollution, aims to prevent and control pollution of rivers, lakes, reservoirs and other surface waterbodies and groundwater. According to the law, the environmental impact statement of construction projects, including large-scale aquaculture projects, should contain an assessment regarding the water pollution hazards, including the impact on the ecosystem and a description of measures for prevention and control. The same applies to coastal construction projects. The EIA Law (2002) which has taken effect on September 2003, expands EIA requirements from individual construction projects to government planning for the development of, inter alia, aquaculture, water conservation and natural resources.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
India	At central level, several key laws may be relevant to aquaculture. They include the Indian Fisheries Act (1897) which penalizes the killing of fish by poisoning water and by using explosives, and the Environment Act (1986) containing provisions for all environment related issues. They also include the Water (Prevention and Control of Pollution) Act (1974) and the Wild Life Protection Act (1972) All this legislation must be read in conjunction with one another to gain a full picture of rules that are applicable to aquaculture.	The Ministry of Agriculture issued Guidelines for Sustainable Development and Management of Brackish Water Aquaculture in order to assist in formulating appropriate shrimp farming management practices and adopting measures for mitigating the environment impact for management of shrimp pond wastes and utilization of resources in a judicious manner. The guidelines also recognize the importance of wastewater treatment and prescribe standards for the treatment of wastewater discharged from aquaculture systems, hatcheries, feed mills and processing plants. Recently the Aquaculture Authority formulated guidelines with the objective of optimizing yield levels and improving the management of shrimp aquaculture in traditional systems, to ensure log-term sustainability of the farming practices and environmental security	India is a party to the Convention on Biological Diversity (CBD) and has signed the Biosafety Protocol. India is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES)	The Aquaculture Authority is responsible for the authorization system approval. The application forms needs to specify several issues, namely the identification of possible negative effects that the activity may cause to the environment. The approval form, given for a period of 3 years, will specify the conditions to the activity. Also an aquaculture farmer will be required to obtain an authorization form from the Pollution Control Board to set up a treatment and disposal system that is likely to discharge sewage or trade effluent into waters or onto the land.	The Environmental Impact Assessment Notification (1994), in accordance with the Environmental Act species the projects that require an EIA. The list does not include aquaculture. However, the Guidelines for Sustainable Development and Management of Brackish Water Aquaculture (1995) recommend to carry out a site selection process, which should include proper EIA. They state that all aquaculture units above 40 hectares should be subject to an EIA. Shrimp culture units above 40 ha should incorporate an environmental Monitoring Plan and an Environmental Management Plan, covering the following potential impacts: local watercourses, groundwater, agriculture, soil and salinisation, waste water treatment and green belt development. Smaller farms, between 10 and 40 ha, must also provide information on these items.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Thailand	The Fisheries Act (1947, amended in 1953 and 1985) is the principal legislative instrument, complemented by the Royal Decree on Administration (1994), which provides the Department of Fisheries with the authority to apply, implement and enforce the Fisheries Act. The overall strategy for country ´s fisheries management is stipulated in the National Fisheries Development Policy, which strategy includes the strengthening of aquaculture techniques and management, promoting cost-effective and environmentally-friend aquaculture.	Code of conduct standards have been developed for the marine shrimp culture industry, in order to achieve international quality standards and to manage the environment for the whole production line. In addition, Good Aquaculture Practice guidelines have been developed for hygienic shrimp production. To produce good quality and safe shrimps for consumers, shrimp farms may be standardized, clean, sanitary, and generate no environmental impacts.	Thailand is a party to the Convention on Biological Diversity (CBD) but not to the Biosafety Protocol. Thailand is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES)	The Fisheries Act classifies fisheries into four categories, i.e. preservation, leasable, reserved and public fisheries. In any case, anyone that wants to cultivate aquatic animals will need a permission obtained from the Director-General for Fisheries and shell comply with the conditions imposed.	Aquaculture is currently not among the range of projects for which an EIA is required.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Indonesia	At national level fisheries and aquaculture are regulated by Fisheries Law n.° 31/2004, which underscores the importance of sustainable use of aquatic resources in the development of fisheries. This Law defines fisheries as all the activities related to the cultivation and utilization of fish resources, which includes both aquaculture and capture fisheries.	Being a member of ASEAN, Indonesia embraces the codes of conduct adopted by the Association, which includes, among others, the Manual of ASEAN Good Shrimp Farm Management Practices Guidelines.	Indonesia is a party to the Convention on Biological Diversity (CBD) and to the Biosafety Protocol. India is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES). AS part of the Southeast Asian Fisheries Development Center (SEAFDEC) Indonesia participates in the Departmental Programmes on Aquaculture and also in the SEAFDEC-ASEAN Programmes, which include the promotion of mangrove-friendly aquaculture and the regionalization of the Code of Conduct for Responsible Fisheries.	The Fisheries Law requires a specific licence to engage in fisheries business, including aquaculture.Small producers are exempt from such requirement.	Pursuant to Environment Management Act (1997) an EIA is required to engage in any business or activity likely to have a major and significant impact on the environment. In this regard, the conduct of aquaculture is subject to EIA procedure, as established by Decree of the State Minister of the Environmental Affairs n.° 3/2000. When required, the EIA is part of the licensing procedure for the conduct of the concerned activity.
Bangladesh	The basic act regulating inland fisheries is the Protection and Conservation of Fish Act (1950) as amended by the protection and Conservation Ordinance (1982) The Marine Fisheries Ordinance (1983) as implemented by the marine Fisheries rules (1983) is the basic act regulating marine fisheries. Although the basic fisheries legislation does not have separate sections on aquaculture, some of its provisions are relevant to the subject. Other legislation relevant to aquaculture includes the Tanks Improvement Act (1939), which provides for the improvement of tanks for irrigation and aquaculture purposes	There are no guidelines or codes of conduct for aquaculture activities	Bangladesh is a party to the Convention on Biological Diversity (CBD) and the Biosafety Protocol. Bangladesh is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES)	There is no authorization or registration system of aquaculture facilities.	The Environment Protection Act (1995) aims to protect the environment and to control and mitigate environmental pollution. Aquaculture projects are not included in the Schedule 1 of the rules, which provides the category classification of most common industries. The Environment Protection Act sets water quality standards for inland surface waters used for fisheries and aquaculture

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Japan	The principle law that regulates fishery activities is the Fisheries Law (1949, as revised in 1962), which deals with several kinds of fishing rights and licences for individuals and groups of persons. Also the Law to Ensure Sustainable Aquaculture Production (1999), seeks to prevent the self induced environmental deterioration around fish farms.	Pursuant to the Law to ensure Sustainable Aquaculture Products, the Ministry of Agriculture, Forestry and Fisheries (MAFF) issued Basic Guidelines to Ensure Sustainable Aquaculture Production (1999)	Japan is a party to the Convention on Biological Diversity (CBD) and to the Biosafety Protocol. Japan is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES) and a member of Southeast Asian Fisheries Development Center (SEAFDEC)	The Fisheries Law recognizes three principal categories of fisheries rights, from which the demarcated rights are granted for aquaculture in specific areas and are usually valid for five years.	The EIA Law (1997) sets procedures and contains provisions designed to ensure that EIA are conducted properly with respect to large-scale projects that could have a serious impact on the environment and prescribes measures to reflect the results of EIA in implementing such projects. The Law does not specifically refer to aquaculture.
Philippines	The Philippine Environment Code (1988) provides the foundation for all measures dealing with natural environment. Being a framework instrument, provides a chapter on fisheries and aquatic resources. The Philippine Fisheries Code (1998) provides for the development, management, conservation and utilization of fisheries and aquatic resources. The Code integrates all relevant laws to these issues. Part of Chapter II of the Code deals with aquaculture.	Fisheries Administrative Order n.º 214 (2001) establishes a Code of Practice for Aquaculture, outlining the general principles and guidelines for environmentally-sound design and operation to promote the sustainable development of aquaculture industry	Philippines is a party to the Convention on Biological Diversity (CBD). It has signed the Biosafety Protocol, but is not yet a party to the protocol. Philippines is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES). Philippines is a member of ASEAN and of Southeast Asian Fisheries Development Center (SEAFDEC)	Authorizations to engage and set up an aquaculture facility are granted by the body that has jurisdiction over the venue of the aquaculture operation. According to the Fisheries Code only 10 percent of the surface area of lakes and rivers may be allotted for the construction and operation of the structures for the culture of fish and other fishery products	The Fisheries Code requires that those, public or private, who intend to undertake activities or projects which will affect the quality of the environment to prepare a detailed Environment Impact Statement prior to undertaking such activity. Fishery projects are included in the list of the Environmental Critical Projects (Presidential Proclamation n.º 2146/1981)

TABLE 7
Relevant legislation – United States of America, Canada, Europe (including Member-States and associated states), the Republic of Chile, and New Zealand

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
United States of America (USA)	In the USA, aquaculture is regulated at the federal and state level. In 1981, a comprehensive review of aquaculture across the USA identifies at least 120 federal laws that either directly (50) or indirectly (70) affected aquaculture, along with more than 1,200 state statutes regulating aquaculture in 32 states. • National Aquaculture Act (1980), establishes a National Aquaculture Development Plan and requires federal coordination of aquaculture activities; • Clean Water Act, the major federal law regulating environmental aspects of marine aquaculture; • Coastal Zone Management Act (1972), requires federal activities to be consistent with State Coastal Management Plans.	The EPA Effluent Limitations Guidelines and New Source Performance Standards for Concentrated Aquatic Animal Production Point Source; Draft Guidance for Aquatic Animal Production Facilities to Assist in Reducing the Discharge of Pollutants, EPA; EPA Animal Feeding Operations – Best Practices; Code of Conduct for Responsible Aquaculture Development in the United States of America Exclusive Economic Zone (NOOA 2003).	The USA is a party of several international agreements with implications for the regulation of aquaculture, namely the Convention on Biological Diversity, the Convention on International Trade in Endangered species of Wild Fauna and flora (CITES).	In principle, it is unlawful to conduct aquaculture operations or to culture approved species of aquatic plants and animals unless registered with state authorities. However, this may vary from state to state; The clean Water Act establishes pollution discharge permits and ocean discharge criteria; Open ocean aquaculture requires approval of United States of America Environmental Protection Agency, United States of America Army Corps of Engineers and National Marine Fisheries Service.	The requirement of an environment impact assessment before an aquaculture facility is registered may vary from state to state.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Canada	The aquaculture industry is overseen in Canada by a combination of federal, provincial and local authorities. In recent years, both the federal and provincial governments have been striving towards a more efficient regulatory framework, balancing the need to protect the environment, sustain fisheries and enable a competitive industry to flourish.	The Canadian Aquaculture Industry Alliance, the umbrella organization for aquaculture associations in Canada, has developed the National Code System for Responsible Aquaculture. Another codes of conduct targeted specifically to the aquaculture industry have also been developed at the provincial level.	Canada is a party of several international agreements with implications for the regulation of aquaculture, namely the Convention on Biological Diversity, the Convention on International Trade in Endangered species of Wild Fauna and flora (CITES).	Both the federal and provincial governments are authorized to issue licences to engage in and set up an aquaculture facility in Canada, depending on whether the operation is located under federal or provincial territory. In the decision, the competent department will consider the potential impact of the aquaculture operation on wild fish, commercial and recreational fisheries, aboriginal fisheries and fish habitat	The Canadian Environmental Act (1992) (CEAA) and its regulations are the legislative basis for the federal practice of environmental assessment. Under the CEAA a marine aquaculture project is subject to an environmental assessment. The CeAA identifies the factors that must be considered in the screening of a project, including the environment effects, public consultation and measures to mitigate significant adverse environmental effects. The provinces also have jurisdiction over EIA for aquaculture.
European Union (EU)	• Water Framework Directive 2000/60/EEC of 23 October; • Marine Strategy Framework Directive 2008/56/EEC of 17 June; • Regulation (EC) n.° 710/2009 of 5 August; • Regulation (EC) n.° 535/2008 of 13 June; • Regulation (EC) n.° 708/2007 of 11 June; • Regulation (EC) n.° 506/2008 of 6 June; • Strategy for Sustainable Development of European Aquaculture COM(2002)511, of 19 February 2002 (Communication from the Commission to the Council and the European Parliament)	The Federation of European Aquaculture Producers(FEAP) is open to all national aquaculture associations. FEAP members adopt the 2000 Code of Conduct for European Aquaculture.	The EU is a member of several international arrangements, namely: •Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Agreement); •Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Convention for the Marine Environment Protection and of the Mediterranean Coastal Area (Barcelona Agreement 1995). •North Atlantic Salmon Conservation Organization (NASCO). • Convention on Biological Diversity (CBD); •Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM); •International Baltic Sea Fishery Convention (IBSFC); • North Atlantic Fishery Organization (NAFO); • North East Atlantic Fishery Convention (NEAFC);	No specific legislation	Directive 85/377/EEC of 27 June 1985, modified by Directive 97/11/EEC of 3 March 1997.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Denmark	The Fisheries Act (2004, as amended) regulates the management, control and development of fisheries and aquatic resources in Denmark.	There are no Guidelines or Codes of conduct.	Denmark is a member of the following international arrangements: •Party to the Convention on Biological Diversity (CBD); •North Atlantic Salmon Conservation Organization (NASCO).	According to the Fisheries act (2004), fish farming in Danish fisheries territories (ocean farming) can only take place if a licence has been granted by the Ministry of Food, Agriculture and Fisheries, a power that has been delegated to the Directorate of Fisheries. The Directorate determines the conditions, including possible time limits, for the licence. The Fisheries act (2004) applies to all kinds of fish farming, hence also for the fish farming of mussels, oysters etc., the setting up of aquaculture facilities placed on land using marine water, as well as for facilities using fresh water.	For new marine water fish farms, or those with considerably changes, if located outside a zone designated for aquaculture in the Regional Plan, an EIA shall be worked out. If the aquaculture facility is designated for intensive fish farming or has an intake of fresh water, an EIA shall be worked out as far as the facility it is likely to have a considerable impact on the environment, even when it is to be established in an aquaculture zone.
France	French aquaculture is ruled by two main sets of legislation, clearly separating inland and marine aquaculture. Inland aquaculture, coupled with inland fisheries, is regulated by the Environmental Code, while marine aquaculture must abide by marine fisheries legislation, among which are Law N.° 97–1051 on Maritime Fisheries and Mariculture (1997), and Decree of January 9th, 1852 on Maritime Fisheries (1852, as amended). The latter explicitly extends the applicability of its provisions to the farming of marine animals and plants.	The aquaculture sector is represented by several associations at national, regional and local level. The French Aquaculture Federation, being open to both freshwater and marine fish farmers, is the national fish farming association. At EU level, membership in FEAP (Federation of European Aquaculture Producers) is open to all national aquaculture associations. FEAP members adopt the 2000 Code of Conduct for European Aquaculture	France is a member of several international organizations, namely: •International Council for the Exploitation of the Sea (ICES); •Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); • Convention on Biological Diversity (CBD) and the Biosafety Protocol Agreement; •Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Agreement); •Convention for the Marine Environment Protection and of the Mediterranean Coastal Area (Barcelona Agreement 1995).	The establishment of aquaculture facilities over private land requires the granting of an authorization, whereas a concession is necessary for the use of State-owned waterbodies.	The EIA system is regulated in Book I of the Environmental Code and in Decree N.° 77–1141 implementing article 2 of Law n.° 76–629 on the Protection of Nature (1977, as amended). The presentation of an EIA study is mandatory for the following aquaculture projects: •Salmon aquaculture farms. •Aquaculture farms with scientific or experimental purposes. •Fish farms with an annual production exceeding 2 tonnes or with a water surface over 3 hectares. •Fish farms intending to extend their production or surface to or over said thresholds.

Country	Basic Legislation	Guidelines and Codes of Conduct	International Arrangements	Authorization System	Environment Impact Assessment (EIA)
Germany	The most important federal acts in the field of water resources management (Federal Water Act and Federal Wastewater Charges Act) are only framework statutes. The water resources regulations in the Federal States (state water acts, state wastewater acts and various statutory orders) also contain important provisions which supplement the federal regulations or define them in greater detail. For example, the Federal States regulate ownership of waters, monitoring of waters, maintenance of waters, licensing procedures for uses of waters, and indirect discharges (i.e. discharges via wastewater treatment plants) into waters. The Federation participates in the discharge of responsibilities of the Länder, in the improvement of the agrarian structure and of coastal preservation including fisheries (Law on the Improvement of the Agrarian Structure and the Coastal Protection).	Guidelines have been developed for eco fish farming in ponds. Additionally, there are general guidelines for organic farming that have to be observed. A commission, partly formed by external experts, decides on the certification of farms on the basis of the observance of the guidelines. The certification refers to a whole farm, not to single products.	Germany is a party to the following international agreements: •Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR); • Convention on Biological Diversity (CBD); •Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM); •International Baltic Sea Fishery Convention (IBSFC); • North Atlantic Fishery Organization (NAFO); • North East Atlantic Fishery Convention (NEAFC); • North Atlantic Salmon Convention (NASCO).	Depending on the kind of project, a building permit might be necessary. A further authorization is required from nature conservation authorities for facilities in protected areas. An additional permit for fish farms has to be obtained from the fisheries administration of the Länder. Furthermore, before starting a fish farm, the regional offices in the Länder in charge, according to § 2 (1) of the Fish epidemics Regulation, have to be notified. The Federal Office for Maritime Navigation and Hydrography authorizes aquaculture and fish farm facilities in the exclusive economic zone and in high seas, according to the Sea Facilities Ordinance.	In Germany, EIA is not an independent administrative procedure but an integrated part of a licensing procedure (§2, 1 of the Act on Environmental Impact Assessment. The EIA provides for the description and assessment of the environmental effects of a project. In particular, the effects of a project on human beings, animals, plants, soil, water, air, landscape, including the relevant interactions, shall be determined. In addition, EIA must assess the effects on these assets in their completeness.

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Ireland	The main legal instrument is the Fisheries (Amendment) Act (1997), which has been further amended by the Fisheries (Amendment) Act (2001). Also relevant to aquaculture are the Foreshore Act (1933), the Foreshore (Amendment) Act (1992) and the Fisheries and Foreshore (Amendment) Act (1998), which require aquaculture project developers to obtain a foreshore licence before occupying or undertaking any works or placing structures on state-owned foreshore for the purpose of, inter alia, aquaculture. The foreshore is defined as the seabed and shore below the line of high water of ordinary or medium tides and extends outwards to the limit of 12 nautical miles.	In 2003, the Irish Sea Fisheries Board developed and introduced, the Environmental Code of Practice for Aquaculture Companies and Traders (ECOPACT) to promote the widespread introduction of Environmental Management Systems in the Irish aquaculture industry. The document lays out in detail the approach that should be taken, an overview of the legislation to be complied with and the extra measures and steps that the farmers can take to minimize the environmental impact of their operations in line with international best practices. Concerning stock health management, ECOPACT recommends implementing ISGA's Code of Practice for the Prevention of Stock Escapes of Irish Farmed Salmonids. In addition, ECOPACT also annexes and refers to the Code of Conduct for European Aquaculture of the Federation of European Aquaculture Producers (FEAP).	Ireland is a member of: • International Council for the Exploration of the Sea (ICES); • North Atlantic Salmon Conservation Organization (NASCO); • Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention); • Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); I• Convention on Biological Diversity (CBD) and the Biosafety Protocol.	The Fisheries (Amendment) Act (1997) requires any person wishing to engage in land-based or marine-based aquaculture to apply for an aquaculture licence or, in the case of aquaculture in an investigative or experimental manner, for a trial licence. The Fisheries and Foreshore (Amendment) Act (1998) prohibits any person making an application from commencing aquaculture operations until duly licensed under the Fisheries (Amendment) Act (1997). Unlicensed operations could entail a fine and/or imprisonment.	According to the Aquaculture Regulations (1998), all applications for aquaculture or trial licenses in respect of seawater salmonid breeding installations shall be accompanied by an Environmental Impact Statement (EIS). An EIS may be required in other cases if the Minister considers that the proposed aquaculture is likely to have significant effects on the environment.

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Italy	From a constitutional point of view, fisheries and aquaculture are considered as matters of regional legislative competence. However, the reform process of the fisheries and aquaculture legislation was carried out by the Central Government, as required by the Parliament with Law n.° 57 of 2001 on the Opening and Regulation of Markets and Law n.° 38 of 2003 on Agriculture. With reference to the 2001 Law, the Government issued Legislative Decree n.° 226 of 2001 laying down Guidelines on the Modernization of the Fisheries and Aquaculture Sector. With regard to the 2003 Law, the Government issued Legislative Decree n.°154 of 2004 on the Modernization of the Fisheries and Aquaculture Sector and Legislative Decree n.°153 of 2004 on Marine Fisheries, which also amend certain provisions of the previous set of Legislative Decrees.	The Italian Agency for Environmental Protection and the Central Institute for Scientific and Technological Research Applied to the Sea drafted in 2001 the guidelines for the application of the EMAS Regulation (Parliament and Council Regulation (EC) n.°761/2001 allowing Voluntary Participation by Organizations in a Community Eco-Management and Audit Scheme) to the aquaculture sector.	Italy is a party of the following international agreements: • Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); •Convention on Biological Diversity (CBD) and the Biosafety Protocol.; • Barcelona Convention of 1976 for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.	At national level, the authorization system for the conduct of fisheries and off-shore aquaculture is regulated by Legislative Decree n.° 153 of 2004 on Marine Fisheries, which has repealed (together with Legislative Decree n.°154 of 2004 on the Modernization of the Fisheries and Aquaculture Sector) the Maritime Fisheries Law of 1965. Transitionally, the Regulation of 1968 (Decree of the President of the Republic, 2 October 1968, n.°1639), is still in force. Moreover, a concession is required for the use of the maritime State property and public inland waters, and for the construction of aquaculture facilities thereon.	The main piece of legislation concerning EIA is Law n.° 349 of 1986 establishing the Ministry of Environment, which provides for transitional procedural rules for the assessment of projects that are likely to significantly affect the environment. These shall be identified by Decree of the President of the Republic, upon proposition of the Ministry of Environment. The competent authority for the assessment at national level is the Ministry of Environment. However, the procedure requires the opinion of the Ministry for Cultural Heritage and Activities and of the concerned Regional Authority. Moreover, Law n.° 67 of 1988 establishes an EIA Commission with advisory and investigative functions.

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Portugal	The legal framework comprises Directive 2000/60/EEC of 23 October, which was encompassed by the Portuguese legislation through Law n.º 58/2005, of 29 December, complemented by Decree-Laws n.º 77/2006 of 30 March and n.º 226–A/2007, of 31 May). It defines the rules for sustainable water management, and applies to coastal, transitional and inland waters. It also comprises Decree-Law n.º 278/87 of 7 July, as amended by Decree-Law n.º 383/98 of 27 November and Regulatory Decrees n.º 14/2000, of 21 September and n.º 9/2008 0f 18 May, dealing with the aquaculture activity.	The European Federation of Producers (FEAP) has adopted a Code of Conduct for European Aquaculture, which is observed by its members. The main objective of this Code of Conduct is to promote the responsible development and management of aquaculture to ensure a high standard of quality in the production process, with consideration to both, environmental concerns and consumer demands. The Portuguese national professional association belongs to FEAP.	Portugal is a member of several international organizations, namely: •International Council for the Exploitation of the Sea (ICES); •Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); •Agreement on the Biological Diversity (CBD).; •Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Agreement);	The establishment of aquaculture facilities over private land requires the granting of an authorization, whereas a licence is necessary for the use of State-owned waterbodies (water public domain).	The legal framework for the regulation of the Environmental Impact Assessment (EIA) procedure comprises Directive 85/377/EEC of 27 June 1985, modified by Directive 97/11/CE, which was encompassed by the Portuguese legislation through the Decree-Law n.º 69/2000, of 3 May. It establishes that projects of intensive aquaculture, with different outputs, depending on location (marine, estuarine or inland waters), are subjected to an EIA.

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Spain	The legal framework for the regulation and promotion of aquaculture consists of several legal instruments, amongst which outstand the Constitution of Spain, the Law for Promotion and Conservation of Riverine Fisheries (1942), the Law on Marine Aquaculture (1984) and the Law on the Coastline (1988). In agreement with the dispositions of the Constitution, the Autonomous Communities exert exclusive competence in inland waters, harvesting of shellfish, aquaculture, hunting and riverine fisheries. The legal instruments issued by the National Government on marine and inland aquaculture regulation have a general and supplementary character,	The European Federation of Producers (FEAP) has adopted a Code of Conduct for European Aquaculture, which is observed by its members. The main objective of this Code of Conduct is to promote the responsible development and management of aquaculture to ensure a high standard of quality in the production process, with consideration to both, environmental concerns and consumer demands. Some of the various Spanish professional associations belongs to FEAP The General Secretariat of Marine Fisheries, with the collaboration of the International Union for Nature (UICN) and the FEAP, has formulated the first of the "Directing Guidelines for the Sustainable Development of Aquaculture".	Spain is a member of several international organizations, namely: •International Council for the Exploitation of the Sea (ICES); •Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); •Agreement on the Biological Diversity (CBD).; •Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Agreement); •Convention for the Marine Environment Protection and of the Mediterranean Coastal Area (Barcelona Agreement 1995).	Potential aquaculturists intending to undertake an aquaculture activity, either marine or inland, must apply for various authorizations or permits before the corresponding authorities. The applicable legal framework for the development of aquaculture falls under the Autonomous Communities which apply their own norms for the execution of the procedures of authorizations or leases. However, those Communities that haven't got their own norms, supplementary Law n.° 23/1984 of Marine Cultivation (for marine aquaculture), the Law of Riverine Fisheries of 1942 (for inland aquaculture), and Law n.° 22/1988 of the Coastline.	The legal framework for the regulation of the Environmental Impact Assessment (EIA) procedure comprises Directive 85/377/EEC of 27 June 1985, which was encompassed by the Spanish legislation through the Royal Legislative Decree n.° 1302/1986, of 28 June and the Royal Decree n.° 1131/1988, of 30 September, modified by Directive 97/11/CE. These modifications have been adopted through Law n.° 6/2001, of 8 May. It establishes that projects of intensive aquaculture with an output higher than 500 tonnes/year are subjected to an EIA whenever the environmental authority determines. The administrative procedure for EIA varies among the Autonomous Communities.

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Norway	The Aquaculture Act (2005) regulates the management, control and development of aquaculture in both inland and marine waters, as well as land based aquaculture. The purpose of the Act is "to promote the profitability and competitiveness of the aquaculture industry within the framework of a sustainable development and contribute to the creation of value on the coast. The agreement on the European Economic Area (EEA) imposes several obligations on Norwegian legislation.	There are no aquaculture guidelines/codes of conduct.	Norway is a party to the Convention on Biological Diversity (CBD) and to the Biosafety Protocol. Norway is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES).	The Aquaculture Act establishes an obligatory licensing system for aquaculture, and provides that the Ministry may, through regulations, prescribe limitations in the number of licences for aquaculture of salmon, trout and rainbow trout.	Any aquaculture licence may, as a general rule, only be granted if it is "environmentally responsible". A whole chapter of the Aquaculture Act is dedicated to environmental considerations, providing that aquaculture facilities shall be established, operated and abandoned in an environmental responsible manner. The Regulation relative to impact assessment (2005), establishes that an EIA is to be carried out for large aquaculture installations, if these activities may have significant effects on the environment, natural resources or community.
Chile	The Fisheries and Aquaculture Law (1989, as amended up to 2006) regulates the conservation of living aquatic resources, capture fisheries, aquaculture, as well as scientific and recreational fisheries.	There are no guidelines or codes of conduct on aquaculture.	Chile is a party to the Convention on Biological Diversity (CBD) but has not yet ratified the Biosafety Protocol. Chile is also a party to the Convention on international Trade in Endangered Species of Wild Fauna and Flora (CITES).	The authorization/concession system to set up aquaculture facilities is regulated by the General Fisheries and Aquaculture Law. An authorization or concession is not required for aquaculture activities carried out entirely on private property, even when inland or marine waters are used, provided they are used in accordance with the respective regulations.	In general, and according to the General Law on Environment, the conduct of aquaculture is subject to an environmental impact assessment, with the exception of minor scale aquaculture.

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New Zealand	The Resources Management Act (RMA) as amended in 2004, provides much of the framework for managing aquaculture. Under the RMA, the Minister of Conservation is responsible for preparing coastal policy statements, approving regional coastal plans and permits for restricted coastal activities. Freshwater aquaculture activities are regulated by the Freshwater Fish Farm Regulations of 1983, under the statutory guidance of the Fisheries Act as amended in 2004.	New Zealand as not adopted a specific code of conduct for fisheries or aquaculture. However, it "fully supports" the FAO Code of Conduct for Responsible Fisheries	New Zealand is a party of several international agreements with implications for the regulation of aquaculture, namely the Convention on Biological Diversity, the Convention on International Trade in Endangered species of Wild Fauna and flora (CITES).	The RMA establishes that aquaculture activities are restricted to designated areas, called aquaculture management areas (AMA). The regional council develops regional plans and policy statements, in order to manage coastal resources, including aquaculture. The rules and plans will determine whether resource consents are required to carry out aquaculture related activities in a coastal zone. Inland fish farming is also subject to an approval from the local authority, in the form of a resource consent or certificate compliance	The RMA requires that any application for a resource consent must contain an adverse effects assessment, which details the scale and significance of the effects of aquaculture and other activities, upon the environment.