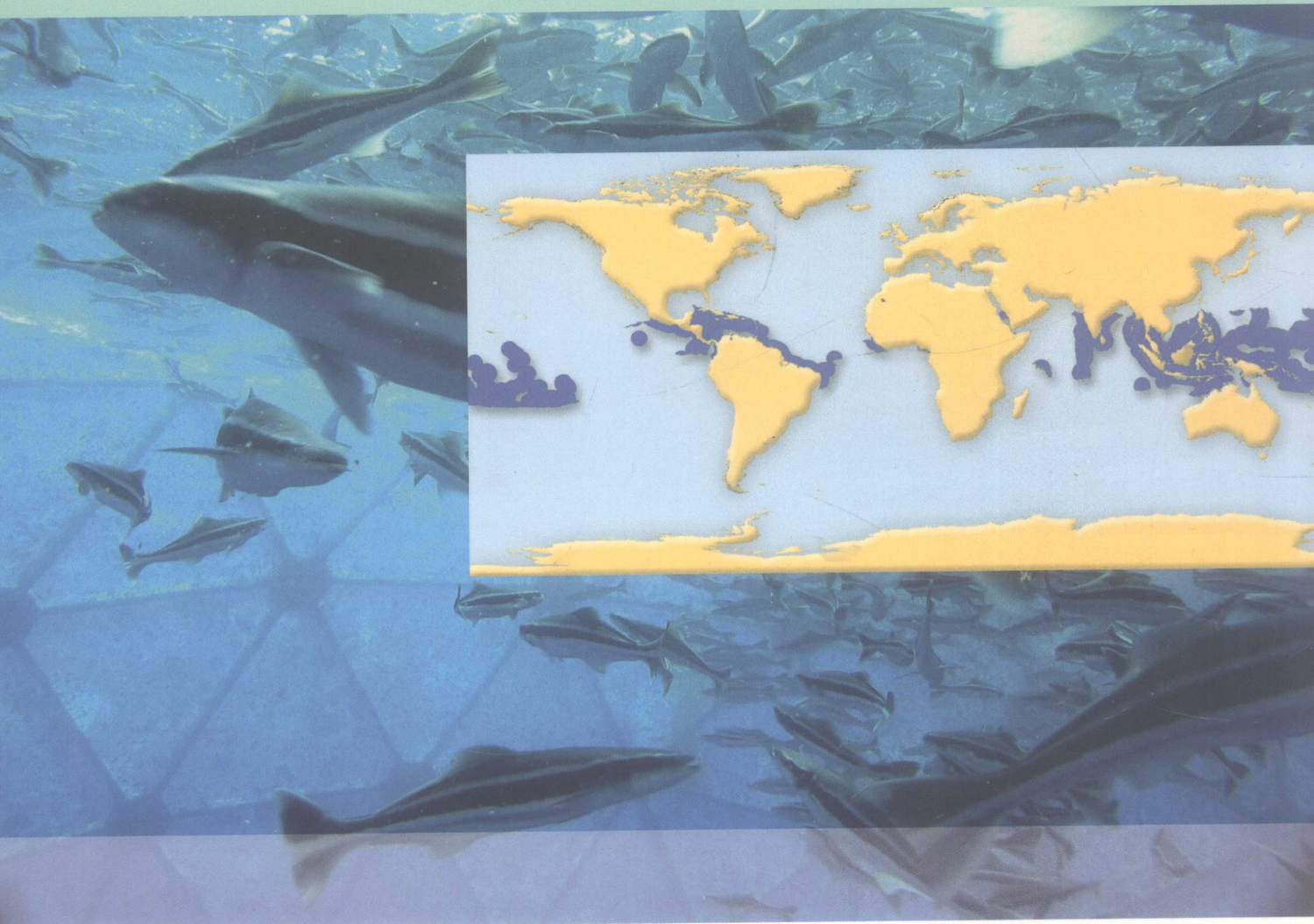


A global assessment of offshore mariculture potential from a spatial perspective



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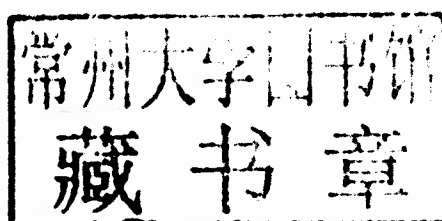
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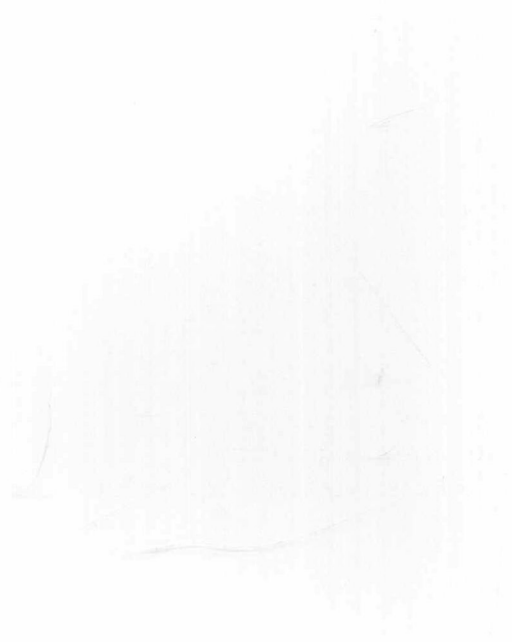
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Cover illustrations:

Map: Areas (dark blue) within Exclusive Economic Zones with temperatures favourable for offshore grow-out of cobia, *Rachycentron canadum*

Photo: Cobia in submerged Aquapod net pens at the former site of Snapperfarm, Puerto Rico (courtesy of Ocean Farm Technologies Inc.).

Preparation of this document

There is growing need to transfer land-based and/or coastal aquaculture production systems further into the sea as a result of the expected increases in human population, competition for access to land, and clean water needed to increase the availability of fish and fishery products for human consumption. Mariculture, in particular offshore aquaculture, offers significant opportunities for sustainable food production and for the development of many coastal communities, especially in regions where the availability of land, nearshore space and freshwater are limited.

This technical paper is an expanded and more detailed version of a contribution entitled “Spatial analysis of the potential for offshore mariculture” to a Food and Agriculture Organization of the United Nations (FAO) workshop proceedings (Lovatelli and Aguilar-Manjarrez, forthcoming) that aims at providing additional guidance in the development of offshore mariculture. The workshop proceedings collect and synthesize global information on the potential for offshore mariculture development by focusing on technical, environmental, spatial and governance challenges. The goal is also to identify major opportunities and challenges that FAO, its Member States and other stakeholders could act upon for the industry to grow on a sustainable footing.

This technical paper responds to the needs of the FAO Member States in providing estimates of the potential for offshore mariculture development, presenting, for the first time, quantitative spatial measures of the status and potential of offshore mariculture development that are comprehensive of all maritime nations and comparable among them.

This document is part of a recent series of spatially oriented activities aimed at the development and management of aquaculture. These activities have included reviews on geographic information systems, remote sensing and mapping for marine aquaculture, and spatial planning tools to support the ecosystem approach to aquaculture. Additionally, the activities also cover marine spatial planning for aquaculture, site selection and carrying capacity, and virtual technology and decision-support tools. Although these activities have had varying objectives, the common theme among them is the demonstration of the essential role of spatial analysis in the development and management of aquaculture from global to local levels. The present document continues this theme.

Abstract

Mariculture accounts for about one-half of total aquaculture production by weight. About one-half of the mariculture production consists of aquatic plants, with the remainder being fish and invertebrates. Nearly all of mariculture is inshore. In contrast, offshore mariculture, which is practised in the open sea with significant exposure to wind and wave action and with equipment and servicing vessels operating in severe sea conditions from time to time, is in its infancy and production is almost exclusively of fish and shellfish. There is an impetus for mariculture to move to the unprotected waters of the open sea. Issues at the local level include competition for space, water quality problems, and a negative public perception of mariculture's environmental and aesthetic impacts. At the global level, there is concern for food security with expanding population along with the conviction that the potential of the world's oceans to supplement the food supply is vastly underutilized. Prospecting for suitable locations is a critical part of spatial planning for offshore mariculture's near-future development. Thus, the objectives of this technical paper are to provide measures of the status and potential for offshore mariculture development from a spatial perspective that are comprehensive of all maritime nations and comparable among them, to identify nations not yet practising mariculture that have a high offshore potential for it, and to stimulate interest in detailed assessments of offshore mariculture potential at national levels.

Estimates of offshore mariculture potential are based on key assumptions about its near-future development: offshore mariculture will develop within exclusive economic zones (EEZs), will mainly use culture systems modified from inshore mariculture, and will mainly employ species with already proven culture technologies and established markets. These assumptions set the stage for the identification of analytical criteria. Thus, EEZs were used as spatial frameworks to define the limits of national offshore mariculture development. Potential was defined by the depth and current speed limits on offshore cages and longlines, the cost-effective area for offshore mariculture development, and the favourable conditions for grow-out of representative species: cobia (*Rachycentron canadum*), Atlantic salmon (*Salmo salar*) and blue mussel (*Mytilus edulis*), and integrated multitrophic aquaculture (IMTA) of the last two species. Verification and comparison with existing mariculture showed that, despite the limitations of the data, the results are indicative of offshore mariculture potential within the specified criteria.

Offshore mariculture potential is large. At present, 44 percent of maritime nations with 0.3 million kilometres of coastline are not yet practising mariculture. About half of the mariculture nations have outputs of less than 1 tonne/kilometre of coastline. About one-half of inshore mariculture production consists of aquatic plants, but there is little production of plants offshore. Scenarios using 5 and 1 percent of the area meeting all of the criteria for each of the three species showed that development of relatively small offshore areas could substantially increase overall mariculture production. Improvements in culture technologies allowing for greater depths and increased autonomies, as well as the further development of free-floating or propelled offshore installations, would add greatly to the area with potential for offshore mariculture development.

Remote sensing for the sustainable development of offshore mariculture is included as Annex 3 to this publication in recognition of the importance of remote sensing as a source of data for spatial analyses to assess potential for offshore mariculture, and also for zoning and site selection as well as for operational remote sensing to aid mariculture management.

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Abbreviations and acronyms

CHL-2	Chlorophyll-a concentration estimated by algorithms that deal with the effects of suspended solids and dissolved organic matter that occur in coastal waters cm/s centimetres per second
CCRF	FAO Code of Conduct for Responsible Fisheries
cs	current speed
EA	ecosystem approach
EAA	ecosystem approach to aquaculture
EEZ	exclusive economic zone
ESRI	Environmental Sciences Research Institute
FAO	Food and Agriculture Organization of the United Nations
FCR	food conversion ratio
GADM	Database of Global Administrative Areas
GEBCO	General Bathymetric Chart of the Ocean
GIS	geographic information systems
GISFish	Global Gateway to Geographic Information Systems, Remote Sensing and Mapping for Fisheries and Aquaculture
GMFMC	Gulf of Mexico Fishery Management Council
HYCOM	HYbrid Coordinate Ocean Model
IMTA	integrated multitrophic aquaculture
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
nm	nautical mile
OECD	Organisation for Economic Co-operation and Development
OHI	Ocean Health Index
MPA	marine protected areas
NMFS	National Marine Fisheries Service
SST	sea surface temperature
SWH	significant wave height
UNEP	United Nations Environment Programme
TGC	thermal growth coefficient
VBA	Visual Basic for Applications
VLIZ	Flanders Marine Institute
WCMC	World Conservation Monitoring Centre

Executive summary

Why mariculture needs to move offshore

Mariculture, with a production of 36.1 million tonnes and a value of US\$37.9 billion in 2010 (FAO Statistics and Information Branch of the Fisheries and Aquaculture Department, 2012), accounts for about one-half of total aquaculture production by weight. About one-half of the mariculture production consists of aquatic plants, with the remainder being fish and invertebrates. Nearly all of mariculture is inshore mariculture, that is mariculture that is situated or carried out near the shore. In contrast, offshore mariculture practice is in its infancy and production is almost exclusively of fish and shellfish. Drivers at local and global levels provide impetus for mariculture to move to the unprotected waters of the open sea. At the local level, there are issues of competition for space both within the mariculture sector and with other users, problems with water quality, and oftentimes there is a negative public perception of mariculture's environmental and aesthetic impacts. At the global level, there is concern for maintaining food security with expanding population. Also, there is the conviction that the potential of the world's oceans to supplement the food supply is vastly underutilized. This situation places a premium on spatial planning for offshore mariculture. Prospecting for suitable locations for offshore mariculture's near-future development is a critical part of a future-focused approach that will take advantage of opportunities for increasing production while minimizing the issues associated with inshore mariculture.

A framework for offshore mariculture development

Recognizing the need to stimulate the development of offshore aquaculture, the FAO Fisheries and Aquaculture Department conducted a workshop on offshore mariculture (Lovatelli and Aguilar-Manjarrez, forthcoming). The workshop recognized that FAO can guide and support its Member States and the industry as a whole in the policy and technical developments needed for expanding mariculture to offshore areas. As part of this framework, spatially derived estimates are essential to define locations and quantify expanses of areas suitable for offshore mariculture development. Furthermore, many of the issues and opportunities associated with the development of offshore mariculture have components that can be addressed separately, or together, using spatial analyses. In particular, spatial analysis lends itself to the integration of technical, economic, environmental and jurisdictional problems of mariculture development, all of which are included in this study.

Objectives of this technical paper

The main objective of this technical paper is to provide measures of the status and potential for offshore mariculture development from a spatial perspective that are comprehensive of all maritime nations and comparable among them. The results are a spatial gauge of the indicative near-future global and national potential for the expansion of mariculture from the present inshore locations to offshore areas. The results are also aimed at stimulating much more comprehensive and detailed assessments of offshore mariculture potential at national levels. A final objective is to identify nations that have a high offshore mariculture potential but that are not yet practising it.¹ With these objectives in mind, the study is aimed at decision-makers of

¹ Mariculture countries for the purposes of this study are those listed in the FAO aquaculture production statistics (FAO Statistics and Information Branch of the Fisheries and Aquaculture Department, 2010) as having mariculture production originating from the marine environment in one or more years for the period 2004–2008.

international organizations and at all levels of governmental administrations involved with aquaculture development as well as at entities in the commercial sector involved with mariculture services and development.

How offshore mariculture potential was estimated and verified

The process began with key assumptions about the near-future development of offshore mariculture. Among the key assumptions are that offshore mariculture will develop within the exclusive economic zones (EEZs), will mainly use cages for fish and longlines for molluscs modified for offshore conditions, and will mainly employ species with already proven mariculture technologies and established markets. These assumptions set the stage for the establishment of analytical criteria and thresholds that are at the core of the spatial analyses. The analytical criteria and corresponding thresholds that define the technical limits on cages and longlines are depths (25–100 m) and current speeds (10–100 cm/s). Likewise, the criteria that define the cost-effective area for development of offshore mariculture are cost limits on travel time and distance from shore to offshore installations (25 nm, or 46.3 km), and reliable access to a port. Species indicative of various kinds of mariculture potential and that meet the culture system technology and market requirement criteria are cobia, Atlantic salmon and blue mussel. Favourable grow-out of fish and mussels is defined by water temperature (22–32 °C for cobia, 1.5–16 °C for Atlantic salmon, and 2.5–19 °C for blue mussel). In the case of the blue mussel, favourable grow-out also is assessed by food availability measured as chlorophyll-*a* concentration ($> 0.5 \text{ mg/m}^3$). Potential for offshore integrated multitrophic aquaculture (IMTA) of the last two species also was analysed. Spatial analyses were carried out using a geographic information system (GIS). Offshore mariculture potential was reported as maps showing the areas with potential, tables that presented surface areas in aggregate globally, and charts with potential ranked by nations.

The results were verified by comparisons of national-level production of each of the three species with national-level offshore mariculture potential, locations of inshore mariculture with offshore potential at national and local levels, and offshore mariculture locations compared with offshore potential in the same areas. The verification and comparison exercises showed that, despite the limitations of the data, the results are sufficiently reliable for the objectives, namely to comprehensively and comparatively deliver locations and surface areas of offshore mariculture potential aggregated globally that are a first approximation of near-future offshore mariculture potential at the national level.

Near-future offshore mariculture potential

Estimates of near-future mariculture potential come from two perspectives. The first is the assessment of the present status of mariculture in spatial terms covering the period 2004–2008. The results of this assessment indicate that the global potential is large for both inshore and offshore mariculture in aggregate and for many nations individually for the following reasons: nearly all of present-day mariculture takes place in sheltered areas, not offshore. Interestingly, about 44 percent of maritime nations are not yet practising mariculture; about one-half of mariculture production consists of aquatic plants, but there is as yet little production of plants offshore. Mariculture intensity measured as production in terms of tonnes/kilometre of coastline reveals that there are 0.3 million km of coastline along which mariculture is not yet practised. Mariculture intensity is highest in the Northern Temperate Zone followed by the Intertropical Convergence Zone, the Arctic Zone and the Southern Temperate Zone. Among the 93 nations and territories already practicing mariculture, 51 percent produce at a relatively low intensity of less than 1 tonne/kilometre of coastline.

The second perspective is based on spatial integration of basic criteria for cage and longline culture systems (depth, current speed) with criteria for favourable grow-out of cultured animals (temperature, food availability as chlorophyll-*a* for the mussel).

- There are large areas globally among many nations with potential for development of offshore mariculture. Overall potential (i.e. without taking into account distance from shore) for cobia is 793 938 km², for Atlantic salmon 30 566 km², for blue mussel 29 960 km², and for IMTA 14 590 km². This approximates potential for other fish and mussel species with similar environmental requirements for grow-out in cages or on longlines.
- Even when further constrained by including the cost-effective area for development as an additional criterion, large areas with potential that include many nations remain. Offshore potential for Atlantic salmon (2 447 km²) and blue mussel (5 848 km²) is limited to the nations already practising their culture in inshore waters. Potential for IMTA of these species is 1 202 km². In contrast, offshore mariculture potential for cobia is 97 192 km² among 80 maritime nations, of which 34 are not yet practising mariculture. This indicates that there is greater offshore mariculture potential for species with warm temperate and tropical grow-out regimes than for those with cool and cold temperate grow-out regimes.
- Mariculture potential has been assumed with other uses of marine space set aside. However, marine protected areas have been used as an illustration of possible competing, conflicting or complementary uses. This is a reminder that, although the area with potential is large, that potential will be reduced considerably by alternative uses for the same marine space, especially in inshore areas where current marine activities are focused.
- A fundamental question is how much area is sufficient for offshore mariculture development that would contribute to the global food supply? Development scenarios using 5 and 1 percent of the area meeting all of the criteria for each of the three species indicated that development of relatively small offshore areas could substantially increase overall mariculture production.
- Improvements in technologies could considerably increase offshore mariculture potential. The area meeting depth, current speed and cost-effective area for development criteria is only 0.1 percent of the total EEZ area. For instance, an increase in the mooring system depth for cages and longlines from the 100 m limit used herein to 150 m would increase the suitable area by 31 percent, or 4.2 million km². Looking to a more distant future, free-floating and propelled offshore culture installations would potentially open immense areas to offshore farming that would still be within EEZs, nearly 158 million km² for a structure requiring a minimum depth of 25 m.

Policy implications for offshore mariculture development

Policy implications for offshore mariculture development are considered as those pertaining to FAO, and possibly to other international organizations providing technical assistance, and to maritime nations.

Policy implications for FAO

- A significant number of maritime nations are not yet practising mariculture, let alone offshore mariculture. This suggests the need for a proactive approach by FAO that would be a rapid appraisal (desk study) to determine the reasons for the lack of development and to make recommendations on steps that should be taken to stimulate mariculture development among the most promising nations. The results of the present study identify the non-mariculture nations ranking highly in offshore mariculture potential and provide one of the starting points for the appraisal.

- It will be important to monitor the growth of the offshore mariculture industry. For this purpose, FAO and Member countries will need to create a new aquaculture statistical category “offshore mariculture”. Underlying that is the need for a simple, spatially oriented but unambiguous, definition for offshore mariculture.
- Spatial planning for offshore mariculture should be considered as one of the components of marine spatial planning.
- FAO is in a position to provide strong worldwide leadership for more holistic development of offshore mariculture that must comprise the full range of components identified under the FAO Code of Conduct for Responsible Fisheries and the ecosystem approach to aquaculture (EAA).
- There is a continuing need to gauge capacities (human resources, infrastructure, finances) at the national and/or regional level to implement the use of appropriate modelling and spatial tools in support of offshore mariculture development so that capacity-building initiatives can be matched to existing capabilities.
- The investigation of aquaculture potential need not be confined to marine environments. A similar approach could be used to investigate and further plan for aquaculture in all environments for nations that have not already done so.

Policy implications for maritime nations

- Maritime nations not yet practising mariculture, particularly those for which this study signals relatively large potential, should consider a broad-based rapid appraisal of opportunities and impediments for mariculture development.
- Nations already practising mariculture should consider undertaking a thorough appraisal of their offshore mariculture potential that would be couched in the EAA. Ideally, the appraisal would be designed so that the results would also satisfy broader efforts for marine spatial planning.
- An important goal of spatial analysis is to locate and quantify the complementary uses while avoiding or minimizing the competing and conflicting uses. This study, in a very broad way, serves to indicate the spatial domains that could become offshore mariculture uses as a component in marine spatial planning at regional and national levels.

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