Global stakeholder vision for ecosystem-based marine aquaculture expansion from coastal to offshore areas

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Running title

Stakeholder vision for marine aquaculture expansion

Abstract

Marine aquaculture is the most promising industry for ensuring future provision of seafood. Yet, the worldwide growth and expansion of this industry has been slower than expected, calling for the identification of environmentally suitable sites while accounting for all factors that could constrain or benefit its establishment. Here, we determine the main obstacles and risks hindering the growth and expansion of marine aquaculture, as well as the needs and recommendations to overcome such constraints. Our analysis is based on results obtained from a consultation process held in 16 study sites located around the world with the participation of 614 stakeholders representing the research community, aquaculture industry, government, conservation groups and, education and fishermen associations. A high level of commonality exists in the main issues hindering aquaculture growth and expansion in coastal, off-the-coast and offshore aquaculture with most being attributed to interactions with other maritime activities, including conflicts with other users and administrative procedures, including licensing. Critical needs for improved management and expansion of the aquaculture industry are related to planning and management of developments and technological advances, with economic and market needs featuring to a lesser extent. Key procedures recommended to assist further aquaculture growth are the standardisation and simplification of regulatory frameworks, improvement of governance, and the adoption of participatory processes to facilitate meaningful and productive stakeholder engagement. We strongly recommend stakeholder participation to enhance insights on the full environmental and human dimensions of marine management and for implementation of ecosystem-based marine spatial planning.

Keywords

Marine spatial planning, management, consultation process, Blue Growth, Ecosystem Approach to Aquaculture

1. Introduction

Annual global consumption of seafood products per capita has doubled over the past 50 years, from almost 10 kg in 1960 to 20.3 kg in 2016 (FAO, 2018) and there is limited scope for further growth as over 89.5% of global wild marine fish stocks are now fully or over exploited (FAO, 2016). Thus, it is expected that the rapidly rising demand for marine food products will not be satisfied by wild fish stocks (Pauly *et al.*, 2002). In this context, aquaculture presents a suitable alternative (Edwards, 2009; Merino *et al.*, 2012) to guarantee food security (Godfray *et al.*, 2010), if properly planned and managed (Lester *et al.*, 2018). Despite the global interest in developing aquaculture, including in offshore regions, comprehensive estimates of potential space allocation for growth of the industry are scarce (Lovatelli *et al.*, 2013). Exclusive Economic Zones (EEZs), claimed by nearly all countries, are the main areas in which aquaculture can expand from present-day operations in coastal areas (0.5 km from shore and <10 m water depth) to off-the-coast (0.5-2 km and 10-50 m depth) and offshore areas (>2 km and >50 m depth) (Lovatelli *et al.*, 2013). Although globally aquaculture contributes importantly to overall aquaculture production and value, out of the 145 sovereign nations with EEZs, only 17 of them account for 98% of aquaculture production (Lovatelli *et al.*, 2013). The marine (also maritime or offshore) aquaculture industry is relatively new in most countries meaning that negotiations are needed to secure its environmental and spatial needs when competing with much stronger economic interests such as those represented by tourism (Hofherr *et al.*, 2015), fisheries (Coccoli *et al.*, 2018), together with conservation and environmental protection (Le Gouvello *et al.*, 2017) taking place in the same regions. Moreover, it is predicted that an acceleration of offshore activities will increase demand and competition for ocean space (Douvere, 2008; Yates and Bradshaw, 2017). Prospecting for suitable locations is a critical part of spatial planning for offshore aquaculture development (Kapetsky *et al.*, 2013). While lack of space has been considered as one of the main obstacles for the expansion of marine aquaculture (Sanchez-Jerez *et al.*, 2016), recent studies highlight the global availability of large areas with suitable environmental conditions, especially offshore (Gentry *et al.*, 2017; Kapetsky *et al.*, 2013; Oyinlola *et al.*, 2018; Weiss *et al.*, 2018). But, currently the commercial or experimental production of off-the-coast and offshore aquaculture is still minimal (Soto and Wurmann, 2019). For example, only around 3% of the European (EU) coastal area is used for aquaculture and the marine finfish sector occupies a

negligible surface area offshore (Hofherr *et al.*, 2015). However, information on the spatial characteristics and needs of aquaculture is limited and there has been little attention to consider aquaculture as part of developments (Corner *et al.*, 2019). Thus, the identification of factors hindering the expansion of marine aquaculture, and offshore aquaculture, is needed to enable policy makers and managers to develop strategies for further sectoral growth. In fact, the expansion of aquaculture industry, as well as other maritime activities, requires integrated management strategies to optimise sea space and reduce conflicts (Gimpel *et al.*, 2018b; Stelzenmüller *et al.*, 2017). Recently, marine spatial planning (MSP; also referred to as coastal and marine spatial planning, ocean planning, maritime spatial planning and marine planning), is advocated as a management tool that allows the consideration of multiple sectoral interests while accounting for ecosystem health (Domínguez-Tejo *et al.*, 2016; Katsanevakis *et al.*, 2011). In the EU, the Maritime Spatial Planning Directive (Directive 2014/89/EU) provides the legal basis for such an integrated management approach; and the development of spatial planning is acknowledged, and adopted, as a measure to promote aquaculture (EC, 2013; Lester *et al.*, 2018). Different spatial planning initiatives have been developed worldwide to balance sustainable development of maritime activities with ecosystem health (Barbanti *et al.*, 2017; Buhl-Mortensen *et al.*, 2017; Feng *et al.*, 2016; Peart, 2017; Vince, 2014). Among others, good practice in MSP demands the definition of planning goals and objectives as well as consideration of the footprint and intensity of current and future human activities (Stelzenmüller *et al.*, 2013). In addition, the Ecosystem Approach to Aquaculture (EAA) (FAO, 2010; Soto *et al.*, 2008), is intended to achieve the sustainable development of aquaculture. This approach requires aquaculture to: (i) be developed in the context of ecosystem functions and services (including biodiversity) (Custódio *et al.*, 2019), with no degradation beyond resilience; (ii) improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of income); and (iii) be developed in the context of other sectors, policies and goals, as appropriate (Aguilar-Manjarrez *et al.*, 2017). Aquaculture spatial planning that follows an EAA can contribute to a long and diverse list of potential improvements across the sector (FAO and World Bank, 2015) to counter the negative external factors of unplanned or uncoordinated development (Corner *et al.*, 2019).

In practice, the development of multiple use management plans is challenging since multiple stakeholder interests and management options need to be balanced (Soma *et*

al., 2014). Thus, the consideration of specific concerns, requirements and interests of each maritime sector calls for stakeholder engagement in the early stages of the planning process (Fletcher *et al.*, 2013; Gilliland and Laffoley, 2008; Gopnik *et al.*, 2012; Gunningham *et al.*, 2004; Olsen *et al.*, 2014; Pomeroy and Douvere, 2008; Ritchie and Ellis, 2010). A carefully designed stakeholder consultation and engagement strategy is a prerequisite to gather such valuable and complex information (Flannery and Ó Cinnéide, 2012; Gopnik *et al.*, 2012; Maguire *et al.*, 2011,2012; Newton and Elliott, 2016). In fact, participatory planning can improve the quality and legitimacy of the resulting plans (Flannery *et al.*, 2018; Reed *et al.*, 2017; Ritchie and Ellis, 2010). Unfortunately, stakeholder consultation processes are often not appropriately considered or taken into account in MSP processes (Flannery *et al.*, 2018; Flannery and Ó Cinnéide, 2012; Fletcher *et al.*, 2013; Frazão Santos *et al.*, 2018; Maguire *et al.*, 2012), resulting in the engagement not always fulfilling participatory requirements (Ellis and Flannery, 2016).

In this context, we build on the results of a global stakeholder consultation undertaken in the course of the AquaSpace (Ecosystem Approach to making Space for Sustainable Aquaculture) project (http://www.aquaspace-h2020.eu). The objective of AquaSpace was to critically examine how to optimise and increase the available area for aquaculture, by adopting the EAA, and spatial planning for aquaculture in the wider context of the most relevant legislation and policies. Within that framework, the scope of this research was the design and performance of a global stakeholder consultation to distill the main constraints hindering marine aquaculture expansion off-the-coast and offshore, and to derive future recommendations to inform MSP around aquaculture. This study makes a case for early stakeholder engagement in integrated spatial planning processes, highlighting its benefits.

2. Study sites and stakeholder consultation process

Our consultation process aimed to investigate the constraints to the expansion of marine aquaculture industry, as well as the main needs and recommendations for better management of this activity from a stakeholder perspective. The consultation process followed a general framework comprising the following six steps (Figure 1): (i) definition of the context and objectives; (ii) identification of relevant stakeholders; (iii) identification of the main topics to design a questionnaire; (iv) consultation process with

stakeholders; (v) analysis and interpretation; and (vi) summary of conclusions and recommendations, and validation by stakeholders. While the general process was defined, the means for the actual consultation varied across study sites due to their particularities and the way in which stakeholders were engaged at each site.

The general context for aquaculture (step 1) was defined in 16 study sites located in Australia, Canada, China, across Europe, New Zealand and the United States of America (USA) (Figure 2). The study sites comprised different: (i) strategies for aquaculture management and growth; (ii) interactions between and among activities; (iii) environmental conditions and production capacity; (iv) technological development; and (v) other economic, social and environmental aspects involved in aquaculture activity. We cross-compared study sites in terms of: (i) production capacity; (ii) historical and expected growth; (iii) management strategies; (iv) aquaculture category (e.g. 4 offshore sites, 9 off-the-coast sites, and 3 coastal sites); (v) production system (i.e. longlines, cages, racks and bag systems on tables, bottom culture and intertidal plots); and (vi) cultivated species including bivalves (13 species), finfish (7 species), seaweed (3 species), echinoderm (1 species), and gastropod (1 species); the most commonly farmed species are the Pacific oyster (*Crassostrea gigas*), the Blue mussel (*Mytilus edulis*), the Atlantic salmon (*Salmo salar*) and the Mediterranean mussel (*Mytilus galloprovincialis*) (Table 1). While some study sites, such as waterbodies in China and Norway, already have high production levels, the management and national aims are to maintain and further develop these production levels. At other study sites, the aim is to increase aquaculture production either by increasing the cultivation area for existing species, or by introducing new species. However, in most study sites, expected increases in production are mainly for shellfish species (such as oysters and mussels) through expansion of the cultivation area (for example into offshore areas), or by promoting it as a new activity. Decreases in production were reported for only the Mediterranean region, with a 16% global decrease production. The USA, Canadian and Norwegian study sites are the only areas where specific progress towards EAA implementation was reported. None of the study sites located in Europe reported EAA as being fully implemented (Table 1). However, the national strategic plans for aquaculture are comparable to some of the steps of the EAA, such as scoping, identifying opportunities for aquaculture growth, consultation with relevant stakeholders and assessment of carrying capacity. More than three quarters of the study

sites have spatial management plans for aquaculture activity and other activities already in place or expected soon (Table 1). MSP is currently fully implemented in three study sites (Germany, North Sea, and, two areas of China: Sanggou Bay and Zhangzidao Island) and one pilot plan has been implemented in the Algarve Coast. Eleven of the case study locations have partially implemented MSP, meaning it is either forthcoming, or has been implemented at a sub-national or local level (*i.e.* Emilia-Romagna; Basque Country; Carlingford Lough; Normandy/Cancale; Argyll, Scotland; Great Bay, Piscataqua; Houtman Abrolhos Islands; Long Island Sound; Norwegian Coast; Nova Scotia Bays; and Pelorus Sound). Stakeholders from the Mediterranean Sea multinational case study reported the existence of a zoning system for aquaculture activities within both European and non-European countries based on the principles of Integrated Coastal Zone Management (ICZM) and EAA.

The next step in the consultation process (step 2) involved the identification of stakeholders to represent private companies, government, research bodies, and NGOs. A questionnaire (step 3) was designed to obtain qualitative knowledge on the key topics relating to efficient management and to obtain stakeholder vision and requirements for marine aquaculture growth. These included identification of data needs for aquaculture spatial planning, availability of data, definition of indicators to help define suitable sites, use of models and tools for site identification, and description of economic and market aspects.

Between 2016 and 2018, a total of 43 workshops (step 4), meetings and communication actions took place in the 16 study sites, plus a Mediterranean region stakeholder workshop. A total of 614 stakeholders were engaged in this process, including representatives from research (36.6%), industry and promoters (32.7%), government (22.3%), conservation and NGOs (4.6%), and other sectors, such as education and fisheries organizations (3.7%) (a summary of workshop details at each study site including total number of workshops held, number of participants and type of stakeholders involved in the workshops is provided as an Appendix; Table A.1). As the aim of the workshops was to investigate views on constraints to the expansion of the industry, the balance was tilted towards industry, researchers and government representatives (91.6%), with the remaining (8.4%) representing conservation agencies and other parts of civil society.

The reported obstacles for aquaculture expansion were then interpreted and classified according to their nature (*i.e.* "type of issue" or "obstacle dimension") and aquaculture category (step 5). In the case of the obstacles derived from the Mediterranean region stakeholder workshop, it was not possible to classify them according to aquaculture category since the information was aggregated. The type of issues comprised: (i) policy and management; (ii) environment related; (iii) other sectors, including social aspects such as perception of the aquaculture and social licensing; and (iv) economy and market, which included technological developments. The number of times each issue type was reported was then counted. As the results were based on the interpretation of qualitative responses, no statistical testing was completed. The same process was replicated for the list of needs and recommendations suggested by stakeholders during the consultation process.

The process ended with the extraction of the main recommendations that could inform policy makers and managers to develop strategies for further marine aquaculture growth and expansion (step 6).

3. Results

3.1. Current obstacles to the expansion of marine aquaculture

A total of 139 issues (of which 93 derived from the individual case study sites and 46 from the Mediterranean region stakeholder workshop), corresponding to 44 different issues (Figure 3), were identified as impeding aquaculture development. In total, 39% of the issues were related to policy and management aspects, which included the administrative framework and the licensing process; 25% were related to environmental factors, referring to the limitations that environmental conditions may pose to aquaculture, as well as the potential effect of aquaculture on the environment; 19% were related to interactions of the aquaculture sector with other maritime activities, including conflicts with other users and social licensing; and finally, 17% related to economic aspects including costs of production, benefits and market issues (e.g. no market stability, product imports, substitutes, etc.) (Table 2). When comparing the three aquaculture categories, the number of reported issues were similar for off-the-coast and offshore aquaculture (44 and 45, respectively), whereas only four issues were reported for coastal aquaculture. For off-the-coast, environmental (32%), other sectors (27%) and

policy and management (25%) were the most important issues; and for offshore aquaculture policy/management (33%), environmental and economic and market were the most important reported obstacles (Table 2).

The number of different obstacles reported was higher for offshore (26), than for off-the-coast (18) and coastal (4) aquaculture. Main issues common to all aquaculture categories were the ones related to conflicts with other users, management and planning, disease exposure and connectivity, and production costs (Appendix, Table A.2).

In terms of the number of times each obstacle was reported, the most cited issue was the conflicts with other users, which was reported for 25% of times for the off-the-coast and in 13% for the offshore. The administrative procedures and licensing were the second most cited issue, being the percentage of citations quite similar (11% for off-the-coast, and 9% for offshore aquaculture).

Concerns relating to off-the-coast aquaculture emphasised climate change effects on production, extreme events, and oceanographic conditions; while concerns for offshore aquaculture focussed on environmental monitoring, low diversity of cultivated species, definition of best principles of operation, different roles of management authorities, economic depression, environmental risk potential, market stability, market studies, need for tools to assess suitability, need to identify new suitable sites, elaborate quality and eco-aware products, stakeholder communication and participation, and war conflicts (Appendix, Table A.2). The main points highlighted by stakeholders are described below in relation to each of the four issue categories.

Policy and management issues

Across the 16 study sites, administrative procedures and licensing were the most frequently reported issues independently of country, species, or cultivation method. A common concern was the complexity, timeframes and costs associated with the administrative and licensing processes required for aquaculture activities. From the aquaculture sector perspective there is little effort by national governments in solving the complexity and timelines associated with administrative procedures. Moreover, it is not clear what processes should be followed by promoters and investors and there is limited access to guidance information during the licensing process. These issues were viewed by stakeholders as resulting from a lack of political will to develop aquaculture at local and global scales. Stakeholders also reported a lack of transparency in the

decision-making process and a lack of specific policies for aquaculture zoning. They stated that even when aquaculture is established, there is a lack of adaptive management. Furthermore, a lack of expertise and capacity for managing increased space for aquaculture by local governments and planning departments was highlighted.

Other sectors

The most frequently reported concern for all aquaculture categories was 'conflict with other users', especially in relation to the use of space. Main issues were associated with incompatibility between or among aquaculture activities and tourism, fisheries and navigation. Visual pollution and aesthetic factors were also reported as a cause of conflict with the recreation and tourism sectors. The adoption of conservation measures, including the designation of marine protected areas, was mentioned as an issue because increasing demand for conservation areas means that available space for existing and planned aquaculture activities is decreased. A lack of social licensing for aquaculture activities, in particular for fish aquaculture was mentioned, as was public opposition based on concerns about negative effects on wild salmon populations, environmental impacts of waste and disease spread. Stakeholders also reported their concerns about less available space for marine aquaculture, and for offshore aquaculture in particular, due to increasing trends in other activities, namely offshore platforms and maritime traffic.

Environmental issues

Environmental conditions suitable for aquaculture production were considered and included, such as issues related to ecological carrying capacity, limited areas suitable for aquaculture, effects of harmful algal blooms, and problems associated with inadequate water quality. More frequent external events causing mass mortalities alongside climate change effects were also reported.

The potential effects of aquaculture on the environment were also discussed. Stakeholders highlighted the environmental impact and risks derived from genetic pollution, noise pollution and foul odours. Disease exposure and connectivity within and between production zones was also frequently reported as an issue. The environmental impacts of aquaculture activities may result in negative effects for the required environmental quality for production, for example, benthic hypoxia impacts

were a persistent concern in Canada and China. However, positive effects through the provision of ecosystem services by aquaculture were also highlighted.

Economic and market issues

Economic and market issues have a direct effect on international market competitiveness for aquaculture products. The stability and reliability of production systems and the lack of market studies which incorporate price structure analysis (particularly export-focused) coupled with the inability of small-scale producers to develop the logistical platforms required, presents a significant market-related bottleneck. The level of consumer demand and public perception of aquaculture products are also relevant topics related to economic performance. Stakeholders stated that production cost was high due to several factors, including expensive fish feed and monitoring and maintenance costs. These reduce the economic capacity of the producer to invest in technologies to solve environmental issues. Additionally, low product prices and a lack of cooperation among companies were reported, and it was highlighted that the economic benefit of aquaculture, and especially of ancillary industries including processing, is not recognised.

3.2. Requirements for aquaculture expansion

A total of 60 needs or measures for improved management and expansion of the aquaculture industry were suggested by stakeholders. Highest number of requirements were reported for off-the-coast and offshore aquaculture (38 and 16, respectively) (Table 3). Most of these can be grouped as policy and management needs (47%) and economic and market needs (including technological aspects) (40%), with a few related to the environment (13%) and other sectors (Figure A.1 in the Appendix).

The need for improvements in planning and management of marine space and related policies was highlighted by most stakeholders, pointing particularly to off-the-coast locations. Such improvements include better integration of national policies, local planning, and industry requirements and the development of specific spatial planning processes to assign ‘priority areas’ for aquaculture. Stakeholders also reported the need to establish committees to create plans for successful aquaculture development and to identify and address new and emerging issues. The need for better cooperation mechanisms between and among industry, environmental management, government and

public scientific research was also put forward. Cooperation among producer associations was also seen as necessary to improve competitiveness and reduce production costs associated with monitoring and biosecurity plans.

The need for technological developments for aquaculture activities was also reported (especially in off-the-coast areas) and included: modernisation and automatization of production, the development of sensors and monitoring equipment, the application of artificial intelligence in the production process (which may result in higher efficiency and lower production costs), the diversification of cultivated species, enhancement of the quality and safety of aquaculture products, increase in productivity per unit area, adoption of measures to mitigate potential environmental impacts, and the development and implementation of new culture technologies for offshore areas. Moreover, streamlining of licensing processes and simplification of administrative procedures are also required to increase transparency, expedite licensing, reduce uncertainty and associated costs for promoters and investors, with an increasing demand from coastal to offshore areas.

The need to address several environmental research gaps for the promotion of EAA was stated repeatedly, but interestingly not in the offshore areas. Environmental considerations in spatial planning of aquaculture should be considered at different stages and scales of zoning, site selection and management area. These include assessment of site suitability and ecological carrying capacity to identify the most suitable and potentially productive areas for expansion, the limits to expansion, as well as areas where compliance costs would be minimal. Other areas of research include: identification and quantification of impacts caused by aquaculture; assessment of positive farm-ecosystem interactions (e.g. ecosystem services provided by certain aquaculture activities); anticipation of risks from climate change on finfish and shellfish production; and disease exposure and connectivity within and between zones (such as potential for disease spreading) to avoid potential risks at present, and in the future. For fish farming, interactions with wild salmonids needs to be further investigated.

Stakeholders reported that more effort should be made to promote aquaculture activities (with more emphasis in offshore areas) and educate consumers about the sustainability of aquaculture products and prices, and the potential environmental benefits of aquaculture. It was thought that increasing public awareness would result in better acceptance and support for aquaculture activity and its derived products. Information

394 regarding the different aspects of aquaculture activities should be made visible and
395 available to support knowledge transfer, exchange of best practices and assist
396 newcomers. Although governments are often criticised for the conflicts that arise
397 between the regulation and promotion of aquaculture, there is no doubt that the
398 promotion of sustainable practices is an important responsibility of government in
399 relation to maritime activities in general, and aquaculture in particular.

400 For off-the-coast aquaculture, visualisation tools combining all available information
401 should be shared among stakeholders and could be used for site identification and
402 selection. Additional tools such as production models to estimate potential biomass
403 yield in identified areas would provide powerful predictors of successful siting. Such
404 tools would also be valuable for environmental impact assessments including potential
405 disease outbreaks. Moreover, these tools can be integrated within more comprehensive
406 planning instruments, but their use requires up-to-date and available data. Hence, the
407 promotion of regional programmes for environmental monitoring, as well as the need to
408 improve and update the monitoring regulations, are matters of importance to
409 stakeholders. Tools are not seen as being permanent in many cases, particularly if they
410 have been developed within the framework of research projects which are time-limited;
411 and thus, a long-term strategy for their maintenance is essential.

412 Production also needs diversification based on consumers' expectations, and
413 productivity needs to be enhanced for higher cost-benefit efficiency. Economic and
414 market needs could be addressed by improving the price competitiveness with imports
415 and the post-harvest value chain, as well as the adoption of measures to increase
416 business certainty. Stakeholders reported that such measures would improve the sector's
417 performance and market competitiveness. Some stakeholders highlighted the need to
418 impose duties for imported products in cases where it is known that their production has
419 involved low environmental, consumer or hygiene standards. Finally, enlarging farms
420 would result in benefits associated with economies of scale.

421 **3.3. Recommendations on how to enhance aquaculture expansion**

422 A total of 34 recommendations were reported. The variety of types of recommendations
423 increases from coastal (1), to off-the-coast (3) and offshore (8) (Table 4), due to the
424 need of increasing developments and implementations on those areas. Most cited
425 recommendations (54%) were related to the adoption of measures for overcoming issues

with other sectors, policy and management (32%), and economy and market (14%) (Figure A.2, in Appendix).

The standardisation and simplification of regulatory frameworks and authorisation procedures, *i.e.* management and planning options, was highly recommended, especially for off-the-coast and offshore areas. This would reduce the time and cost of establishing new aquaculture operations and reduce uncertainty for investors. Therefore, the development of common criteria and standards in legislation, as well as clearly defined guidance for aquaculture zoning was recommended. Regular compliance reviews and clearly defined lease periods were also suggested.

Governance should be improved between administrative authorities and the private sector, and an intermediary organization between private and public sectors would be beneficial to avoid potential conflicts with other users. Analysing potential synergies with other marine uses, such as offshore wind farms, was strongly recommended. Economic impact assessment studies were suggested to allow compensatory measures when aquaculture is not compatible with other activities. The most frequently cited example was competition between fishing activity and the establishment of aquaculture.

Management plans should consider adequate evidence-based buffer zones between adjacent farms to prevent spread of disease, food depletion and consequent decrease in or collapse of production. Another suggested management measure was the allocation of sites for extensive longline production of bivalves, which is expected to have low environmental impact, and the bordering of these sites with strictly protected areas (no-take areas) as a way of limiting fishing access.

A participatory process should be adopted to facilitate meaningful and productive stakeholder engagement, with more involvement from local communities in identifying opportunities for aquaculture, especially in off-the-coast and offshore locations. It was reported that the licensing authorities often merely perform public consultation to fulfil legal requirements and do not undertake the sort of stakeholder engagement that would ensure success. The process of participation must be transparent, and the results should be shared with other marine sectors. More actions to promote aquaculture and increase its local acceptance (social licence) were also recommended. Public perception of aquaculture activities should be improved, as well as public awareness of different aquaculture types. A code of conduct including best practice guidelines for aquaculture

operations should be developed. Staff training should be guaranteed and promoted by government and industry, and research results should be widely disseminated, including to the general public. Further development and implementation of tools, especially those that are ecosystem-based in offshore areas, were recommended to optimise the use of space based on regional hydrodynamics and carrying capacity. However, it was emphasised that tools should be simple and web-based; which is not always possible for complex modelling tools.

4. Discussion

Recent studies suggest that there is enough space worldwide with suitable conditions to increase aquaculture production in most coastal regions and especially in off-the-coast and offshore areas (Gentry *et al.*, 2017; Oyinlola *et al.*, 2018; Weiss *et al.*, 2018). Nevertheless, aquaculture production is growing at a slower rate than expected, meaning that there are other factors limiting its expansion, especially offshore. Therefore, more evidence-based data are needed to determine the status of the aquaculture industry and to provide more effective management practices and recommendations (Fox *et al.*, 2019).

In this study, we have presented the results of a comprehensive and global stakeholder consultation process that aimed to identify current obstacles and future requirements for the expansion of marine aquaculture. These results show a surprisingly high level of commonality among study sites in relation to the identified issues independent of region, management context, production volume or cultivation system, but with some gradient from coastal areas to off-the-coast and offshore areas, due to the different requirements and stages of development. This enables the identification of conclusions, needs and recommendations for future spatial management and governance strategies of marine aquaculture in those three areas, and provides valuable information for the practical implementation of an ecosystem-based approach to MSP (EB-MSP) (Ansong *et al.*, 2017; Katsanevakis *et al.*, 2011; Stelzenmüller *et al.*, 2013) and EAA (FAO, 2010; Soto *et al.*, 2008).

Our work provides an overview of the stakeholder perspectives necessary to facilitate a more robust MSP process in coastal and offshore areas (Ritchie and Ellis, 2010). We have highlighted relevant issues and useful recommendations, contributing to the ongoing discussion of best practices for the implementation of EAA and MSP and the

strategic objectives of increased activities that contribute to the Blue Growth agenda (EC, 2018). With more competition for marine space than ever before, it is difficult to determine priorities, especially where there are already established activities that are culturally or economically significant (such as fishing and tourism). Moreover, new problems and needs are arising as the aquaculture sector moves into off-the-coast and offshore areas. The adoption of best management options needs to consider the different perspectives regarding the performance of each activity in each of the three areas investigated (i.e. coastal, off-the-coast and offshore). To achieve this, closer links across sectors, including industry, scientists, managers and administrators, and society, are required to understand the issues experienced by each industry, as well as the options for optimal management. Thus, stakeholders considered should include those from organizations that are part of the aquaculture industry, its supply and processing chains; public bodies that plan and regulate the activity; competing sectors; those with concerns for the natural environment (including civil society and environmental regulators) and those who study aspects of social-ecological systems in which aquaculture takes place.

The lack of a directly applicable tool to assist with the MSP process is one of the major obstacles identified (Flannery *et al.*, 2019). Several consulted stakeholders acknowledged the MSP framework as an opportunity to allow for the coexistence of aquaculture with other uses of the sea, recognising the rights of other users and the need for integrated management. This, in turn relates to the adoption of measures for resolving historical conflicts of aquaculture with other users (Coccoli *et al.*, 2018). Sectoral conflict has been described as stemming from competing uses of coastal resources and institutional failures (Douvere and Ehler, 2009). The outcomes of the participation process indicate that the aquaculture sector is aware that the space available for marine activities is finite, and that spatial planning could be a means to alleviate negative public perception about the environmental impacts of aquaculture, especially those associated with marine fish farming, and access to and use of coastal resources.

In the implementation of MSP, stakeholder engagement is most productive when it includes consultation and deliberation. Our results support the development of spatial plans that consider biophysical interactions amongst all relevant sectors. However, more participatory processes might need to be developed when formulating and applying these policies to better integrate the needs and knowledge of all stakeholders (see

Section 3.3). To ascertain what management measures are required for MSP, maritime sectors operating in the same space need to be transparent about their concerns, needs, interests and strategies. The implications of the issues and their relevance, as well as the capacity to overcome limitations, need to be thoroughly considered when spatial management plans are being developed. It is recognized that transparency can help gain social license, improve public perception, and reduce conflict between users (Gunningham *et al.*, 2004). Two factors that could hinder informed discussion and decisions about aquaculture are the lack of applicable knowledge, and issues associated with local development. Better communication and investigation of the real *versus* perceived impacts of aquaculture could aid in clarifying the debate about aquaculture and help support future sustainable growth (Froehlich *et al.*, 2017). Thus, our study revealed that public participation and informative decision making vary considerably in MSP processes across the study sites. Globally there are major differences among countries regarding the emphasis placed on stakeholder participation, due to different political systems and traditions.

Spatial plans that have included stakeholder engagement in their development will not automatically overcome the social causes of sectoral conflicts, such as those arising from fisheries claims to a pre-existing right to use a sea area even if that area might be better used for aquaculture (Gimpel *et al.*, 2018a). In fact, stakeholder deliberation, if it takes place in conditions suitable for 'communicative action' (Habermas, 1984), provides several benefits that cannot be obtained from consultation alone. As a minimum, it can lead to a better understanding of the vision and priorities for each conflicting sector. In some cases, this can lead to improved outcomes, in which sectors working together find a mutually beneficial solution that is more than simply sharing space (Billing *et al.*, 2017; Franzén *et al.*, 2011). The deliberative process can also serve as a method for feeding scientific results into the development of public policy.

The environmental issues identified summarise the general concerns within the aquaculture industry: there is too little space available in coastal waters with the requisite of environmental quality and carrying capacity appropriate for the cultivation of each kind of organism. This concern is intensified where there is a need for biosecurity such as the need for appropriate spacing between farms. Such issues are especially relevant in coastal and off-the-coast aquaculture, as they reduce the area suitable for aquaculture (Gentry *et al.*, 2017; Oyinlola *et al.*, 2018; Weiss *et al.*, 2018).

The need for tools, such as circulation models for prediction of oceanographic conditions (specially to predict how harmful algal blooms or disease vectors can be transported) and estimates of environmental and climate change risk potential, and environmental carrying capacity were highlighted. Despite good representation of industry stakeholders within the workshops, environmental issues had relatively little prominence and thus may be considered of less concern than issues relating to the expansion of the industry. The aquaculture sector is aware and recognizes the need to minimize negative environmental effects as these can ultimately also affect their production capacity. Moreover, they understand the social aspect where 'clean' aquaculture activities will be more accepted by the public than activities that are shown to cause detrimental environmental impacts.

The need for tools to identify suitable sites, for off-the-coast and offshore aquaculture development were highlighted. Spatial planning support tools can facilitate site selection processes (Gimpel *et al.*, 2018a; Pınarbaşı *et al.*, 2019; Pınarbaşı *et al.*, 2017), and EB-MSP is the main framework that will assist in overcoming obstacles to aquaculture expansion. Aspects of planning include mapping of fisheries grounds, critical habitat for wild species, and closed areas (sanitation). Such a framework serves multiple resource users simultaneously, avoiding isolated plan for aquaculture activities that might not be viable. The results obtained from this participation process show that engaging stakeholders can highlight sector-specific issues, acting as a compass for research and for implementing solutions that are mutually agreeable to stakeholders. This means that the scale and method to address each problem (or interlinking problems) can be established and can inform discussions with wider stakeholder groups and communities of interest. The participatory framework implemented here can be applied to each maritime sector individually and, comparing the results across the sectors, has the potential to provide a clear way to identify shared issues or those that relevant to a specific few or unique to individual cases.

5. Conclusions

Our work provides significant insights and enhances our knowledge of the views and perceptions of relevant stakeholders to inform EB-MSP of aquaculture in coastal, off-the-coast and offshore waters. In this context, it is timely to consider the issues and recommendations from the aquaculture sector if expansion is going to be promoted

offshore and management plans are to be developed and implemented to support such growth. Additionally, cross-sectoral integration of the aquaculture industry with other maritime activities, especially those predicted to increase, such as renewables and tourism, must be taken into consideration. EB-MSP is seen as an opportunity to establish transparent procedures and licensing processes that would make the development pathway shorter and reduce the uncertainties and costs associated with establishing new aquaculture activities. EB-MSP would also reduce conflicts with other user activities, in the gradient from coastal to offshore areas.

According to our results, the issues hindering aquaculture growth seem to be mostly related to conflicts with the use of marine space and the implementation of existing policies and legislation. The aquaculture sector is aware of the need to implement the ecosystem approach as a way of promoting sustainable aquaculture development and improving its social perception, and stakeholders recognize the need to improve communication with other maritime sectors and civil society in order to minimize conflicts. The diversity and number of participants at each workshop provides evidence of the known benefits of participating in events aiming to contribute solutions or to knowledge acquisition.

The stakeholder consultations reported here were mostly focused on the aquaculture sector, although a robust EB-MSP process should consider all maritime sectors and interest groups by identifying their visions via a bottom-up approach. Our outcomes highlight the main issues that need to be tackled by management bodies if aquaculture industry is to expand. The same consultation process should be replicated for each of the sectors operating in the marine realm, and the resulting information made available to all sectors. Bringing together results from multi-sectoral stakeholder engagement would guarantee the representation of multiple perspectives. The consultation process would contribute to the development of a common understanding and assist in reaching agreement and common solutions, which in turn, would enhance the legitimacy of public policy decisions to be adopted within EB-MSP framework.

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7. Tables

Table 1. Summary of the 16 study sites where general context for aquaculture was defined. Aquaculture categories: Coastal: <0.5 km from shore (center of licensed area) and <10 m depth; Off-the-coast: 0.5-2 km and 10-50 m depth; Offshore: >2 km and >50 m depth (after Lovatelli *et al*., 2013). EAA: Ecosystem Approach to Aquaculture. See Figure 2 for study sites geographical locations.

STUDY SITE	COUNTRY	STUDY SITE AREA (km^2)	LICENSED AQUACULTURE AREA (km^2)	CULTIVATION ENVIRONMENT	AQUACULTURE CATEGORY	CULTIVATED SPECIES	DEPTH (m)	DISTANCE FROM SHORE (km)	DISTANCE TO THE NEAREST POPULATED SITE (km)	AQUACULTURE SPATIAL MANAGEMENT IN PLACE	EAA IMPLEMENTATION STATUS
01. Emilia-Romagna, Adriatic Sea	Italy	1561	50	Open sea	Off-the-coast	Mediterranean mussel, Pacific oyster	10-15	<6	<6	In progress†	Partially§
02. Algarve Coast	Portugal	Not defined (cover a large area of the Algarve coast)	$30km^2$	Open sea	Off-the-coast	Clam, Mediterranean mussel	17-27	1.85	3-5	Pilot plan	Partially§
03. Basque Country	Spain	1024	5.7	Open sea	Offshore	Mediterranean mussel	30-45	0.750-7.50	3-7	In progress†	Partially§
04. Carlingford Lough	Ireland – UK*	49	2.4 (+9.3 subtidal area)	Fjord/Sea loch	Off-the-coast	Pacific oyster, Blue mussel	2-5	0.1-2	7	In progress†	Partially§
05.Great Bay, Piscataqua	USA	54.7	0.1	Estuary	Coastal	Eastern oyster	4	?	?	Partially‡	Yes
06. Houtman Abrolhos Islands	Australia	2500	30	Open sea	Offshore	Yellowtail kingfish	37.5	65	65	Partially‡	Partially§
07. Long Island Sound	USA	3259	267	Estuary	Off-the-coast	Eastern oyster, Quahog clam	20	6	<30	Partially‡	Yes
08. Mediterranean Sea Multinational	Multinational	2500000	*ca*. 3.6	Open sea	Offshore	Gilthead seabream, European seabass, Atlantic bluefin tuna	28	900	900	Partially‡	Partially§
09. Normandy/Cancale	France	20000 (including inland and marine zones)	*ca*. 65	Open sea/Bay	Coastal	Pacific oyster, Blue mussel, Atlantic salmon	<4	<7	<15	In progress†	Partially§
10. North Sea	Germany	28600	33	Open sea	Offshore	Blue mussel. European seabass	22-45	81-245	30-142	Yes	Partially§
11. Norwegian Coast	Norway	76000	40 (in 2011)	Fjord	Coastal	Atlantic salmon, Rainbow trout	50-300	0.1	1-10	Partially‡	Partially§
12. Nova Scotia Bays	Canada	75	3	Estuary	Off-the-coast	Atlantic salmon	20	1	1.5	Yes	Yes
13. Sanggou Bay	China	133	99	Bay	Off-the-coast	Kelp, Pacific oyster, Scallop, Abalone, sea bass, sea cucumber	8	1	1	Partially‡	Partially§
14. Argyll	Scotland	9890	8.6	Fjord/Sea loch	Off-the-coast	Atlantic salmon, Rainbow trout, Blue mussel, Pacific oyster, Native oyster, Queen scallop, King Scallop, Seaweed	10-50	0.05-2	1-10	In progress†	Yes
15. Zhangzidao Island	China	1600	1600	Open sea	Off-the-coast	Scallop, sea cucumber, abalone	25	5	5	Yes	Partially§
16. Pelorus Sound	New Zealand	750	25	Estuary	Off-the-coast	Greenshell mussel, Chinook salmon, Pacific oyster	10-35	0.1-1	10	Partially‡	Partially§

† Marine spatial plan (MSP) or spatial management for aquaculture at the implementation stage.
‡ Aquaculture management, which considers the spatial component, is in place.
§ The EAA is not mentioned in the management plans but some parts of the management could be considered as equivalent to particular stages of the EAA.
* Only the UK part of Carlingford Lough was studied in AquaSpace.

Table 2. Number of issues (and percentages of the total of issues), according to issue type and aquaculture category.

Type of issue	Coastal	Off-the-coast	Offshore	Mediterranean region stakeholder workshop*	Total
Economic / Market	1 (25%)	7 (16%)	10 (22%)	6 (13%)	**24 (17.3%)**
Environmental	1 (25%)	14 (32%)	12 (27%)	7 (15%)	**34 (24.5%)**
Other sectors	1 (25%)	12 (27%)	8 (18%)	6 (13%)	**27 (19.4%)**
Policy / Management	1 (25%)	11 (25%)	15 (33%)	27 (59%)	**54 (38.8%)**
Total	**4 (100%)**	**44 (100%)**	**45 (100%)**	**46 (100%)**	**139 (100%)**

* It was not possible to classify the issues according to aquaculture category since the information was aggregated.

862 Table 3. Requirements for aquaculture expansion by aquaculture category.

Requirements	Aquaculture category			Total
	Coastal	Off-the-coast	Offshore	
Management and planning - marine policies	1	8	3	12
Technological	1	9	2	12
Improved administrative procedures / licensing	1	3	5	9
Environmental research	2	6		8
Promotion		2	4	6
Monitoring		2	1	3
Tool/models/methods		3		3
Activity management		3		3
Social acceptability and lincese	1	1		2
Economic and market			1	1
Legislation		1		1
Total number of requirements reported	**6**	**38**	**16**	**60**
Total number of different types of requirements	**5**	**10**	**6**	**11**

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864 Table 4. Recommendations on how to enhance aquaculture expansion according to
865 aquaculture category.

Type of recommendation	Aquaculture category			Total
	Coastal	Off-the-coast	Offshore	
Management and planning		8	4	12
Promotion		4	2	6
Stakeholders engagement		4	2	6
Economic and market			4	4
Networking, cooperation and communication	1		2	3
Administrative procedures / licensing			1	1
Monitoring			1	1
Tools			1	1
Total number of recommendations reported	**1**	**16**	**17**	**34**
Total number of different types of recommendation	**1**	**3**	**8**	**8**

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8. Figure legends

Figure 1. Stakeholder engagement process adopted in each of the 16 study sites. NGO: Non-governmental organisation.

Figure 2. Geographical location of the 16 study sites and main production.

Figure 3. Most frequently reported obstacles for aquaculture growth and expansion (A) and corresponding dimensions (B) by stakeholders.

9. Appendix

Table A.1. Summary of workshop details at each study site including total number of workshops held, number of participants and type of stakeholders involved in the workshops. I: Industry; P: Promoter; G: Government; M: Manager; PM: Policy maker; R: Research; C: Conservation and NGOs; O: Other (e.g. education, fisheries association).

Study sites	**Number of workshops**	**Stakeholder type**					**Total number of attendees**
		I/P	**G/M/PM**	**R**	**C**	**O**	
01. Shellfish culture in Emilia-Romagna, Adriatic Sea	1	19	18	10			**47**
02. Algarve Coast	5	18	17	12			**47**
03. Basque Country	2	14	16	6	3	5	**44**
04. Carlingford Lough	Delayed†						**0**
05. Great Bay, Piscataqua	1 workshop + phone call dialogue	60	3	14		2	**79**
06. Houtman Abrolhos Islands	5 meetings + 12 interactions/dialogues	1	8	3		2	**14**
07. Long Island Sound	Phone call dialogue	1	1	14		8	**24**
8. Mediterranean Sea Multinational	1	1	4	8			**13**
9. Normandy/Cancale	2	12	14	18	8	3	**55**
10. North Sea	1	5	6	8	3		**22**
11. Norwegian Coast	3	10	13	44	13		**80**
12. Nova Scotia Bays	2	4	2	4	1		**11**
13. Sanggou Bay, China	3	23	3	38			**64**
14. Argyll, Scotland	1	8	5	9		3	**25**
15. Zhangzidao Island	1	5	1	22			**28**
16. Pelorus Sound	1						**0**
Mediterranean region stakeholder workshop	1	20	26	15			**61**
TOTAL	**43**	**201**	**137**	**225**	**28**	**23**	**614**

†Due to ongoing issues with active license applications within Carlingford Lough it was not possible to conduct a local stakeholder workshop within the timeframe of the AquaSpace project.

887 Table A.2. Main obstacles for aquaculture growth and expansion according to aquaculture category.

Type of obstacle	Issue	Coastal	Off-the-coast	Offshore	Mediterranean region stakeholder workshop*	Total
Policy / Management	Administrative procedures / licensing		5	4	8	17
	Management and planning	1	3	4	3	11
	Regulation		2	3	3	8
	Promotion				3	3
	Lack of adaptative management				2	2
	Environmental monitoring			2		2
	Stakeholder communication and participation			1	1	2
	Aquaculture performance				1	1
	Data collection and management				1	1
	Different roles of management authorities			1		1
	Lack of expertise				1	1
	Lack of funding for statutory agencies – regulatory capacity				1	1
	Lack of insurance		1			1
	Need for cooperation within aquaculture sector				1	1
	Need for innovation				1	1
	Need for promotion				1	1
Environmental	Environmental carrying capacity		4	3		7
	Disease exposure and connectivity	1	2	2	1	6
	Environmental impact				5	5
	Environmental status for production		3	1	1	5
	Harmful Algal Blooms		2	1		3
	Low diversity of cultivated species			2		2
	Environmental risk potential			1		1
	Climate change effects on production		1			1

Type of obstacle	Issue	Coastal	Off-the-coast	Offshore	Mediterranean region stakeholder workshop*	Total
	Extreme events		1			1
	Need for tools to assess suitability			1		1
	Need to identify new suitable sites			1		1
	Oceanographic conditions predictions		1			1
Other sectors	Conflicts with other users	1	11	6	3	21
	Need for social acceptability		1	1		2
	Visual impact				2	2
	Definition of best principles of operation			1		1
	Lack of an intermediary organization for private and public sectors				1	1
Economic / Market	Production cost	1	1	2	2	6
	Market competitiveness		2	1	2	5
	Stability and reliability of production systems		2	1		3
	Lack or high distance to logistic infraestructures		1	1		2
	Market studies			1	1	2
	Consumer demands		1			1
	Economic depression			1		1
	Market stability			1		1
	Product quality and eco-aware			1		1
	Public perception				1	1
	War conflicts			1		1
Total number of reported obstacles		**4**	**44**	**45**	**46**	**139**
Total number of different types of obstacles		**4**	**18**	**26**	**23**	**44**

888 * It was not possible to classify the issues according to aquaculture category since the information was aggregated.

889 Figure A.1. Most frequently reported needs by stakeholders (A) and their proportions
890 (B).
891 Figure A.2. Most frequently reported recommendations reported by stakeholders (A)
892 and their proportions (B).
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