Chapter 6
Aquaculture Site-Selection and Marine Spatial Planning: The Roles of GIS-Based Tools and Models

Vanessa Stelzenmüller, A. Gimpel, M. Gopnik and K. Gee

Abstract Around the globe, increasing human activities in coastal and offshore waters have created complex conflicts between different sectors competing for space and between the use and conservation of ocean resources. Like other users, aquaculture proponents evaluate potential offshore sites based primarily on their biological suitability, technical feasibility, and cost considerations. Recently, Marine Spatial Planning (MSP) has been promoted as an approach for achieving more ecosystem-based marine management, with a focus on balancing multiple management objectives in a holistic way. Both industry-specific and multiple-use planners all rely heavily on spatially-referenced data, Geographic Information System (GIS)-based analytical tools, and Decision Support Systems (DSS) to explore a range of options and assess their costs and benefits. Although ecological factors can currently be assessed fairly comprehensively, better tools are needed to evaluate and incorporate the economic and social considerations that will also be critical to identifying potential sites and achieving successful marine plans. This section highlights the advances in GIS-based DSS in relation to their capability for aquaculture site selection and their integration into multiple-use MSP. A special case of multiple-use planning—the potential co-location of offshore wind energy and aquaculture—is also discussed, including an example in the German EEZ of the North Sea.

V. Stelzenmüller (✉) · A. Gimpel
Thünen-Institute of Sea Fisheries, Palmaille 9, 22767 Hamburg, Germany
e-mail: vanessa.stelzenmueller@thuenen.de

M. Gopnik
Independent Consultant, Washington DC, USA

K. Gee
Helmholtz Zentrum Geesthacht, Max-Planck-Str. 1, 21502 Geesthacht, Germany

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6.1 Reconciling Ocean Uses Through Marine Spatial Planning

The last decades have witnessed an unprecedented race between different sectors for access to the sea. With interests such as offshore renewable energy, sand and gravel extraction, national security, fishing, and nature conservation all pushing for more space, exclusive uses of marine areas are being replaced by a search for more integrated solutions (Halpern et al. 2008b; Katsanevakis et al. 2011). Marine Spatial Planning (MSP) has been widely advocated as one such place-based, integrated tool for managing human activities in the marine environment (Douvere 2008; Douvere and Ehler 2010; Collie et al. 2013).

A key challenge for MSP is to make spatial choices that strike a balance between multiple ecological, economic and social objectives, typically identified through a political process (Katsanevakis et al. 2011; Jay et al. 2012; Carneiro 2013; Foley et al. 2013). Regardless of the governance framework present, or specific process selected, sustainable spatial planning should account for the cumulative effects of all human activities on the marine environment at meaningful ecological scales (Halpern et al. 2008a; Stelzenmüller et al. 2010). Tradeoff analyses using, for instance, explicit weighting criteria can improve transparency in decision-making and should form a crucial part of any MSP process (White et al. 2012; Stelzenmüller et al. 2014). These analyses should focus not only on economic and ecological values, but also on social and cultural values associated with coastal communities and the sea, many of which are extremely difficult to measure (Gee and Burkhard 2010).

A recent EU Directive (EPC 2014a); (Article 3) describes MSP as a cross-cutting policy tool, enabling public authorities and stakeholders to apply a coordinated, integrated, and trans-boundary approach "to promote sustainable development and to identify the utilization of maritime space for different sea uses as well as to manage spatial uses and conflicts in marine areas." The Directive specifically encourages nations to explore multi-purpose uses in accordance with relevant national policies and legislation, and encourages Member States to cooperate in the sustainable development of offshore energy, maritime transport, fisheries, and aquaculture. Nevertheless, existing MSP initiatives show that spatial planning remains open to very diverse interpretations.

Although they do consider multiple maritime uses, early marine spatial plans within the EU, such as the German plan for the EEZ, were often driven by specific sectoral needs (Halpern et al. 2012; Collie et al. 2013; Olsen et al. 2014), often reflecting changing political priorities, shifting prioritization among sectors, or technological advances. This has been particularly apparent with regard to the desired expansion of offshore renewable energy (Gimpel et al. 2013; Christie et al. 2014; Davies et al. 2014). Different ideas about how to *implement* MSP have also emerged. Some marine spatial plans (e.g. in the UK) favor a broad, strategic approach that sets out general guidelines for the use of sea areas, while others (e.g. in Germany) are based on more detailed zoning, creating areas that favor a particular use and other areas where certain uses are prohibited (Schultz-Zehden and Gee 2013, Jay and Gee 2014). As MSP develops from isolated initiatives and projects into statutory plans, broad strategic planning and the concept of co-location or multiple-uses of marine offshore areas are set to become more and more significant (Buck et al. 2004).

6.2 Potential Benefits of MSP to Aquaculture

Effective spatial management is being recognized as one avenue for advancing sustainable aquaculture development worldwide. Europe, keen to encourage growth in the aquaculture sector, has published Strategic Guidelines that identify improved access to space as one of four priority areas to be tackled (EPC 2014b). In the Baltic region, even countries without existing aquaculture facilities are expected to consider future operations as part of their emerging marine spatial plans (project 2013). The Finnish regional fisheries administration prepared regional aquaculture site selection plans that identify offshore areas where existing production can be concentrated and new production begun, using a participative process and Geographic Information System (GIS) mapping as a supporting tool (Olofsson and Andersson 2014).

Although aquaculture is usually mentioned in reports on Integrated Coastal Zone Management (ICZM) and MSP, they rarely focus specifically on aquaculture siting because of their multiple use orientation (Olofsson and Andersson 2014). The English East Inshore and East Offshore Marine Plans (Government 2014) do identify a range of "optimum sites of aquaculture potential" where other uses would be restricted to preserve the potential for aquaculture development. In Germany, the 2014 draft spatial plan for Mecklenburg-Western Pomerania also calls for "spatially compatible" siting of aquaculture operations to minimize environmental impacts (MEIL; Ministerium für Energie 2014).

After initial hesitation in many countries, fisheries and aquaculture stakeholders are now becoming actively engaged in MSP to secure the most suitable sites for their activities (Jentoft and Knol 2014). MSP is also seen as a possible means of resolving animal welfare issues (e.g. assessing maximum carrying capacities) which can help improve public acceptance of the sector (Bryde 2011). These considerations apply not only to existing types of aquaculture operations, but also to future trends such as large offshore installations, potentially combined with offshore wind farming, and specialized production, such as sturgeon, feed production, nutrient removal, and energy production from micro and macro algae (Wenblad 2014). While it could be argued that other place-based approaches to aquaculture siting and management might deliver similar benefits, statutory MSP brings certain strategic advantages.

To start, MSP brings a more coordinated approach to overall sea use, promising greater accountability and transparency of decision-making by including a wide range of stakeholders from all sectors. It may also increase the effectiveness of investments, reduce duplication of effort, and speed up decision-making

(FAO 2013). For example, designating appropriate aquaculture areas and then linking these areas to streamlined licensing procedures could render development less uncertain and increase investor interest (EC 2013). As a strategic tool, MSP can allocate space for aquaculture at sites with both favorable operational characteristics (economic and ecological) as well as lower potential for conflict with other sectors (FAO 2013). MSP would also allow for more structured consideration of co-location of different uses, such as aquaculture taking place around offshore wind structures, providing both a venue for the respective stakeholders to come together and a greater incentive for investment. Hence, the most important reason for aquaculture proponents to engage fully in MSP may be its emphasis on cross-sectoral dialogue and conflict resolution. A well-run MSP process can turn aquaculture from a relatively minor player in a very large debate to an equal participant at the table, able to explain and advocate for its requirements for space at sea (project 2013). The value of open, fair dialogue is particularly relevant in interactions with the environmental sector, but also in considering other uses that might restrict or conflict with aquaculture operations. A 2006 report that examined the suitability of co-locating aquaculture and offshore wind farms in the UK found that the offshore wind energy sector would resist such efforts and concluded that MSP, accompanied by semi-commercial trials, was the only viable way forward for this type of co-use in the UK (Mee 2006).

6.3 Decision Support Systems for MSP and Aquaculture Siting

The EU MSP Directive stipulates that maritime spatial plans should be based on reliable data and encourages Member States to share information and make use of existing instruments and tools for data collection (EPC 2014a); (Article 19). Given the spatial context of MSP, applications to scale economic, environmental, and social dimensions geographically are in high demand (Kapetsky et al. 2013). Spatial data are commonly handled in GIS that make it possible to translate many workflows into a connected series of process steps (Stelzenmüller et al. 2012). Thus, from a practical perspective, sustainable MSP requires not only spatially explicit information about suitable areas but also a sound spatial assessment of the overlap of human activities (Stelzenmüller et al. 2012) and their combined impact on the marine environment (Kelly et al. 2014). Even more challenging, the identification of a suitable site for a given use does not just depend on physical, chemical and biological factors, but also on political, economic, and social criteria (Wever et al. 2015).

As a result of these challenges, flexible Decision Support Systems (DSS) that are able to consider complex interactions in a unique analytical framework are critical. DSS can be distinguished based on their relative focus on data, models, knowledge, or communication (Power 2003). Current DSS can range from simple spreadsheet models to complex software packages (Bagstad et al. 2013). One example of a DSS for use in MSP is MIMES (Multi-scale Integrated Models of Ecosystem Services), which uses GIS data to simulate ecosystem components under different scenarios defined by stakeholder input. It features a suite of models to support MSP decision making (www.afordablefutures.com/services/mimes). Further, the MMC (Multipurpose Marine Cadastre) is an integrated, online marine information system for viewing and accessing authoritative legal, physical, ecological, and cultural information in a common GIS framework (www.marinecadastre.gov). Another example is MaRS (Marine Resource System), which is a GIS-based DSS designed to enhance marine resource analysis and ultimately identify areas with potential for development in UK waters by The Crown Estate (www.thecrownestate.co.uk/mars-portal-notice). It assists in identifying areas of opportunity and constraint, by identifying how different activities would interact in a particular area and providing statistics showing the value of the area to a competing industry.

6.3.1 The Importance of Spatial Data in the Planning Process

In general, GIS-based data and robust spatial analyses help collate and harmonize data for use at different stages of the planning process (Jay and Gee 2014; Shucksmith et al. 2014), including scoping, development, and evaluation of planning options (Stelzenmüller et al. 2010, 2013a). The use of GIS to support aquaculture development and planning has a long tradition (Kapetsky et al. 1990) and the identification of suitable sites for aquaculture has been among the most frequent applications of GIS (Fisher and Rahel 2004). In recent years, the use and relevance of spatial data in supporting informed decision making in MSP has been increasingly demonstrated (Caldow et al. 2015). For instance, the development of GIS data layers to inform MSP includes: the mapping of sensitivity of seabirds to offshore wind farms (Bradbury et al. 2014); the assessment of potential whale interactions with shipping (Petruny et al. 2014); the mapping of offshore (Campbell et al. 2014) and inshore (Breen et al. 2015) fishing activity; or the mapping of ethnographic information (Sullivan et al. 2015). Decision makers and planners are most likely to require spatial data layers at the development stage of a MSP process, enabling them to explore the data, and develop and evaluate planning scenarios (Stelzenmüller et al. 2012).

6.3.2 DSS for Aquaculture Siting

The combination of DSS into one GIS-based system that can support sustainable aquaculture development has been identified as an important future need (Ferreira et al. 2012; Filgueira et al. 2014). Suitability modeling refers to the spatial overlay of geo-data layers to identify suitable aquaculture sites by identifying, for instance, favorable environmental factors or constraints. Such studies can determine the suitability for aquaculture development at various intensities (Longdill et al. 2008) or can distinguish suitability by type of aquaculture cage (Falconer et al. 2013).

GIS-based suitability modeling is one of the most frequent DSS applications used to evaluate potential aquaculture sites. The first applications of these techniques date back to 1985 when the siting of aquaculture and inland fisheries using GIS and remote sensing was conducted by the FAO. Until the mid-1990s, most studies continued to target data-rich, small-scale environments (Gifford et al. 2001). Early studies looked primarily at coastal or land-based aquaculture related to oysters (shellfish) and shrimps and by using simple siting models (Fisher and Rahel 2004). The main drawback of applying suitability models in offshore environments was a lack of fine-scale data with the necessary temporal and spatial resolution (Fisher and Rahel 2004). Since GIS applications and models have become significantly more complex, and the resolution and quality of data has greatly improved (Fisher and Rahel 2004), one might expect the focus to have shifted to offshore areas. However, as yet, the majority of GIS-based site selection efforts are still focused on shrimp aquaculture in coastal areas around Asia, while studies in offshore environments remain rare.

Once spatially resolved data are available, a GIS-based Multi-Criteria Evaluation (GIS-MCE)—also referred to as area weighted rating (Malczewski 2006)—can be used as a flexible and transparent DSS for potential aquaculture siting. Applications of GIS-MCE in offshore areas were undertaken in a study by Perez et al. (2005) in which suitable sites were modelled for offshore floating marine fish cage aquaculture in Tenerife, Canary Islands. The untapped potential of offshore mariculture is addressed in a global assessment wherein all spatial analyses of suitability and constraints were conducted with the help of GIS (Kapetsky et al. 2013).

Recently, the combination of GIS and dynamic models to identify suitable sites, as done by Silva et al. (2011) for shellfish aquaculture, is becoming more popular. Superimposed models such as FARM (Farm Aquaculture Resource Management; www.farmscale.org) aim to support the siting process with detailed analyses of production, socio-economic outputs, and environmental effects (Silva et al. 2011). In Nunes et al. (2011), the implementation of an ecosystem approach to aquaculture has been advanced by testing various complementary analytical tools. The tools were used to assess multiple aspects of blue mussel cultivation in Killary Harbour, Ireland at different spatial scales (farm- to system-level), times (seasonal to annual to long-term analyses) and levels of complexity (from simple to complex process-based modelling). The selected tools included a system-scale, process-based ecological model (EcoWin 2000; www.ecowin2000.com), a local-scale carrying capacity and environmental effects model (FARM), and a management level eutrophication screening model (ASSETS). Further examples of combining different ecosystem tools for decision support for aquaculture is presented in Filgueira et al. (2014).

In terms of advanced, web-based interactive DSSs, AkvaVis includes site selection, carrying capacity, and management monitoring modules (Ervik et al. 2008, 2011). With suitable adaptations, it appears to be a promising tool for estimating offshore aquaculture potential at national levels and for managing its subsequent development. Filgueira et al. (2014) proposed dynamic, fully-spatial modeling, scenario-building, and optimization tools such as PEST (model-independent Parameter ESTimation, www.pesthomepage.org) as an ideal combination of tools for effective MSP. In the context of MSP decision support, other tools such as MaxEnt (Maximum Entropy modelling) or MARXAN have been utilized in combination with GIS to identify trends, opportunities and concerns related to sustainable management and farm locations (http://dspace.stir.ac.uk/handle/1893/19465) or to identify fisheries areas (Schmiedel and Lamp 2012). ARIES (ARtificial Intelligence for Ecosystem Services) assists in mapping service flows of the ecosystem such as aquaculture benefits (ariesonline.org/docs/ARIESModelingGuide1.0.pdf) and InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) enables the user to evaluate how aquaculture can affect production and value of marine ecosystem services (www.naturalcapitalproject.org/models/models.html).

As described in Ferreira et al. (2012), the data requirements for DSS expand with the scale of the aquaculture operation. Thus, it will be challenging to use aquaculture-specific DSS in a broader spatial planning system, such as MSP or ICZM, where a large ecosystem scale is required. Indeed, as might be expected, and as articulated by Gifford et al. (2001), there are no "ideal" sites for aquaculture and compromise will always be required. Fortunately, a range of GIS-based DSS exist already to help to find this compromise and to support MSP using transparent data management and advanced visualization.

Several tools have been developed to help assess conflicts and synergies between fisheries, aquaculture, and other marine sectors and to advance practical applications based on that knowledge (Stelzenmüller et al. 2013b). Given the multiple-use context of many sea areas, the identification of suitable sites for aquaculture will depend on location-specific understanding of conflicts and synergies between various proposed types of sea use. While conflicts should be minimized, the discovery of synergies can help identify areas suitable for co-location (Stelzenmüller et al. 2013b; Griffin et al. 2015).

6.4 The Co-location Scenario: Combining Offshore Wind Energy and Aquaculture

Both English and German marine plans encourage the combination of aquaculture with other uses. In the UK, a strong national policy statement calls for consideration of the "significant opportunities for co-existence of aquaculture and other marine activities" (Government 2011, 3.9.6). The UK's East Inshore and Offshore Marine

Plans also stipulate that co-location opportunities should be maximized wherever possible, and that "proposals for using marine areas should demonstrate the extent to which they will co-exist with other existing or authorized activities and how this will be achieved" (Government 2014, p. 106). Identifying opportunities for, and the technical feasibility of, co-location becomes all the more important for supporting decision-making (Christie et al. 2014; Hooper and Austen 2014).

6.4.1 Co-location as an Opportunity for Spatial Planning?

The co-location of offshore infrastructure and aquaculture has been a particular focus of research (Buck et al. 2004; Lacroix and Pioch 2011; Wever et al. 2015), with "infrastructure" typically referring to offshore wind energy facilities. During the past ten years there has been growing interest among policy makers, scientists, the aquaculture industry, and other stakeholders in implementing pilot studies to demonstrate the feasibility of such co-location. In the southern North Sea and German Bight, the potential co-location of offshore wind and aquaculture has gained momentum due to the allocation of large areas for offshore wind, including approximately 35% of the German EEZ of the North Sea, and the resulting loss of space for other sectors, such as fisheries (Stelzenmüller et al. 2014).

Based on an extensive stakeholder consultation process, Wever et al. (2015) identified future research needs to support implementation of the co-location concept. One of these needs was the development of site-selection criteria that include environmental, economic, socioeconomic, and technological parameters. A recent study by Benassai et al. (2014) used a GIS-MCE DSS to evaluate suitable areas for the co-location of offshore wind and aquaculture at a large spatial scale, using only environmental criteria. At a much finer resolution, Gimpel et al. (2015) assessed the potential for coupling offshore aquaculture and wind farms in the German EEZ of the North Sea based on environmental and infrastructure criteria. In the following section we provide a brief summary of the methods, key criteria, and results of this case study.

6.4.2 Case Study in the German Bight

In order to evaluate different spatial co-location scenarios for the coupling of offshore Integrated Multi-Trophic Aquaculture (IMTA) systems and wind farms, possible aquaculture candidates (seaweed, bivalves, fish and crustaceans) were identified. Those have been selected accounting for their native occurrence in the German North Sea, their resistance to hydrodynamic conditions in offshore environments as well as their economic potential for the EU market. The study area comprised the German EEZ of the North Sea with a surface area of 28.539 km^2 (Fig. 6.1). A vector grid was superimposed to the study area with a grid size

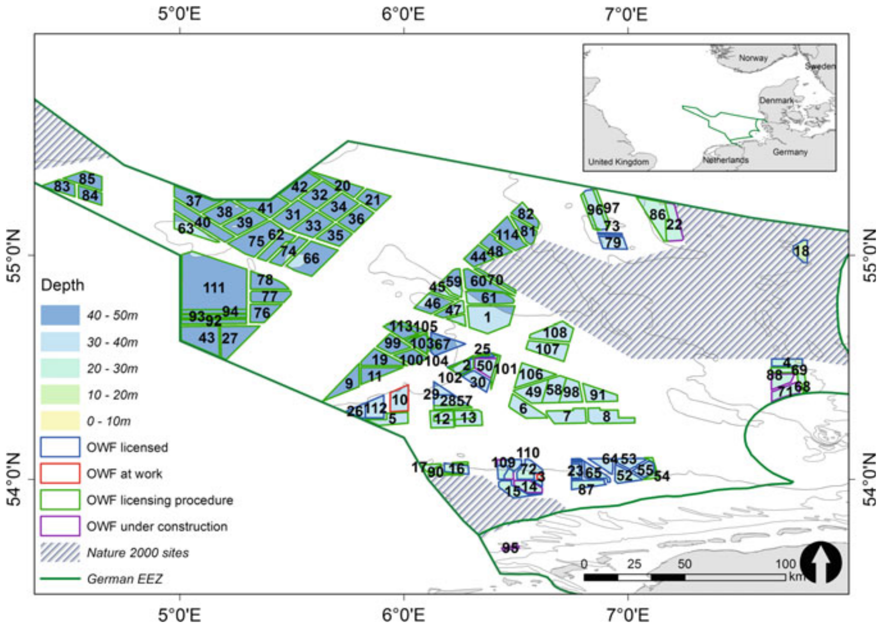

Fig. 6.1 Map of Offshore Wind Farm (OWF) areas in the German EEZ of the North Sea, numbered, coloured per depth level and framed per status. *Shaded* districts show the Nature 2000 areas. Note that depth, the OWF areas (effective from December 2013; BSH) and the Nature 2000 sites constituted a physical constraint applied, limiting suitable sites for co-use with aquaculture. OWF 18, 80 and 95 have not been considered during this study, as they appear within the 12 nm zone or in Nature 2000 sites (redrawn from Gimpel et al. 2015)

resolution of 9.26 km^2. A GIS-MCE technique was applied to index suitable co-sites. In order to provide all criteria needed (Fig. 6.2), hydrographic data were extracted, analysed and interpolated to derive depth stratified mean values per quarter of the year. Further all data were standardised using fuzzy membership functions with control points to guarantee comparability among factors, whereby the choice of function and control points was based on expert knowledge and literature research. With the pairwise comparison method of the Analytical Hierarchy Process (AHP) all factors were weighted by priority for all grid cells. Also a range of weighting designs was modelled using an Ordered Weighted Average (OWA) approach to address the uncertainty in prediction results. If one grid cell appeared to be unsuitable during OWA weighting, it had been excluded from further assessments. The final weighting of the factors was based on expert judgement and focused on the optimal growth under farmed conditions. Using this weighting scheme the GIS-MCE resulted in a series of geo-referenced aquaculture suitability layers comprising the whole German EEZ of the North Sea. In a next step, an offshore co-location suitability index was developed by accounting for overlaps between the aquaculture sites and referenced offshore wind farms provided

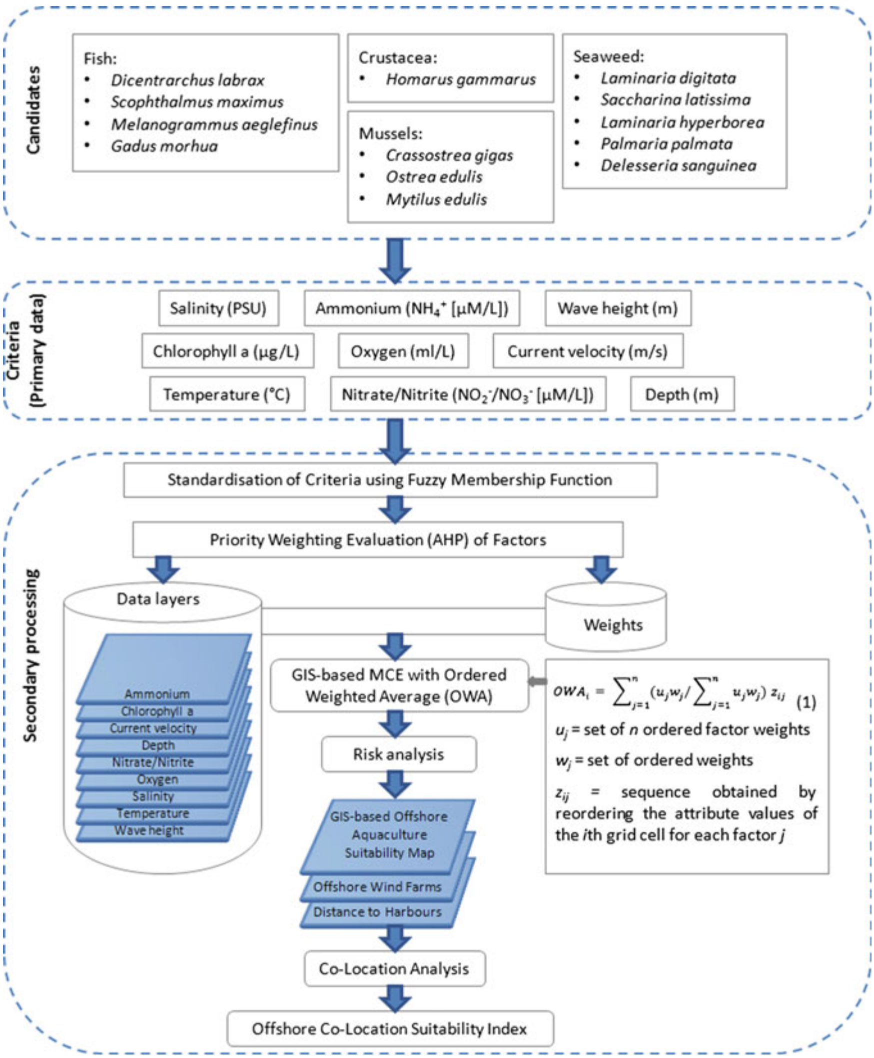

Fig. 6.2 Overall methodological approach used to index potential co-use locations of offshore wind farms in combination with offshore aquaculture, redrawn from (Ouma and Tateishi 2014) (taken from Gimpel et al. 2015)

by the Federal Maritime and Hydrographic Agency (BSH), excluding the wind farms located in existing nature conservation sites or within the German territorial waters (18, 56, 82 and 95). Further, the co-location sites were examined concerning their suitability for IMTA techniques. The overall methodological approach is shown in Fig. 6.2.

While the conditions for fish proved to be highly suitable during summer, the mussels and algae revealed peak suitability in spring. Still, when examining suitable sites at 10–20 m depth for spring, haddock (*Melanogrammus aeglefinus*) showed highest suitability of all aquaculture candidates closest to the coast (Fig. 6.3). Though fish can be cultured offshore the whole year around, but they require a high degree of care (feeding, clearing of cages etc.). Therefore, due to logistic constraints a cultivation approach closer to the coast is preferred. In contrast, oarweed (*Laminaria digitata*) presented the highest suitability scores at wind farm areas located further offshore. When seaweed is seeded elaborately on the rope and transferred at sea at a juvenile stage, holdfasts will not be dislodged and cauloids will not break leading to a resistance to harsh conditions. As they require a very low level of maintenance, a cultivation approach offshore is forthcoming. In general, if seaweed is part of an IMTA approach and also a candidate to be sold on the EU market, it has to be harvested latest by the end of spring. If the seaweed is cultivated within a bioremediation concept and is only used to extract nutrients from the water column, it can be on-site year around.

Results showed several wind farms were de facto suitable sites for IMTA systems combining fish species, bivalves and seaweeds. As Laminaria species (*L. digitata, Laminaria hyperborea*) cultured near fish farms bring along better growth rates, a candidate set of Oarweed (*L. digitata*), Pacific oyster (*Crassostrea gigas*)

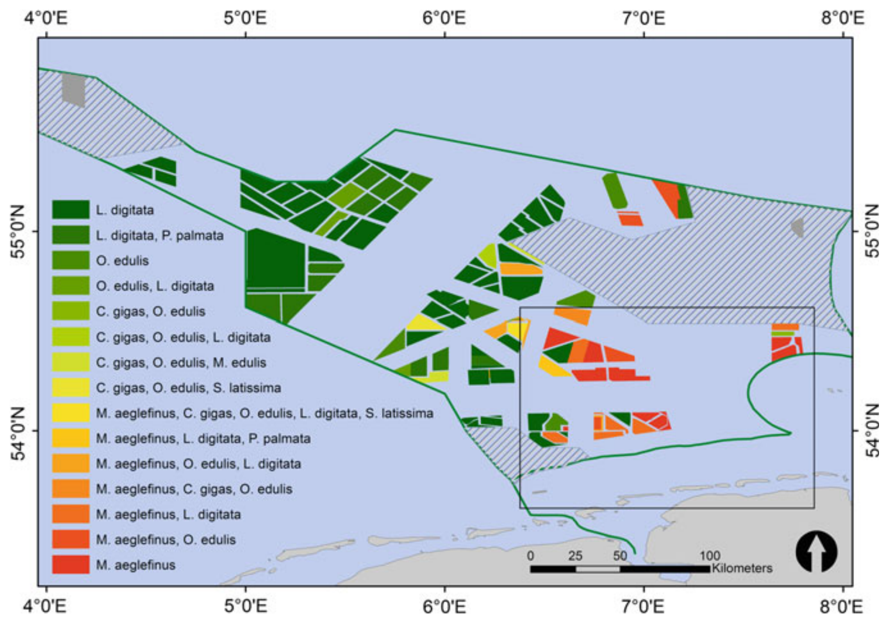

Fig. 6.3 Map of suitable co-location sites in the German EEZ of the North Sea, colored per aquaculture candidate featuring the highest suitability per wind farm area. Results are shown for spring at 10–20 m depth with Nature 2000 areas indicated as shaded areas

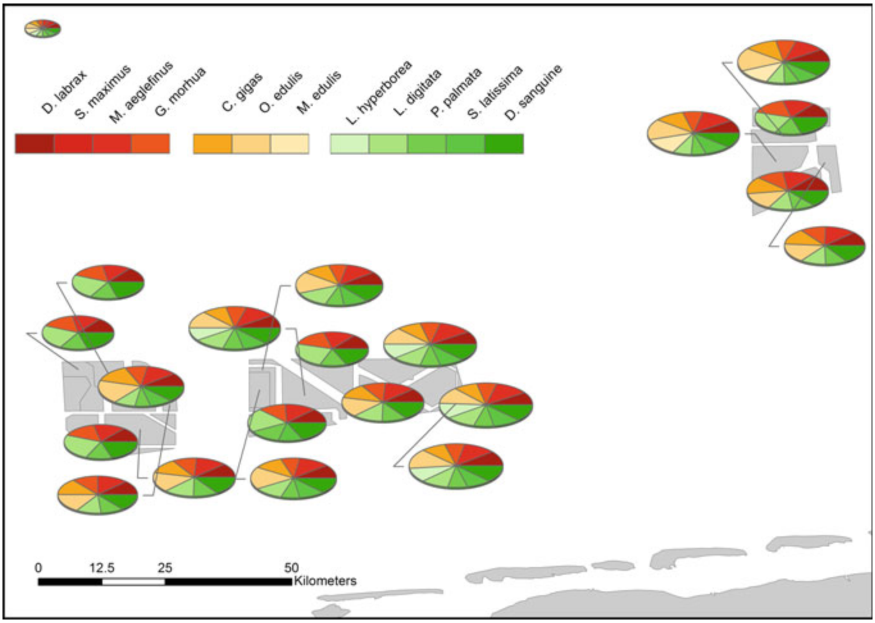

Fig. 6.4 Co-location sites for aquaculture candidates, suitable for possible IMTAs close to the German coast (North Sea) are shown as an example. Results presented depict the conditions given at 10–20 m depth during spring time. The size of the pies reflects the height of the relative suitability scores

and *M. aeglefinus* could be of interest regarding IMTA, especially if cultured in spring near the coast (Fig. 6.4). If it is about an IMTA candidate set which could be on site year around, Atlantic cod (*Gadus morhua*), blue mussel (*Mytilus edulis*) and sea beech (*Delessaria sanguine*) can be mentioned. Though, the here presented suitability for co-locations does not account for economic viability analyses for the respective candidates. Nevertheless, the case study example illustrated how competing needs might be balanced by strategic planning for the needs of sectors, offshore wind energy and offshore IMTA. This might offer guidance to stakeholders and assist decision-makers in determining the most suitable sites for pilot projects using IMTA techniques.

6.5 Conclusions and Future Needs

As highlighted by the here presented examples, some form of strategic spatial planning will be critical in advancing sustainable offshore aquaculture. Olofsson and Andersson (2014) describe a successful planning process conducted in the Baltic Sea Region to site sustainable aquaculture farms for finfish and mussels.

GIS tools were used to evaluate geographical data and identify suitable areas, fish carrying capacity was calculated, mussel settling in the selected areas was estimated, and a public consultation process was carried out in both regions. Hence, such a spatial planning process will be crucial for aquaculture development as it lowers the threshold for new entrepreneurs, minimizes the risk of appeals, makes the business more environmentally safe, and lowers the risk of social conflicts.

But, increasingly, aquaculture siting will be conducted in a broader, multiple-use context where tradeoffs will be more complex. As stated by Lovatelli et al. (2014), "meeting the future demand for food from aquaculture will largely depend on the availability of space [and] 'MSP' is needed to ensure [that] allocation of space." Although a variety of GIS-based tools and DSS are currently available to assist in the planning process, the allocation of space in the ocean remains a complex, contentious process unlikely to be fully resolved by even the most sophisticated mathematical calculations. Successful MSP, including the co-location of compatible activities, relies as much on the willingness of relevant stakeholders to become involved as it does on tools and techniques for identifying optimum areas (Gopnik 2015). The integration of relevant actors is a "complex and controversial issue" (Buck et al. 2008) which depends on a multitude of factors, including inclusiveness, transparency of the process and of decision-making, timing, credibility of the data and science, and impartial mediation.

Despite these caveats, GIS-based DSS will continue to play an important role in planning and spatial decision-making because of their ability to evaluate the results of many different spatial scenarios. Ideally, this should include assessments of the economic and socio-cultural impacts of different siting decisions, which can be the main sources of conflict and are too often overlooked (ICES 2013). Socio-economic data integrate publicly-held values into the decision-making processes. Primary data on socio-cultural values—such as the importance people give to cultural identity and the degree to which that is related to the ecosystem (de Groot et al. 2010)—are usually not available. Surveys on secondary data as well as their spatial analysis still remain complex tasks. In general, the spatial aggregation of socio-economic data in a GIS framework is difficult, involving close collaboration with the respective sectors (Ban et al. 2013). Most progress can be found with regard to the mapping of fleet-specific fisheries activities due to technical advances in combining Vessel Monitoring System (VMS) and logbook information (Bastardie et al. 2010; Lee et al. 2010; Hintzen et al. 2012). Finally, GIS-based DSS should be flexible enough to respond to shifting circumstances, such as changes in environmental conditions, environmental targets, growth expectations in the aquaculture sector, or policy environments. Like all analytical tools, GIS-based DSS are only as good as the quality and thoroughness of the data they are based on, and their strengths and limitations should be clearly explained to stakeholders during the planning process.

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