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Integration of fisheries into marine spatial planning: Quo vadis?

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ABSTRACT

The relationship between fisheries and marine spatial planning (MSP) is still widely unsettled. While several scientific studies highlight the strong relation between fisheries and MSP, as well as ways in which fisheries could be included in MSP, the actual integration of fisheries into MSP often fails. In this article, we review the state of the art and latest progress in research on various challenges in the integration of fisheries into MSP. The reviewed studies address a wide range of integration challenges, starting with techniques to analyse where fishermen actually fish, assessing the drivers for fishermen's behaviour, seasonal dynamics and long-term spatial changes of commercial fish species under various anthropogenic pressures along their successive life stages, the effects of spatial competition on fisheries and projections on those spaces that might become important fishing areas in the future, and finally, examining how fisheries could benefit from MSP. This paper gives an overview of the latest developments on concepts, tools, and methods. It becomes apparent that the spatial and temporal dynamics of fish and fisheries, as well as the definition of spatial preferences, remain major challenges, but that an integration of fisheries is already possible today.

1. Introduction

Fisheries in MSP has only been evaluated to a limited extent, even while the concept of MSP has been promoted in various marine regions around the world over the last two decades (e.g. revision of Australia's Great Barrier Reef Marine Park, Ocean Acts in the U.S. states of Oregon and California, Canada's Ocean Act, European Integrated Maritime Policy, EU Natura 2000 areas, ocean zoning in China and Taiwan, UNESCO-IOC initiative on MSP). Several scientific studies highlighted the extensive relevance and significance of fisheries in MSP (e.g. Gray et al., 2005; Crowder and Norse, 2008; Berkenhagen et al., 2010; van Deurs et al., 2012; Bastardie et al., 2015). However, fisheries are usually not or not fully integrated into today's marine spatial plans (if regulations on marine protected areas are understood as conservation law, not as spatial planning regulations). The English East Inshore and East Offshore Marine Plans (HM Government, 2014), for example, seek to integrate fisheries, but ultimately they do not come up with spatial designations, but instead pass the issue on to subsequent licensing procedures. The Norwegian Integrated Management Plan for the Barents Sea-Lofoten area (NME, 2011) mentions fisheries, but the plan actually focuses mainly on sectorial fisheries management. Canada is currently developing integrated management plans for its marine regions that shall also address fish and fisheries. As seen in the example of the Gulf of St. Lawrence Integrated Management Plan, this also included, during the preparation phase,

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the identification of spawning grounds, but in the end the management plan resulted only in a strategic plan (DFO, 2013). For the preparation of the U.S. Rhode Island Ocean Management Plan, spatial demands of fisheries and of fish species during different life stages were mapped, but this management plan also did not come up with spatially explicit solutions for the integration of fisheries (CRMC, 2010). A bit different is the example of the Great Barrier Reef Marine Park zoning, which gives spatial designation for fisheries and other human uses (GBRMPA, 2004).

Modern MSP plans do not seem to achieve their theoretical integration potential when it comes to fisheries. While several studies proposed ways in which fisheries could principally be included in MSP (e.g. Douvere et al., 2007; Fock, 2008; Stelzenmüller et al., 2008), an often-cited argument for the non- or partial integration is that data on spatial demands of fish and fisheries cannot yet be provided in a spatial and temporal quality adequate for MSP purposes (Petra Schmidt-Kaden, personal communication, January 15, 2014). This raises the question of the current state of knowledge on spatial demands of commercially important fish species and fisheries.

In this article, we present brief overviews of the state of the art of approaches which seek to overcome fisheries integration challenges by providing spatially explicit knowledge for the inventory, draft development, and negotiation phases of MSP processes. The aim is to give an overview of the progress in providing data and knowledge for MSP processes. We define six sub-challenges on the integration of fisheries and MSP, and for each of them, progress is checked against the applicability in MSP practice.

2. Methodology/approach

In formulating a suitable methodology for the review, an initial conceptualization of the challenges in the integration of fisheries into MSP was undertaken. Based on guiding MSP principles (e.g. Ehler and Douvere, 2009; Ramieri et al., 2014), scientific support for the inventory, draft development, and negotiation phases of MSP processes, in particular, was thought to be necessary. As highlighted by Jentoft and Knol (2014) and de Groot et al. (2014), being able to table good spatial data is crucial in many MSP processes. According to Hopkins et al. (2011) and HELCOM-VASAB (2015), the above-mentioned MSP steps are of great importance for the integration of ecosystem-based activities, such as fisheries. In order to identify relevant literature on the integration of fisheries into MSP, a structure of MSP-relevant knowledge challenges was developed as follows:

- MSP inventory phase:
    - Where do fishers actually fish (effort allocation)?
    - Which areas are more, which are less valuable for fishers?
    - What locations do commercially important fish species need access to during their different life stages?
- MSP draft plan development and negotiation phase
    - Long-term changes in species and life stage distributions, e.g. due to climate change, eutrophication, etc.
    - Effects of fisheries management (CFP, national) on MSP goals.
    - Effects of MSP and human maritime uses on fisheries.

This structure laid the basis for a literature review with the aim to draw together information on the progress in research on the above-mentioned integration challenges and the applicability of today's scientific approaches in MSP practice.

Articles published from 2000 to 2015 were selected by means of a structured literature search in SciVerse (ScienceDirect & Scopus), Web of Science, Google Scholar, and OCLC WorldCat. Supplementary papers were found by following the references of articles found in the above-mentioned databases and search engines. Search words were combinations of “MSP”, “marine/maritime spatial planning”, “fisheries”, “spatial”, “effort”, “closure”, “spawning”, “EBM”, “VMS”, “anchovy”, “cod”, “flatfish”, “herring”, “plaice”, “saithe”, and “sole” in differing dictions and including Latin names of fish species. Studies were included in this review if they dealt with one of the above-mentioned challenges, had a marine focus, led to spatially explicit results with an extent comparable to the average MSP planning regions, and if they were written in the English language. In the case of identical or conceptually similar studies, those studies were included in this review that best summarize longer development trends or had the stronger focus on MSP requirements.

To get an overview about the different types of contributions to the integration of fisheries into MSP we structured the publications by using the Grounded Theory methodology (Strauss and Corbin, 1994). Each publication was assigned within four dimensions via open and axial coding on the basis of the paper titles, abstracts, and keywords. The categorisation was based on contrasting pairs (model-based - sample-based; fleet – fish; inventory – projection) and the axial coding elements as defined by Strauss and Corbin (1998).

3. Results

The literature search led to more than 3000 results with general relevance to the topic. Of these, 121 studies had higher significance for the integration of fisheries into MSP. Most of these were studies which focus on conceptual issues, aspects of stakeholder integration and participation, and details of interdependencies of ecosystem components or of human activities and fish stocks. Thirty-four of those 121 studies fulfilled the above-mentioned criteria, whereof 25 studies were published since the year 2010 (see Table 1 below and Table 2 in chapter 3.2).

As a result of the coding the majority of reviewed papers were identified as having a focus on model-based assessments of the behaviour of fishing fleets (16 papers). Nine of those studies included information on the wider context or on the effects of interventions on fishermen's decision-making (see Fig. 1). A total of eight papers described mainly phenomena, another eight articles included causal conditions, while only five studies were so applied to give concrete advice on MSP action strategies or similar. The smallest group of papers used sampling to deduce the effects of managements measures on stock development or species behaviour (3 papers). Model-based approaches clearly predominate the reviewed studies (26 articles), while the relation between stocktaking studies and those that make use of projections is balanced. Studies coded as containing information on context, intervention, action strategies, or consequences were later on more frequently considered as offering advice not only for the MSP inventory phase (Table 1), but also for the plan development and negotiation phase (Table 2).

3.1. MSP inventory phase

3.1.1. Mapping fishing effort in space and time

The spatial resolutions of ICES statistical rectangles (30′ latitude x 60′ longitude) or other grid-based landings and fishing effort statistics are usually too coarse to fulfil the information requirements of MSP on fisheries' demand for space. Suitable resolutions have been defined, for instance, by Jin et al. (2013), who suggest a grid system of maximum 10′ x 10′ to be able to assess economic values of marine space. Marchal et al. (2014a) recommend a more delicate system of 3′ x 3′ to be able to analyse the interactions between fishing activities and other human offshore activities. Actually, catch and effort data for fleets is often available at finer scales than the ICES rectangle in most national fisheries institutes. Recent technological progress has led to massive acquisition of fishing vessels' movement data (e.g., Vessel Monitoring System, VMS), which offer new means of studying the spatio-temporal dynamic of fishermen (e.g. Bertrand et al., 2008; Patterson et al., 2009; Bastardie et al., 2010; Vermard et al., 2010; Walker and Bez, 2010; Hintzen et al., 2012; Gloaguen et al., 2015). But because VMS transmits the vessel positions at best every hour (without any further information such as the current activity of the vessel, the catches, etc.) these data alone, especially if displayed within ICES rectangles, are usually insufficient for MSP processes, and information on where fishermen actually fish has to be inferred from the data, and additional information (gear type used, catches) obtained from coupling to the fishermen's logbooks. Various methods have been applied to model non-observed fisher behaviour (cf. Hutton et al., 2004). The studies show quite well the value of model simulations for getting insights into detailed fishing vessel behaviour, as required for a holistic MSP. However, the authors also mentioned various constraints which currently limit the validity and reliability of the simulation results, such as general uncertainties in model simulations and the liability of covariates describing the environment (e.g. the time of the day, the season, or the habitat and knowledge of the gear actually used by the fishing vessel). This causes limitations in the general advantage of numerical models in comparison to limited observational studies (limited in space, time, and in the number of individuals observed). As shown by Pascual et al. (2013) and Turner et al. (2015), it may therefore also be necessary to conduct analyses of fisher behaviour based on sightings and interviews for MSP purposes. A recent example integrating data on fishing effort in Israeli draft MSP plans was published by Mazor et al. (2014), who developed surrogate opportunity cost layers of commercial fishing with a resolution of 1 × 1 km.

3.1.2. *Biotope identification*

To fully integrate fisheries into MSP, knowledge of spawning areas and other essential fish habitats (EFH) is a prerequisite. To be able to define relevant spawning areas, this includes knowledge of the importance of variability in environmental conditions for egg survival. In a series of studies, Hüssy et al. (2012), Hinrichsen et al. (2012) and Petereit et al. (2014) used hydrodynamic drift modelling to test whether the environmental conditions in different regions are *i)* suitable for spawning, and *ii)* suitable for egg survival, and then used this data to estimate the population connectivity of the egg stage between different spawning grounds. The modelling exercise showed that the dispersal of individual stocks of a species may depend on complex patterns of different external forces, such as topography, local winds, barotropic and baroclinic pressure gradients. As a consequence, traditional sampling methodologies are unable to provide high spatial and temporal resolution of egg distributions in the western Baltic Sea without considering flow dynamics and the impact of abiotic conditions on egg survival. In regions like the western Baltic the identification of EFH needs to be stock-specific and requires the use of hydrodynamic modelling. Brown et al. (2000) highlighted the value of habitat suitability

Table 1
Approaches to overcome integration challenges during the inventory phase.

Challenge/MSP step	Approach	Regions	Scale	Species	Reference	Specifics	Stage of development
Inventory – effort allocation	Vessel sighting, log-book data, questionnaires, VMS data analysis (model based),	English Channel; North Sea; Celtic Sea; North East Atlantic, East Pacific	0 - 100 nm	Various	Bertrand et al., 2008; Patterson et al., 2009; Vermard et al., 2010; Walker and Bez, 2010; Hintzen et al., 2012; Pascual et al., 2013; Campbell et al., 2014; Gloaguen et al., 2015; Turner et al., 2015	Limited validity, limitations of individual data sets, high effort, lack of access to high-resolution gear-specific fisheries data	Operational, partly usable for MSP
Inventory – biotope identification (e.g. spawning grounds, essential fish habitats)	Statistical analyses, habitat suitability indices, drift modelling	Caribbean Sea; North West Atlantic, Western Baltic Sea	Small scale; model: 1–500 nm	Cod, flounder, salmon and others	Brown et al., 2000; Harborne et al., 2008; Hüssy et al., 2015; Hinrichsen et al., 2012; Petereit et al., 2014	Insufficient coverage of MSP planning areas; traditional sampling unable to predict egg distributions	Operational, partly usable for MSP
Inventory – long-term changes in fish distributions and fishing fleets	Modelling	Global, Northern Atlantic, North Sea	0.5–500 nm	Various, cod, plaice, sole	Cheung et al., 2009; Drinkwater, 2005; Teal et al., 2012; Bartelings et al., 2015	Large uncertainties, e.g. in high-res projections of stocks and key prey items	Operational, but not yet fully usable for MSP
Inventory – designation of fishery management areas	Genetic analyses and stock assessment, retrospective analysis	Baltic Sea, North Sea	0.5–300 nm	Cod, sole, plaice, shrimp	Beare et al., 2013; Eero et al., 2014	Fisheries and their management can be highly dynamic in space and time; ICES rectangles not suitable for MSP; potential socio-economic, political, and governance dimensions to be taken into account	Operational and usable, mainly for sectorial management; partly insufficient understanding of ecological processes
Inventory – economic values of ocean space	Empirical data analysis	Gulf of Maine	0.17–100 nm	about 200 species	Jin et al., 2013	Recommended spatial scale: at least the 10-min square	Operational and usable for MSP

Table 2
Approaches to overcoming integration challenges during the draft development and negotiation phases.

Challenge/MSP step	Approach	Regions	Scale	Species	Reference	Specifics	Stage of development
Draft development/Impact assessment – effects of multiple pressures on biotopes during different life stages	Modelling	English Channel, Irish Sea, Baltic Sea	0.25 –150 nm	Various	Rochette et al., 2010; Stelzenmüller et al., 2010; Janßen and Schwarz et al., 2015; Archambault et al. (2018)	Uncertainties caused by limited knowledge on impacts and on connectivity; fisheries may benefit from MSP	Operational, party usable for MSP
Draft development/Impact assessment – effects of multiple pressures on fisheries	Modelling (various), stress level analysis	Gulf of Maine, North West Atlantic, Eastern English Channel, North Sea, Baltic Sea	1 - 500 nm	Various	Holland, 2000; Hamon et al., 2013; Marchal et al., 2014a, b; Bastardie et al., 2015; Girardin et al., 2015; Simons et al., 2014, 2015; Tidd et al., 2015	Effects may be complex and fleet dependent; ICES rectangles not suitable for MSP, limited validity	Operational, but not yet fully usable for MSP

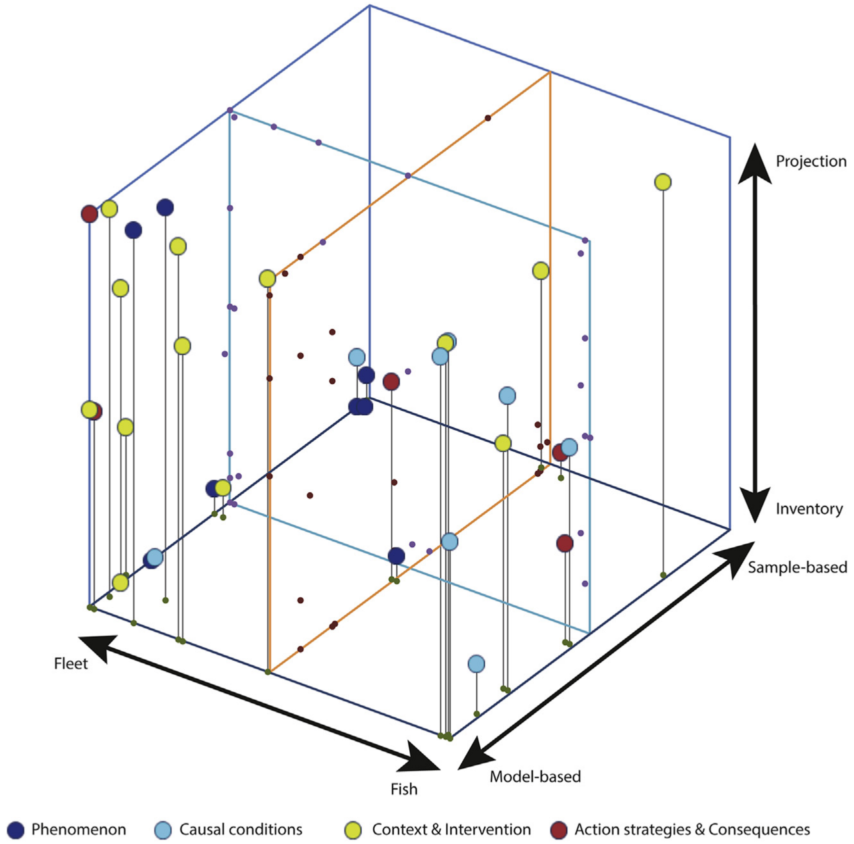

Fig. 1. Scatterplot of reviewed publications on challenges for the integration of fisheries into MSP published between 2000 and 2015. Based on concepts of Grounded Theory the publications were categorized by means of contrasting pairs (model-based - sample-based; fleet – fish; inventory – projection) and additionally structured along the axial coding elements.

index models for the identification of EFH in different life stages. Overviews of predictive species-habitat modelling approaches have been published for various species (cf. Valavanis et al., 2008). There is a wide array of literature on marine habitat mapping with some relation to MSP (cf. Cogan et al., 2009). However, detailed biotope maps are currently not available for most regions worldwide, due to a lack of full-coverage environmental data (Schiele et al., 2015). It becomes apparent that advances in biotope identification and its usefulness for MSP are dependent on evolving technological and modelling capabilities (ibidem), but also on a rigorous approach for model validation to force modellers to combine observations and experiments as an integral part of the overall modelling process (Hannah, 2007).

3.1.3. *Long-term changes in fish distributions and fishing fleets (climate change impacts)*

Cheung et al. (2009) showed that climate change and related warming sea water temperatures are expected to drive global changes in ectothermic marine species ranges due to physiological limitations in thermal tolerance levels. Spatial shifts of commercial fish species may be of importance for MSP in those cases where fisheries follow these shifts. MSP usually has a planning horizon of decades. It therefore has a need to understand these changes if it wants to develop reliable spatial management regimes. Few studies in the literature collected here give spatial information in a resolution and quality sufficient for MSP. Studies like the one from Drinkwater (2005) are informative for MSP processes, but not explicit enough for the designation of spatial management schemes for human offshore activities. The study of van Keeken et al. (2007) is an example of spatial information which is too coarse for MSP purposes, but of interest to MSP is the authors' indication for a potential need for spatial changes in fisheries management schemes, i.e. adaptation needs in sectorial management with interdependencies to MSP. Teal et al. (2012) used a mechanistic tool to predict size- and season-specific distributions of fish based on the physiology of the species and the temperature and food conditions for two flatfish species in the North Sea: plaice, *Pleuronectes platessa*, and sole, *Solea sole.* This kind of mechanistic modelling approach enhances the predictability of fish distribution under different environmental scenarios above what is possible with simple correlative studies, and the results may also serve as input for economic scenario models. The effects of such changes in fish distributions on fisheries were simulated by Bartelings et al. (2015). In their case study, the authors showed that long-term effects of fish displacement due to climate change had little impact on the spatial distribution of flatfish and shrimp fisheries. This could be explained by the range of the shift and the expected productivity. The range shift of sole and plaice is not expected to be very large by 2050 and the final distributions largely overlap with the current fishing areas.

The authors mentioned that predicting the availability of key prey items remains a challenge. Together with the fact that fish and fleet distributions are effected not only by physiology and availability of suitable habitat but also by behavioural choices, migration routes for spawning grounds, species interactions and fishing pressure, this results in limitations of the validity of these approaches in their application in MSP. Additionally, the application of bio-economic models to new fisheries may require a considerable amount of time and data. One of the difficulties comes from the availability of spatial data to parameterise this kind of model (e.g. estimations on the spatial distribution of stock). This type of prospective modelling exercise should only be used as “what-if” scenarios, with underlying assumptions clearly stated. Indeed, a sensitivity analysis by Bartelings et al. (2015) showed that the fishery was much more impacted by changes in fish and energy prices than by fish displacement or area closures.

3.1.4. *Designation of fishery management areas*

In the majority of cases, the designation of fishery management areas will be an issue of sectorial management, and not of MSP itself. However, spatio-temporal restriction and closures of smaller areas for fishing are commonly applied, for example, to protect spawning aggregations, habitats, etc. (Babcock et al., 2005; Stelzenmüller et al., 2008; Lorenzen et al., 2010; Sciberras et al., 2015) and these management measures are taken within the context of an encircling MSP. Challenges arise from the fact that fish and fisheries, together with their management, can be highly dynamic in time and space, in contrast to MSP, which is generally associated with stable conditions (wind farms, shipping routes, etc. stay at the same location for decades or longer). This has been demonstrated for the western Baltic cod management area, where mixing with the eastern Baltic population is taking place at varying proportions (Eero et al., 2014). This may require temporal reallocations of fishing effort within a management area to protect local populations, depending on natural variability in population distributions, which would result in temporally varying overlap of fisheries with other human uses of the sea. These examples demonstrate that integrating wide-scale ecosystem processes (where appropriate) and accounting for spatial and temporal ecological changes influencing fisheries management should be incorporated into MSP strategies. This is in line with other studies, e.g. Beare et al. (2013), which additionally emphasise the need to consider socio-economic and governance dimensions (MSP dimensions) in the designation of fishery management areas. For this review, we only found retrospective studies that analysed imperfect management examples and called for more sound and holistic strategies, linking MSP and fishery management areas.

3.1.5. *Economic value of marine space*

The importance of seas and oceans for human prosperity, as expressed e.g. in the transatlantic Galway Statement, has always been an important driver for marine exploitation, management, and research. Numerous authors stress the importance of the ability of spatio-economic analyses to balance multiple uses of marine space. Surprisingly, only one study could be found that analysed the spatial distributions of economic values in a resolution that would be informative for MSP. Jin et al. (2013) compiled empirical data on the economic values arising from commercial fishing around the Gulf of Maine. The authors showed that it is, in principle, possible to identify the specific location in a planning area where a specific industry would be able to generate the highest value among alternative uses.

3.2. *MSP draft development and negotiation phase*

3.2.1. *Spatial dynamics and vulnerability of fish during different life stages*

MSP may influence economically important fish species with life cycles that depend on different habitats (coastal vs. offshore areas) that are subjected to different pressures (pollution, habitat destruction, fisheries) and policies. There are numerous studies available on impacts of the destruction or impairment of specific habitats. Most of these studies operate on scales that are too detailed for MSP but which are of relevance for more detailed impact assessments within the framework of licensing procedures. Stelzenmüller et al. (2010) assessed, on a larger spatial scale, the vulnerability of various fish species to aggregate extraction. The authors highlight the crucial importance of spatial scale for such exercises and stress that the scale of the human activity has to be balanced with the occurrence of the ecological receptor. Rochette et al. (2010) and Archambault et al. (2018) disentangled the effects of multiple interacting stressors on population renewal (e.g. estuarine and coastal nursery habitat degradation, fishing pressure) of common sole abundance in the Eastern Channel. Their results emphasise the importance of nursery habitat availability and quality for this species, with a two-thirds increase in catch potential for the adjacent subpopulation. Pressures on those habitats can be managed by MSP by-laws, with a potential benefit for the fisheries. The study showed that it is feasible to integrate coastal habitat and fisheries management in MSP based on today's knowledge. However, some uncertainties remain, caused by fragmentary knowledge on the effects of anthropogenic pressures and spatial connectivity. Janβen and Schwarz (2015) outlined the potential benefit of MSP for stock development, here for western Baltic herring. But the authors also mentioned limits of MSP in regulating some of the most important stressors; in the given case this is valid mainly for eutrophication and partly for pollutants.

3.2.2. *Effects of MSP and other human uses on fleet behaviour*

Effects of spatial management measures and competing human activities on fisheries have been analysed in numerous retrospective studies. Usually such studies are of little use for MSP, as their findings depend on specific case study conditions. This challenge can be overcome by using predictive fleet behaviour models, which have been used in various parts of the world to simulate potential impacts of various kinds of scenarios on fisheries fleets. Holland (2000) used bioeconomic modelling and showed that marine protected areas might affect catches, revenues, and spawning stock of principal groundfish species in southern New England and the Gulf of Maine. His simulation results also demonstrated that the impacts of sanctuaries can vary greatly across species, sometimes increasing yields for some while decreasing yields for others. Bastardie et al. (2015) used bioeconomic modelling to show that spatial restriction scenarios (offshore wind farms, marine protected areas) may lead to a net effort displacement with a subsequent change in the spatial origin of the landings. The impact of the fishing activities changes for the harvested stocks, with various fishing pressure put on them after the implementation of the zonation. The divergence in catch composition from alternative effort allocations was, however, sufficient to create a surplus of abundance in the long term that helps the fisheries to compensate for the zonation effect. Outcomes from the simulations were more nuanced when studied at the individual vessel scale because some vessels were not able to cope with space restrictions without a significant loss in individual profitability. Simons et al. (2014) reported that changes in fishing behaviour, in terms of effort allocation patterns (e.g. caused by MSP) or entry and exit of vessels, affect not only the catch, but also fishing mortality of species and ultimately the development of the fish stocks (here: saithe in the North Sea). Simons et al. (2015) identified areas which could lead to the greatest increase in spawning stock biomass. This could be of interest not only for fisheries management but also for an MSP that either seeks to stabilize fisheries as an economic sector or aims for efficient contributions to the preservation of ecological functions.

Cumulative losses caused by the displacement of fisheries are often evaluated on a macroeconomic level (Berkenhagen et al., 2010; Oostenbrugge et al., 2010), whereas impacts for single enterprises or coastal regions are often ignored. As shown by Marchal et al. (2014a) this can be overcome by conducting an individual stress level analysis (ISLA), i.e. calculating the future potential losses in per cent (stress level) of a fisheries enterprise (individual vessel) by comparing the revenues (alternatively effort or catch) gained in the past in an area which might be closed to fisheries in the future with the total revenues of that individual vessel. By aggregating this data per coastal area, harbour or other entity, an individual stress level profile for a specific future spatial management option can inform decision makers about the consequences of implementing a spatial plan. The authors report that impacts on single vessels and/or single harbours may differ significantly.

Discrete-choice models incorporating a random utility model (RUM) are now widely used in fleet dynamics and effort allocation studies (Holland and Sutinen, 1999; Hutton et al., 2004; Vermard et al., 2008; Marchal et al., 2009). In these studies, the main drivers of fishing behaviour considered are economic opportunities and traditions, and these indeed appeared to determine spatial effort allocation. Similar RUMs were applied to a variety of French and English fleets operating in the Eastern English Channel (Girardin et al., 2015; Tidd et al., 2015), but with additional explanatory variables reflecting spatial interactions/competitions with other fishing fleets, maritime traffic, aggregate extractions and closed areas. To the best of our knowledge, this was the first time discrete-choice models have been applied to evaluate the impact of spatial interactions (effects of other human uses and closed areas) on fleet dynamics. Alternative spatial approaches, including spatially-explicit time series analyses, have been complementarily conducted to investigate more specifically, at a finer spatial resolution than that considered in the RUMs, the spatial interactions between (1) fishing activities and aggregate extractions (Marchal et al., 2014a) and (2) fishing activities and maritime traffic (Girardin et al., 2015). As shown by these authors, competing activities, such as maritime transport or aggregate extraction, generally have a repelling effect on the distribution of fishing fleets. However, this effect is probably not linear, and it also depends on the spatial and temporal scale of the analysis, on the fleet, and on the targeted species. In the study by Marchal et al. (2014b), some fleets (e.g., potters targeting whelks and large crustaceans, netters targeting sole, and even some scallop dredgers) were attracted to the vicinity of aggregate extraction sites. For shipping lanes, it was shown that, when stock density was high, the influence of maritime traffic decreased, possibly because the risk of being caught in an accident within the shipping lanes was offset by the expected profit.

These results indicate that the interactions between fishing activities and other human activities offshore are complex in nature, and hence highlight the importance of choosing a sufficiently accurate spatial scale to implement MSP efficiently. In the case of the Eastern English Channel, the ICES rectangle (30′ x 60′), or even the 1/8th of an ICES rectangle (15′ x 15’) would not be of sufficient precision to monitor spatial interactions between human uses.

4. Synthesis and discussion

During recent years, research on the integration of fisheries into MSP has been gaining momentum. Three-fourths of the reviewed studies were published recently (since 2010). As shown above, tools and methods for identifying productive areas with relevance for fish resources, fisheries and the management of fish stocks (e.g. fishing grounds, spawning grounds, nursery grounds, benthic habitats, etc.) are widely available or under development. The same is true for models that support analyses on changes in species distribution and of effects of MSP or human uses on existing fisheries. While we found fewer than three dozen studies with direct significance for the topic, there is a large number of publications with general relevance. This suggests that the knowledge that is actually available might be much larger, while the publications might simply have been written in a style that did not focus on spatial management approaches and were therefore not included in this review. The papers, approaches and case studies reviewed here indicated that very often the presented tools, methods and models are still in a scientific stage and not directly usable by MSP management bodies. Most of the modelling approaches require large amounts of data, including satellite-based VMS data, fishermen's declaration of catches in logbooks, sales slips from fish auctions, and biological information that is available on various scales over a range of species, as well as biological and economic processes and functional relationships. Not all of the data needed is always easily accessible, e.g. logbook data of foreign fleets operating in the planning region. In addition, this kind of tool requires advanced modelling skills; some may even require access to supercomputing facilities.

As seen in the reviewed studies, extensive and broad expertise is needed to integrate fisheries and MSP. This may include detailed knowledge on benthic communities, the biology of selected fish species during different life stages, and various forms of cause-effect relationships, as well as proficiency in statistics, economics or modelling, among others. While such expertise is usually not part of the infrastructure of MSP agencies, it is increasingly available, as shown by the reviewed studies.

Spatial resolution is still a challenge for the integration of fisheries and MSP. Fisheries research and management often operate on the basis of grid systems which are not optimal for MSP. Resolutions of 30′ x 60’ (ICES rectangle) or even 10′ x 10’ are often not informative enough for MSP processes. Stock dynamics and fleet movements operate on fine spatial scales, while the catches and fishing effort (fishing logbooks) are usually reported at the ICES rectangle scale or similar grid systems (e.g. Bastardie et al., 2010). The ICES rectangle resolution does not seem adequate to describe the space and time structure and change in stock and fleet distribution (nursery areas, spawning areas, economic zones, ports and vessel mobility, etc.). Offshore platforms are also fine-scale settlements, which makes the use of the current fisheries zoning (for reporting, i.e. ICES rectangle at best) quite irrelevant. New information are now requested by ICES (2015 ICES/OSPAR/HELCOM data call) to advise on the impact of fishing and the use of space in European waters on a much finer scale than previously used, by making use of transnational VMS data. VMS tracks (at least the vessel position data collected every 2 h) will be coupled to the logbook information to map the fishing per activity category. Fine fishing distribution mapping, using coupled VMS/logbook data information and fishing gear questionnaire surveys at a European scale, is furthermore currently under way in the EU-FP7 BENTHIS project. The example by Mazor et al. (2014) suggests that 1 × 1 km could be an adequate grid resolution.

The reviewed studies gave insights into a number of more general issues in the integration of fisheries into MSP:

4.1. Space is not equally important to fish stocks and fisheries.

What sounds like a platitude for a fisheries biologist is a challenge for MSP. Very often, MSP processes fail to identify those priority areas which are of increased relevance for fisheries or for fish species during different life stages (cf. Jay et al., 2013). A planning area should be divided into subspaces to which different qualitative values of fisheries' relevance need to be assigned to, e.g. values on the importance for relevant species during different life stages or on the relevance for fishing fleets. If such assessments are omitted, an integration of fisheries into MSP will not succeed. The approaches used in the reviewed studies are not without constraints and obstacles and they may still be unsatisfactory for the needs of MSP authorities. But they show that detailed assessments on the dynamics of fishing effort and fish stocks (spawning activities, etc.) are possible and available. The same is true for the identification of habitats over different life stages and fleet models which link species dynamics with fleet behaviour. Another crucial aspect in this context is foreseeing unwanted detrimental effects of the plan, such as effects that a misplaced area closure for fisheries could potentially create by concentrating the fishing effort on the most sensitive parts of the stock or the ecosystem components (Suuronen et al., 2010).

4.2. How to define valuable areas?

Fisheries are often mainly understood as an economic sector. In these cases (e.g. Jin et al., 2013; Bartelings et al., 2015), areas valuable for fisheries are often defined as those areas with high fishing effort, high catches, or high revenues. These methods usually work fine but they partly ignore the broader approach of spatial planning as defined within the European Regional/Spatial Planning Charter (Council of Europe (1983)), according to which “spatial planning gives geographical expression to the economic, social, cultural and ecological policies of society.” In particular, the integration of social and cultural dimensions may require additional criteria for the definition of valuable areas. These could, for instance, be information on those areas to which small-scale fishermen are most attached (which might not be of high value at the scale of the whole fisheries) or information on areas for recreational fisheries. Currently, the link to social aspects is still relatively weak in the tools and models developed, and only a small amount of literature on the social value of marine areas was found.

Even in those cases where economic goals are in the focus, a decision on how “value” is defined may be necessary (e.g., employment vs. total revenue from catches; cf. Bastardie et al., 2014). The definition of valuable areas can be dynamic and changeable, as is often the case with societal decision-making processes. It is important that this discussion is taken up by MSP processes to prove that MSP actually reflects societal policies, as stated above.

4.3. MSP's responsibility for fisheries and fish stocks

How MSP goals and approaches are understood around the world differs from country to country, and ranges from lean zonation methods to comprehensive ecosystem-based ocean management approaches (Jay et al., 2013). If and how fisheries are integrated into MSP processes is influenced in part by these differences in how MSP is understood. Independent of a country's MSP philosophy, MSP may affect fisheries and fish stocks on various levels. MSP assigns spaces to human uses which usually impose limitations on fisheries, with effects on effort, fleet behaviour, and revenues. These effects can be analysed with model simulations, and these analyses can also help to identify affected stakeholders, down to the level of single harbours and coastal communities. Even if these assessments sometimes include a large number of uncertainties, they are still capable of supporting stakeholder mapping and the establishment of MSP discussion fora.

Examples like Simons et al. (2015) and Janβen and Schwarz (2015) indicate that MSP may have direct and indirect influence on the development of fish stocks. In the case of indirect impacts, one could argue that these effects are usually not caused by the MSP itself but by single human activities (e.g. sediment extraction, harbour dredging) which MSP merely coordinates but does not implement. In that case, these impacts would have to be addressed within sectoral Environmental Impact Assessments (EIA), but not necessarily within a MSP procedure. On the other hand, these interactions between human uses and fish stocks may well be relevant for the decision making on spatial designations within MSP. Within Europe, Article 5 of the EU MSP Framework Directive (Directive 2014/89/EU) obliges member states to implement MSP, among others with the objective of achieving a sustainable development of the fisheries sector. MSP also requires, from the perspective of the fisheries, some evaluations on how biological targets and targets set within the fishery management context can still be achieved in the broader context of multi-sector use of the sea. The above-mentioned examples give various indications on issues and interactions, which MSP processes should reflect. The increasing competition for marine space and the cumulative impact of human activities on marine ecosystems render the current, fragmented decision-making in maritime affairs inadequate, especially for co-management of fisheries and other pressures on fish habitats and fish populations. A MSP which ignores its responsibility for that would not only not be rising to its full potential, but might also fail to meet the requirements of the EU MSP Directive. MSP could be especially efficient for preventing new alteration by managing present human activities.

4.4. Spatial dynamics and temporal dimension

The spatial dynamics of commercial fish species and fisheries are often understood as a major challenge for MSP. However, this is, in principle, nothing new, as all ecological and social systems are dynamic, such that specific management decisions and tools should and often already use an adaptive management process (cf. Foley et al., 2010). Fish and fisheries, together with their management, can be highly dynamic in time and space, in contrast to MSP, which is often associated with more stable conditions and planning horizons of decades (see Directive 2014/89/EU). This may include space and time displacement of fishing effort within a management area, depending on natural or non-natural variability in population distributions. With certain limitations, these shifts can be projected. The scientific foundations of those projections may still be too weak to be directly used in administrative MSP decisions, but they can nevertheless serve today as assessments for the identification of areas with an increased probability for shifting fisheries effort. This may help to define areas for the application of the precautionary principle in MSP, e.g. areas that may be suitable for limited or non-permanent human uses. Long-term changes, e.g. impacts of climate change, may further complicate the integration of fisheries into MSP. But again, model simulations can help to identify the spatial and temporal dimensions of these shifts with the aim to identify those areas that fish and fisheries might shift towards (and away from).

If a zonation scheme is set in stone, then fishermen can lose fishing grounds or access, in the case of a hypothetic shift in stock distribution, e.g. due to climate change. This touches the question of revision periods of MSP plans, which should occur with an appropriate time frame of at most 10 years. However, it is unrealistic to require infrastructure to be moved because of a plan revision. It will therefore be important to define, at an early stage, those areas that underlie relevant fish and fisheries dynamics and to apply this knowledge to the implementation of the precautionary principle.

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