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Decision support tools in marine spatial planning: Present applications, gaps and future perspectives

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ABSTRACT

Evidence-based decision making is an essential process for sustainable, effective, and efficient marine spatial planning (MSP). In that sense, decision support tools (DSTs) could be considered to be the primary assistant of planners. Although there are many DSTs listed in tool databases, most of them are conceptual and not used in real MSP implementation. The main objective of this review is to: (i) characterize and analyse the present use of the DSTs in existing MSP implementation processes around the world, (ii) identify weaknesses and gaps of existing tools, and (iii) propose new functionalities both to improve their feasibility and to promote their application. In total, 34 DSTs have been identified in 28 different MSP initiatives with different levels of complexity, applicability and usage purposes. Main characteristics of the tools were transferred into a DST matrix. It was observed that limited functionality, tool stability, consideration of economic and social decision problems, ease of use, and tool costs could be considered as the main gaps of existing DSTs. Future developments are needed and should be in the direction of the specific need of marine planners and stakeholders. Results revealed that DST developments should consider both spatial and temporal dynamics of the ocean, and new tools should provide multi-functionality and integrity; meanwhile they should be easy to use and freely available. Hence, this research summarised current use, gaps, and expected development trends of DSTs and it concludes that there is still a big potential of DST developments to assist operational MSP processes.

1. Introduction

Due to the present and future demand for marine resources, human activities in the marine environment are expected to increase, which will produce higher pressures on marine ecosystems, as well as competition and conflicts among marine users [1–4]. This fact highlights the need for new management approaches, synergies, transnational coordination, visions, and actions [4]. At present, marine or maritime spatial planning (MSP) is considered as a promising management approach to transform conflicts into solutions, when managing multiple activities and users at sea [5]. MSP aims to balance the development of maritime activities and increase cross-border cooperation through transparency, clearer legislation, better coordination between administrations, and the early identification of impacts that can arise from the multiple uses of marine space [6]. Thus, MSP is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process [7–9]. In addition, the widely accepted management philosophy of MSP is ecosystem-based management, which strives to support healthy and productive marine ecosystems [10–13]. Ecosystem-based MSP covers effective implementation of ecosystem management frameworks in planning processes and focuses on achieving sustainable management of marine resources [5]. This approach enhances other responsibilities and activities to reach sustainable development. Despite the limitations and questionable aspects, MSP has been already implemented in many countries around the world [14].

One of the earliest examples of MSP was the plan developed for the Great Barrier Reef Marine Park in Australia [15]. Since 1975, initial zoning plans have been produced for concerns about oil and gas exploration, limestone mining, overfishing and environmental protection. The United States is another pioneer country in MSP. In 2013, the federal government provided a policy guidance framework: National

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Table 1
Reviewed Marine Spatial Planning experiences for Decision Support Tools identification and application analysis MPA: Marine Protected Area.

Scale	Plan/Initiative name	Reference
International	BaltSeaPlan	Fetissov, Aps and Kopti [38], Göke and Lamp [39], A. Schultz-Zehdenn [30], Jörg and Lamp [40]
International	Trilateral Wadden Sea Plan	Common Wadden Sea Secretariat [41]
National	China Territorial Sea zoning	Feng, Chen, Li, Zhou and Yu [19]
National	Barbuda Blue Halo	SeaSketch: http://www.seasketch.org/projects (accessed 15.02.17)
National	New Belgium Marine Spatial Plan (2014)	Belgian Royal Decree [23]
National	Germany Spatial Plan for North Sea and Baltic Sea	BFN [21,22,42]
National	Israel Marine Spatial Plan Pilot	Israel Institute of Technology [20]
National	The Netherlands National Water Plan	Ministry of Infrastructure and the Environment [24]
Local	Rezoning of the Great Barrier Reef Marine Park	Great Barrier Reef Marine Park Authority [15]
Local	Habitat Risk Assessment Module: Belize Case	Rosenthal, Verutes, Arkema, Clarke, Canto, Rosado and Wood [43]
Local	Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM)	ESSIM Planning Office [44] SeaSketch: http://www.seasketch.org/projects/ (accessed 15.02.17)
Local	Galapagos Marine Reserve Zoning, Ecuador	Direction of the Galapagos National Park [45]
Local	Sea Change, Hauraki Gulf New Zealand	SeaSketch: http://www.seasketch.org/projects (accessed 15.02.17)
Local	Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands	Norwegian Ministry of the Environment [46]
Local	Irish Sea Pilot Project	Kidd [47], Kidd and McGowan [48], Vincent [49]
Local	MPAs in the Channel Islands National Marine Sanctuary	Airamé, Dugan, Lafferty, Leslie, McArdle and Warner [50]
Local	Gulf of Mexico	Beck and Odaya [51]
Local	Massachusetts Ocean Plan	MassGIS (http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/) MORIS (http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris) North East Ocean Data (http://www.northeastoceandata.org/) (accessed 15.02.17) Altman, Boumans, Roman and Kaufman [52]
Local	Channel Islands National Marine Sanctuary Education and Outreach Platform	SeaSketch: http://www.seasketch.org/projects (accessed 15.02.17)
Local	Washington Marine Spatial Plan	SeaSketch: http://www.seasketch.org/projects (accessed 15.02.17)
EU Project	BONUS BALTSPACE Project	[37], SeaSketch: http://www.seasketch.org/projects (accessed 15.02.17)
EU Project	PartiSEApate Project	http://www.partiseapate.eu/ (accessed 15.02.17)
EU Project	Vectors Project: Ecosystem Model	http://www.marine-vectors.eu/ (accessed 15.02.17)
EU Project	Coexist Project	Coexist: http://www.coexistproject.eu/coexist-results/tool (accessed 15.02.17)
EU Project	MASPNOSE Project - Maritime Spatial Planning (MSP) in the North Sea	https://www.wur.nl/en/show/maspnose-maritime-spatial-planning-in-the-North-Sea.htm (accessed 15.02.17)
EU Project	AquaCross Project: Trade Off´s in Ecosystem Based Fisheries in the North Sea	AquaCross Website: http://aquacross.eu (accessed 15.02.17)
EU Project	BALANCE – Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning	Andersson, Korpinen, Liman, Nilsson, Piekäinen and Huggins [53]
EU Project	ADRIPLAN: Adriatic Ionian Maritime Spatial Planning	Barbanti A. [54], Menegon, Sarretta, Barbanti, Gissi and Venier [55] ADRIPLAN Website: http://adriplan.eu/
EU Project	MESMA: Monitoring and evaluation of spatially managed marine areas	Buhl-Mortensen, Galparsoro, Vega Fernández, Johnson, D'Anna, Badalamenti, Garofalo, Carlström, Piwowarczyk, Rabaut, Vanaverbeke, Schipper, van Dalfsen, Vassilopoulou, Issaris, van Hoof, Pecceu, Hostens, Pace, Knittweis, Stelzenmüller, Todorova and Doncheva [27]

Policy for the Stewardship of the Ocean, Coasts, and Great Lakes [16]. Additionally, responsible authorities of several states (Oregon, Massachusetts and Rhode Island) have planned the human use of their marine space within their marine waters (three nautical miles of the coast). One of the most well-known MSP cases in United States is the state of Rhode Island, which used a previously-existing federal law as a legal framework for policy guidance: the Coastal Zone Management Act of 1972 [17]. The Massachusetts Ocean Management Plan has been revised and re-published recently [18]. In Asia, China has implemented the National Marine Functional Zoning Scheme for the period from 2001 to 2020 [19]. A pilot project, the Israel Marine Plan (IMP), was completed in November 2015 [20]. At the European scale, the Maritime Spatial Planning directive [6] is legally binding for Member States to complete their maritime spatial plans by 2021. In this legislation, the European Commission and DG MARE use the term “maritime spatial planning” to underline the holistic and cross-sectorial nature of MSP and to differentiate their work from that of the environmentally-oriented authority, DG Environment (*in this paper we use both terms with the acronym of MSP). Several countries in Northern Europe, such as Germany, Norway, Belgium, and the Netherlands have already implemented their plans [21–25]. Furthermore, some eastern European countries such as Lithuania, Poland and Latvia have quite advanced MSP achievements [26]. Apart from the political initiatives, research projects are also contributing significantly to different aspects of the MSP development and implementation. The main objectives of such projects have been to provide knowledge, science-based approaches and tools to improve the capacity of countries and to support the implementation of MSP. Many projects have developed analytical frameworks, guidelines, and recommendations for countries that are initiating MSP [13,26–30].

During these MSP processes, experiences have demonstrated that marine spatial planning should be a continuous, iterative, and adaptive participatory process, comprising a set of actions including research, analysis and planning, financing, implementation, monitoring, and evaluation of the plan. It has been stated that all of these individual functions must be carried out for successful management [13,27,31]. This process frequently requires planners to undertake essential tasks, such as specifying spatial and temporal boundaries, mapping important areas, identifying spatial conflicts of use, defining scenarios, and designing management actions at different stages of the MSP implementation process [32]. Moreover, it has been observed that DSTs can be used to simplify these tasks [33]. The aforementioned characteristics of a MSP implementation process require decision making to achieve efficient and sustainable plans. In that sense, decision support tools (DSTs) are considered to be an important assistant in this process [34]. Considering the various definitions of DSTs, the following was agreed upon for the purposes of this paper. DSTs are software-based intermediaries that provide support in an evidence-based, decision making process [35]. Tools may help users, including managers (but also scientists, industry, or NGOs, among others), and support decision making. These tools can also be used for data and information transfer, analysis or storage [35]. They can be either fully computerised, human-powered or a combination of both [33,35]. Based on these characteristics and functionalities, DSTs can be considered as important intermediaries to help planners in the management plan development, in an objective, efficient, and fast manner [35]. With the help of these tools, support for decision making could be undertaken in a more systematic and objective manner. Hence, DSTs can be used to support decision making processes and alternative management plan development, including ecosystem-based MSP.

Previous studies have focused on DSTs and their role in MSP. These studies described a selected number of tools in specific case studies by using workshops as a bottom-up source for tool functionality requirements [34,36,37]. There are also web databases on DSTs that can be used at different stages of the MSP implementation process steps (e.g. MESMA: http://mesmacentralexchange.eu/tools.html and EBM (Ecosystem-Based Management) Research Network: https://ebmtoolsdatabase.org). Despite the wide range of DSTs for different purposes, reported uses in MSP process are limited. Tool databases list approaches that could be classified as DSTs according to their nature, but many of them are conceptual and not used in real MSP implementation [14]. Hence, this indicates that there is a significant need for DST development and improvement to fulfil the expectations and functionality requirements of planners in the planning process. As a result, existing research needs to be updated and a broader review is required. Thus, this research aims to: (i) characterize and analyse the present use of the DSTs in existing MSP implementation processes, (ii) identify weaknesses and gaps of existing tools, and (iii) propose new functionalities both to improve their applicability and to promote their application.

2. Methods

A comprehensive review of the use of DSTs in international, national and local MSP implementation experiences around the world was performed (Table 1). Main characteristics of the tools were transferred into a comprehensive DST matrix.

The UNESCO MSP reference list (http://msp.ioc-unesco.org (accessed 15.02.17)) was used to select MSP examples. At the European scale, the European MSP Platform (http://www.msp-platform.eu/ (accessed 15.02.17)) was used to understand the current status of EU Member states. While multiple websites of planning authorities were consulted to characterise management plans, technical reports were used to understand the general role of DSTs in the planning processes along with the aim of use and technical characteristics. As not all management and technical reports mentioned DSTs, related websites and scientific articles were systematically screened. In addition, EU projects related to MSP were considered to track the tool production and their use in the planning process. This research was conducted between April 2016 and February 2017.

2.1. MSP stages

Seven different stages of the MSP process were defined after reviewing the ones proposed by Coleman et al. [36], Ehler & Douvere [32], and Stelzenmüller et al. [34]:

i. Define goals and objectives
ii. Gather data and define current conditions
iii. Identify issues, constraints, and future conditions
iv. Develop alternative management actions
v. Evaluate alternative management actions
vi. Monitor and evaluate management actions
vii. Refine goals, objectives and management actions

Each of the analysed DSTs was assigned to one of those stages according to its functionality. The application of the tool in more than one of the aforementioned MSP stages was also taken into account.

2.2. General characteristics

These fields refer to general information related to the specific MSP initiatives, including country, aim of use, spatial scale, year, and references. The aim of use field listed the main uses that were reported in the case studies. Since there were multi-functional DSTs, this field contained one or more aims for each tool. The following application categories were defined: (1) environmental impact assessment, (2) communication, (3) data gathering, (4) economic analysis, (5) evaluation, (6) governance assistance, (7) management plan proposal, (8) scenario creation and analysis, (9) site identification, (10) socio-economic analysis, and (11) uses conflict analysis. Besides this general categorization, the field "specific aim" defined more detailed tool functions and capabilities. If an existing tool was used in a MSP initiative or a new tool was produced specifically for the plan, this information was listed in the "Existing / Produced" field.

2.3. Technical characteristics

DSTs were categorized according to their technical characteristics. The type of information used as input for the DST was identified for each. These inputs were broadly grouped into three categories, represented in MSP frameworks [26,32]: environmental, economic, or social data. Tools were listed according to their technical classification as qualitative, quantitative, spatially explicit and temporally explicit. The prerequisites to run specific software were defined for each tool (i.e., geographic information system (GIS) software, LAN or server connection, Microsoft Excel, etc). Further, the output data of each tool were identified. In addition, types of the tools were recorded in different categories (toolbox, website, web-based application, add-in, etc).

2.4. User fields

The user field includes user skills (skills needed to operate tools such as GIS or modelling), user groups (i.e., authorities, general public, marine users, NGO's, planners, and scientists) and cost of DSTs.

3. Results

The results given were extracted from the DST matrix as a result of the review that is publicly available in http://dst.azti.es. A review of 34 DSTs from 29 MSP experiences can be found in the matrix.

3.1. Present application of DST in MSP

Classification of DSTs according to MSP stages showed that 5% of tools are dedicated to defining goals and objectives (Stage i of the MSP process) (Fig. 1).

The majority (57%) of the identified DSTs were used for gathering data, defining current situation and identification of issues, constraints, and future conditions (Stages ii and iii). Moreover, 16% of the tools were used for the development of alternative management actions (Stage iv). Among first four stages, 7% of DSTs were dedicated to evaluate alternative management actions (Stage v), 10% of DSTs were

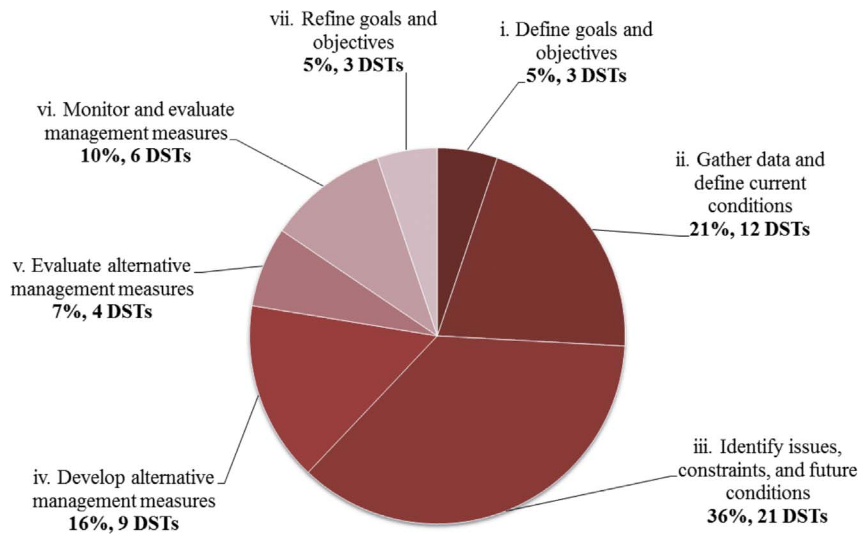

Fig. 1. Percentage and number of the total of Decision Support Tools (DST) used at different stages of Marine Spatial Planning process (see Section 2.1 for the definition of MSP stages).

used in monitoring and evaluation of management action (Stage vi) and just 5% of DSTs were applied to refine goals and objectives (Stage vii).

3.2. Purpose of use

The principal purpose of use of DSTs was site identification (21% of DSTs). In eight different experiences (i.e., 16% of the total), DSTs were used to assess environmental impact of marine activities (e.g. InVEST, Marxan). Communication was the third most common purpose of the DST use (14% of the total). Interactive platforms, web-based maps, communication lists, databases and other practical tools were used for interaction between planners and stakeholders (e.g., SeaSketch, etc.). In each of the seven cases, a new DST was created to communicate with stakeholders, and most of them were web-based. The next most frequent purpose of use (12% of cases) was scenario creation and analysis (Fig. 2).

The reviewed DSTs were also used in MSP for data gathering, economic analysis, management plan proposal, socio-economic analysis, and governance assistance purposes (see DST matrix online (http://dst.azti.es) for the specific tools cited here).

3.3. Type of users

DSTs were used by six different types of users in MSP processes. Most of the users were planners (47% of all tool users) followed by marine users (24% of the total users) (Fig. 3).

Approximately a third of the tools required the user to employ GIS skills. On the other hand, some ecosystem-related tools (i.e. Artificial Intelligence for Ecosystem Services and Atlantis), require additional modelling skills. In 14 cases (48%), planners used tools that could have been applied with basic computer skills.

3.4. Technical characteristics

Most of the DSTs were spatially explicit (68%) including mapping and visualisation tools. Mapping tools and visualisation options can. In contrast, just 16% of tools were temporally explicit. This result was in parallel with a low number of scenario creations and analysis tools (12%).

In total, 56% of tools were dedicated to environmental data processing, with a smaller number of tools dedicated to process economic and social data (22% and 22%; respectively). Although

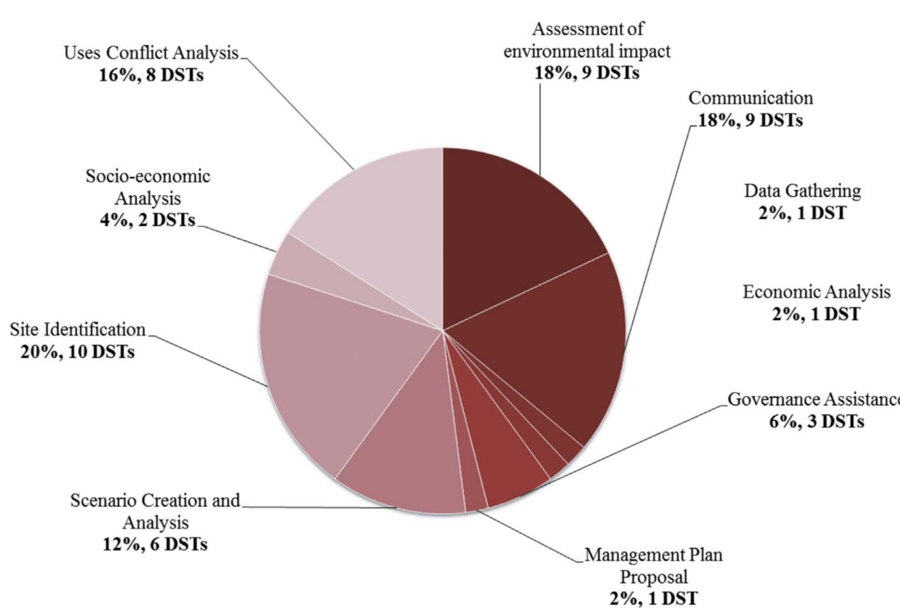

Fig. 2. Purpose of use for Decision Support Tools (DST) (percentage and number of the total number of cases) within Marine Spatial Planning process.

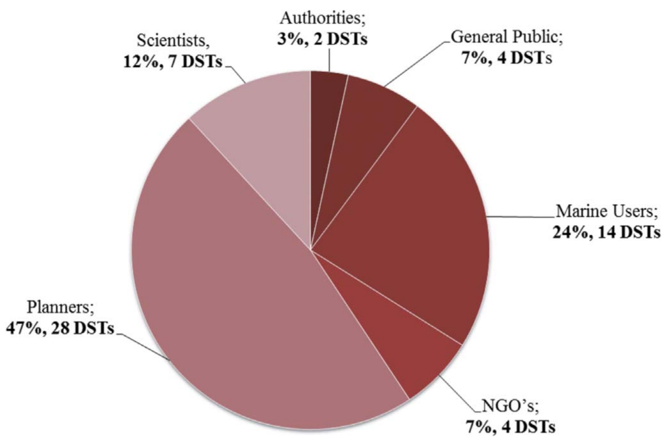

Fig. 3. Percentages number and of different type of Decision Support Tools (DST) users.

economic data were taken into account in ten different cases, there was just one tool that was used for economic analysis purposes (Dorset Coastal Explorer Planning).

A total of 84% of tools used quantitative input data in decision support process and only 16% of tools used qualitative data as input. In terms of type of tool, 46% of all tools were stand-alone tools and 29% of tools were websites. GIS-based tools, add-ins, toolboxes and web-based applications were representing just 14% of all tools that were found in research.

3.5. Cross-cutting characteristics of DSTs

Diversification of aims of use according to MSP stages was identified (Fig. 4).

These results showed that MSP initiatives used DSTs in the same stage and for the same purposes. This analysis demonstrated the lack of DSTs used for data gathering, economic analysis, governance assistant and scenario creation and analysis. DSTs were not used for data gathering, socio-economic analysis, and governance assistance in many MSP stages. In contrast, DSTs used for communication and site identification were distributed throughout all MSP stages.

According to an analysis of user groups in different MSP stages, planners were actively involved in most of the MSP stages (Fig. 5).

Planners were able to apply 14 DSTs in stage iii and nine DSTs in stage ii. On the other hand, scientists were observed as the user group in stage iv "development of alternative management actions" and in stage v "evaluation of alternative management actions". DSTs for marine users were mostly employed in stage vi "monitoring and evaluating management actions". These results revealed a scarcity of DSTs used by authorities and the general public.

4. Discussion

This study reviewed DSTs that were used in MSP processes, and analysed their characteristics that vary according to MSP stages in which they have been used, the specific purpose of their use, their technical characteristics and user profiles. Experiences from existing MSP initiatives showed the necessary development for DSTs to satisfy the needs of the MSP process. The considerations in this section refer to the outcomes abovementioned and open source initiatives; therefore, they may have another interpretation or valuation in the real planning process.

4.1. Experiences in the applications of DSTs in the MSP process

Even if there is general agreement on the usefulness of DSTs in plan development, there are many plans that did not use DSTs. Since marine spatial plans are created to help society adapt to change, DSTs can be considered as a part of the plan or aid to planners. As a result of this, their real application is not evident. It was observed that usage of DSTs is not explicitly cited in MSP reports [21–23,47,48], whereas pilot projects are more DST-friendly due to less time pressure and financial resources from external institutions. Pilot projects allow testing many different approaches. On the contrary, real MSP processes are rapid, output-oriented, in many times authority-driven with limited financial resources [26]. On the other hand, one must also take into account that management plans will not rely solely on outputs of DSTs, and that these plans will be developed by different approaches and expert knowledge [56]. Thus, it could be expected that the use of DSTs could be undertaken at different stages and on a very informative level.

Results revealed that the majority of DSTs were used in the first stages of the MSP process. These stages include the tasks of gathering

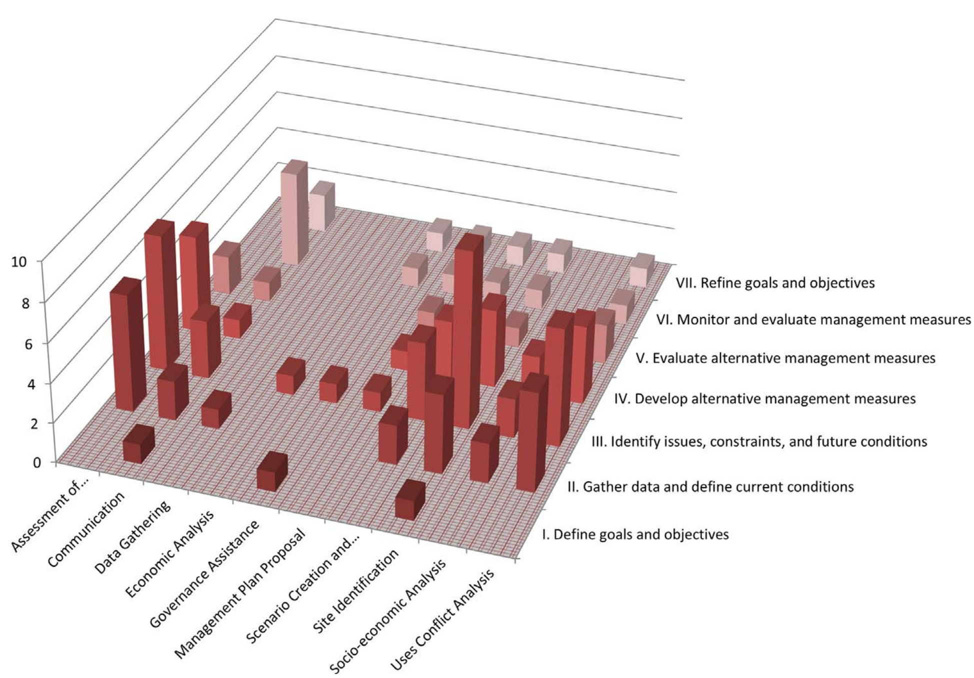

Fig. 4. Aim of use of Decision Support Tools at each Marine Spatial Planning stage (see Section 2.1 for the definition of MSP stages).

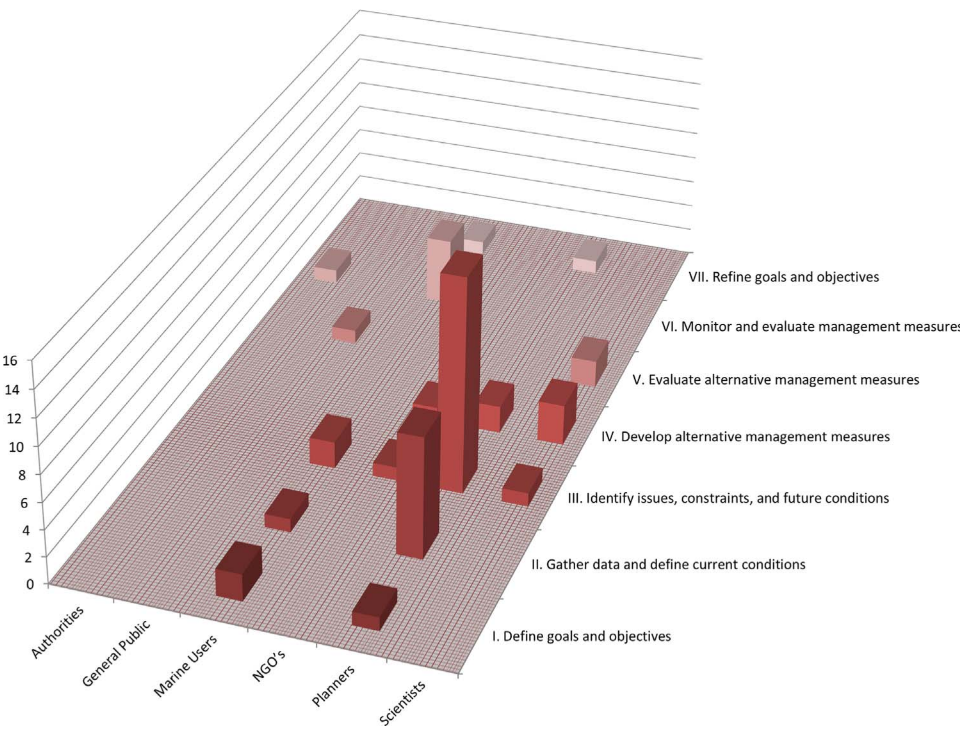

Fig. 5. Diversity of user types at different Marine Spatial Planning stages (see Section 2.1 for the definition of MSP stages).

data, defining the current situation and the identification of issues, constraints, and future conditions. Ehler [32] defined collecting and collating spatially-explicit databases as the most time consuming aspect of planning activities. The current situation analysis of a planning area highlights the direction of next planning stages. The outputs of tasks undertaken in the initial stages of the MSP process feed the development and evaluation stages of management plans. The use of DSTs in the first stages of the MSP process reflects the current level of the MSP process around the world. Even though MSP is not a new concept, its real implementation is in progress and at an early stage in many countries. It could be expected that the development of new tools will be needed for future stages (i.e., evaluation, monitoring and refining goals and objectives).

Furthermore, it can be observed that planners drew on assistance of DSTs for site identification in the initial stages of MSP implementation process. In this sense, DSTs were used by planners to analyse large amounts of data, to visualise current spatial allocation of marine activities, and to perform integrated suitability analysis. As a part of integrated suitability analysis, DSTs were also used in the initial stages of MSP to identify existing human activities that could create conflicts [44,55]. Sustainable and precise spatial allocation is an important task that can help balance high competition for limited marine space between sectorial interests [57]. In addition to using DSTs for site identification of a certain human activity, planners also used DSTs to assess the environmental impact generated by the uses on the environmental components in current and future scenarios [43,44,54,58]. DSTs were used to see actual or potential effects of planned activities on adjacent and other ecosystems [55].

Among others, one extended use of these tools was to identify suitable areas for declaring Marine Protected Areas (MPAs), as well as for the establishment of renewable energy production platforms [39,40,59]. In this context, DSTs were used to achieve conservation targets for MPA identification, and to seek energy production targets for renewable energy platforms. In terms of particular species, ecosystems, or processes and hence, for humans (i.e. delivering ecosystem services), some parts of the sea have much greater importance than others [60]. As in land planning, the 'real estate value' varies greatly in the sea space [32]. Experiences showed that DSTs were helpful to fulfil predefined environmental targets and to see which locations were compatible with development of new human activities, which is central to the art of MSP.

Tools dedicated to communication were used mostly in the last stages of MSP (i.e., monitor and evaluate management measures) [38,49]. Unfortunately, there are few DSTs dedicated to eliciting the opinion of stakeholders in the beginning stages of the MSP process. In contrast, identified tools were able to provide advanced collaboration and engagement options, as well as analytical feedback about planned areas. Online communication tools can increase transparency and collaboration in the MSP process through the involvement of stakeholders' opinions (i.e., Belgium North Sea Atlas: www.noordzeeatlas.nl (accessed 15.02.17)). Using communication-focused DSTs in the beginning stages of the MSP process could allow stakeholders to share their opinions of potential outcomes early on. Stakeholder participation is a requirement for community-based and adaptive management from the early planning stages. Stakeholders may give a better understanding of issues and conflicts through participation in the co-design and co-development of management plans [61].

4.2. *Current gaps of decision support tools*

Functionality gaps of existing tools and the requirements within the MSP process can highlight the future development of DSTs. Fulfilment of these gaps related to tool functionality, MSP stages, maintenance, and complexity of use would help tool developers satisfy the requirements of MSP process.

As compared to other reasons, limited functionality could be considered as the main reason for the infrequent usage of DSTs. Planners may need to use more than one tool for the tasks in a single stage as a result of limited functionality. This observation highlights the need for integrated and multi-functional tools. Furthermore, recognised tool functions are mostly focused on specific purposes, such as site identification and environmental assessment. Only a few tools offer future projection, socio-economic analysis, and stakeholder engagement. These are the functions expected to be needed in future stages like plan monitoring, evaluation and adaptation. In addition to deficiencies of the tools, the limited use of DSTs can also be caused by a lack of demand from the MSP side or a lack of awareness of the available tools that could support the planning tasks. We recognize that this assumption requires screening of the demand side and opinions of marine spatial planners and stakeholders.

As mentioned earlier, tool functions are mainly used for the early stages of MSP. Besides, the use of tools for the evaluation of management actions, monitoring, and refinement of goals / objectives is limited today. Assistance of DSTs is weak in these later stages. The provision of tools that help monitor implemented plans and collect opinions from stakeholders is essential. Fulfilment of these gaps may increase the usage frequency of DSTs in further stages of the MSP process. These future expectations should be considered by planners because the life-cycles of DSTs are directly dependent on their demand and usage. As a result of low-frequency tool usage, many developed DSTs are not available anymore or given sources are not active. These tools have mostly remained as scientific experiences and disappeared. Maintenance and stability of DSTs is one of the primary challenges of tool developers [33].

Although the MSP process should be focused on the balance of environmental, social and economic interests, DSTs were mostly used to assist in environmental issues. There are few DSTs that can support planners to solve economic and social issues in the MSP process. In Europe, diversity of socio-economic activities in marine areas is expected to increase [32]. Thus, tool functions that can analyse economic and social data, in a balanced and integrative way, could have high relevance. For instance, stakeholder-focused DSTs can provide an opportunity for conflict identification and resolution, and also for the proposal of jointly designed solutions. Development of participatory DSTs may increase the ownership and ease of acceptance of management plans.

As these tools reach a wide range of user groups, one of the critical issues in their application is the technical skills needed for tool operation. GIS and modelling knowledge are often needed to apply DSTs. These skills bring the necessity of expert team members to use tools in MSP processes. The use of tools would become more popular if they are easy to use or user-friendly with simple interfaces/apps. Additionally, education and training should be a prerequisite to introducing a DST into the MSP process. The importance of educating and training non-technical users, including marine planners and stakeholders may be underestimated by DST developers and advocates.

Furthermore, cost is another important parameter that affects the degree of DST usage. Some of the tools require commercial licenses to execute. Accessibility of such tools should be free to achieve broader range of users. Especially for developing countries, the licence cost, data collection and labour costs for DST usage can limit MSP developments. In most cases, DSTs require a large amount of information, and the effort of collecting/organizing the data is often time-consuming. This activity can draw resources away from equally important tasks such as specifying clear and measurable objectives and management actions. One can observe examples where data portal developments became the principal output of MSP rather than a plan. Such time consuming and costly tasks have caused MSP initiatives to be finalized as data portals that put real planning actions off until the next round. (e.g. Mid-Atlantic Ocean Data Portal: http://portal.midatlanticocean.org/, Northeast Ocean Data: http://www.northeastoceandata.org/ (accessed 15.02.17).

4.3. Future DST developments for MSP

Developments for DSTs should be parallel to the future needs of the MSP process. Since there are many countries in the initial stages of MSP, demand for DSTs for review and monitoring tasks may increase in the near future. Successful implementation requires a wide range of tasks and complex decisions. In this regard, it is necessary to aim for more attractive innovations and new strategies for the market. Development trends can be analysed from this perspective in parallel with the MSP process.

Firstly, DSTs should be more functional and integrative in order to assist present and future needs of MSP. Future projection, scenario analysis, plan review, monitoring, cost-benefit analysis and online participation functions can be foreseen as the future functionality needs of MSP. On the other hand, DSTs that can perform more than one function may have higher demand for complicated and multi-phased decision problems such as the spatial allocation of human activities affecting the marine environment. DSTs should address needs of decision makers for different kind of tasks that may be continuous given the dynamic nature of the sea.

In this sense, DSTs may be an important contribution for temporally explicit analysis. By taking into account the time dimension, potential future conflicts may be highlighted prior to their development. Historical data can highlight future patterns, and tools may use flexible input to change conditions for different objectives. For instance, DSTs should be able to run scenarios in which climate change, as well as human activities on the sea, will influence marine ecosystems [58]. Since changes in sea level, air pressure and wind conditions are expected due to climate change, DSTs can help planners to foresee possible impacts. As a result of impacts on fisheries, marine traffic, aquaculture and other human activities, society will also be affected directly [62]. Therefore, DSTs can be useful to help society adapt to these changes in the geographical distribution of the marine ecosystem with a more sustainable MSP.

In contrast, tool innovations should focus social and economic concerns [63]. As an alternative to different techniques, computer-based tools can support planners to project economic effects of spatial decisions [6]. In that sense, cost-benefit analysis may help planners to compare expected utility and possible impacts for economy and society. Planners can have a broader perspective if they can evaluate the opportunity cost of a spatial decision. In that sense, tools supporting bio-economic and socio-economic assessment in an integrative way may have great potential in the future.

Besides advanced functionality, financial and technical stability should be also maintained and DSTs should be sustainable. Tool developers should seek multiple revenue streams and ensure financial support [33]. Although academia develops many tools, financial sources are not sufficient to maintain and host all of the DSTs that are created. It is recommended that responsible authorities establish a public funding system for maintenance of DSTs and project outputs. MSP tools developed by an academic project shouldn't have the same lifetime with a project website. For instance, the European Commission can act as a key institution in collecting project results and providing maintenance as well as technical support for upcoming tools. Although there were platforms that keep records of tool examples, a clear and constantly funded database that hosts existing and future DSTs may help to achieve sustainability. Future developments should be in this direction to satisfy the need of planners that seek for stable tools.

Moreover, the development of communication tools can increase stakeholder involvement. Online tools that ask for the feedback of marine users in real time can have a significant effect on participation. DSTs can be used in stakeholder meetings and workshops to increase the participatory process. Furthermore, the development of user-friendly tools that require fewer technical skills can help to reach different user profiles and increase application frequency. The involvement of stakeholders in DST development should be improved to decrease reluctance of users. Essential needs and rules for decision making proposed by stakeholders should be considered in the first phase of tool development. In that sense, there is still the need for DST developments that could fulfil the needs of planners and stakeholders to support MSP.

Although the characteristics given here may describe an ideal tool for MSP, it is hard to include all desired features in a single DST. Given the specificities and individual planning processes, it seems rather impossible to develop a tool, which considers both spatial and temporal dynamics of the ocean, provides multi-functionality and integrity, meanwhile being easy to use and available for free. But these concepts should not be forgotten. On the contrary, this analysis summarizes the expected development trends and innovations for DSTs and new DSTs can be positioned according to the current level of MSP around the world.

5. Conclusions

In this work, a detailed review of scientific papers and MSP implementation work was completed to analyse and assess the use of DSTs, allowing the identification of existing functionality gaps and future requirements. Most of the MSP reports examined did not explicitly state the application of DSTs. Thus, it is possible that this lack of specificity could lead to uncertainty regarding the DST outcomes in the management plans. It was identified that most of the tools were applied in the first stages of the MSP process, which reflects the fact that most countries have only just started to apply MSP. Based on these results, it is likely that as more countries implement MSP measures, this might trigger the demand of additional functions of DSTs. Thus, new tools and functionalities should be available to fulfil this demand. Based on expected needs, new DSTs should have the capacity to address future scenarios, socio-economic aspects, and improve communication and participation of stakeholders. Moreover, it can be expected that the availability of user-friendly tools with advanced functions and stable financial and technical support will facilitate further tool development and encourage decision makers to use them in the MSP process.

In conclusion, this review contributes to the present status and the future development of DSTs by highlighting current gaps and future needs in the MSP implementation process. In addition, it is likely that additional information derived from inputs and perceptions of end-users and planners will provide a broader perspective on further research.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2017.05.031.

References

[1] B.S. Halpern, S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck, R. Watson, A global map of human impact on marine ecosystems, Science 319 (5865) (2008) 948–952.
[2] L. Uusitalo, S. Korpinen, J.H. Andersen, S. Niiranen, S. Valanko, A.-S. Heiskanen, M. Dickey-Collas, Exploring methods for predicting multiple pressures on ecosystem recovery: a case study on marine eutrophication and fisheries, Cont. Shelf Res. 121 (2016) 48–60.
[3] M.G. Burgess, M. Clemence, G.R. McDermott, C. Costello, S.D. Gaines, Five rules for pragmatic blue growth, Marine Policy.
[4] K. Gee, A., H.B. Kannen, BaltSeaPlan Vision 2030: towards the Sustainable Planning Of Baltic Sea Space, BaltSeaPlan, Hamburg, 2011.
[5] E. Domínguez-Tejo, G. Metternicht, E. Johnston, L. Hedge, Marine spatial planning advancing the ecosystem-based approach to coastal zone management: a review, Mar. Policy 72 (2016) 115–130.
[6] EC, Directive of the European Parliament and of the Council of 23 July 2014, Establishing a Framework for Maritime Spatial Planning 2014/89/EU, Official Journal of the European Union, 2014.
[7] C. Ehler, F. Douvere, Visions for a Sea change, IOC, Man. Guides 48 (2007).
[8] M.M. Foley, B.S. Halpern, F. Micheli, M.H. Armsby, M.R. Caldwell, C.M. Crain, E. Prahler, N. Rohr, D. Sivas, M.W. Beck, M.H. Carr, L.B. Crowder, J. Emmett Duffy, S.D. Hacker, K.L. McLeod, S.R. Palumbi, C.H. Peterson, H.M. Regan, M.H. Ruckelshaus, P.A. Sandifer, R.S. Steneck, Guiding ecological principles for marine spatial planning, Mar. Policy 34 (5) (2010) 955–966.
[9] D. Rodríguez-Rodríguez, D.A. Malak, T. Soukissian, A. Sánchez-Espinosa, Achieving Blue Growth through maritime spatial planning: offshore wind energy optimization and biodiversity conservation in Spain, Mar. Policy 73 (2016) 8–14.
[10] A. Borja, M. Elliott, J.H. Andersen, T. Berg, J. Carstensen, B.S. Halpern, A.-S. Heiskanen, S. Korpinen, J.S.S. Lowndes, G. Martin, N. Rodriguez-Ezpeleta, Overview of Integrative Assessment of Marine Systems: the Ecosystem Approach in Practice, Front. Mar. Sci. 3 (20) (2016).
[11] Á. Borja, M. Elliott, J. Carstensen, A.-S. Heiskanen, W. van de Bund, Marine management – Towards an integrated implementation of the European Marine Strategy Framework and the Water Framework Directives, Mar. Pollut. Bull. 60 (12) (2010) 2175–2186.
[12] S. Katsanevakis, V. Stelzenmüller, A. South, T.K. Sørensen, P.J.S. Jones, S. Kerr, F. Badalamenti, C. Anagnostou, P. Breen, G. Chust, G. D'Anna, M. Duijn, T. Filatova, F. Fiorentino, H. Hulsman, K. Johnson, A.P. Karageorgis, I. Kröncke, S. Mirto, C. Pipitone, S. Portelli, W. Qiu, H. Reiss, D. Sakellariou, M. Salomidi, L. van Hoof, V. Vassilopoulou, T. Vega Fernández, S. Vöge, A. Weber, A. Zenetos, Rt Hofstede, Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues, Ocean Coast. Manag. 54 (11) (2011) 807–820.
[13] V. Stelzenmüller, P. Breen, T. Stamford, F. Thomsen, F. Badalamenti, Á. Borja, L. Buhl-Mortensen, J. Carlstöm, G. D'Anna, N. Dankers, S. Degraer, M. Dujin, F. Fiorentino, I. Galparsoro, S. Giakoumi, M. Gristina, K. Johnson, P.J.S. Jones, S. Katsanevakis, L. Knittweis, Z. Kyriazi, C. Pipitone, J. Piwowarczyk, M. Rabaut, T.K. Sørensen, J. van Dalfsen, V. Vassilopoulou, T. Vega Fernández, M. Vincx, S. Vöge, A. Weber, N. Wijkmark, R. Jak, W. Qiu, R. ter Hofstede, Monitoring and evaluation of spatially managed areas: a generic framework for implementation of ecosystem based marine management and its application, Mar. Policy 37 (2013) 149–164.
[14] J.S. Collie, W.L. Adamowicz, M.W. Beck, B. Craig, T.E. Essington, D. Fluharty, J. Rice, J.N. Sanchirico, Marine spatial planning in practice, Estuarine, Coastal and Shelf Science 117 (2013), pp. 1–11.
[15] Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Zoning Plan (2003).
[16] National Ocean Council, Guidance for Marine Plans, Marine Planning Handbook (2013).
[17] S.B. Olsen, J.H. McCann, G. Fugate, The State of Rhode Island's pioneering marine spatial plan, Mar. Policy 45 (2014) 26–38.
[18] E. Executive Office of Energy and Environmental Affairs, Massachusetts Ocean Management Plan, (2015).
[19] R. Feng, X. Chen, P. Li, L. Zhou, J. Yu, Development of China's marine functional zoning: a preliminary analysis, Ocean Coast. Manag. 131 (2016) 39–44.
[20] T. Israel Institute of Technology, The Israel Marine Plan, (2015).
[21] B. Bundesamt, für Seeschifffahrt und Hydrographie, Spatial Plan for the German Exclusive Economic Zone in the Baltic Sea, 2009.
[22] B. Bundesamt, für Seeschifffahrt und Hydrographie, Spatial Plan for the German Exclusive Economic Zone in the North Sea, 2009.
[23] Belgian Royal Decree, Marine Spatial Plan for the Belgian Part of the North Sea, (2014).
[24] Ministry of Infrastructure and the Environment, National Water Plan 2016–2021, (2015).
[25] E. Olsen, H. Gjøsæter, I. Røttingen, A. Dommasnes, P. Fossum, P. Sandberg, The Norwegian ecosystem-based management plan for the Barents Sea, ICES J. Mar. Sci. 64 (4) (2007) 599–602.
[26] J. Zaucha, Vision, S.a.t.B.S. Secretariat, The key to Governing the fragile Baltic Sea: maritime spatial planning in the Baltic Sea region and way forward, VASAB Secr. (2014).
[27] L. Buhl-Mortensen, I. Galparsoro, T. Vega Fernández, K. Johnson, G. D'Anna, F. Badalamenti, G. Garofalo, J. Carlström, J. Piwowarczyk, M. Rabaut, J. Vanaverbeke, C. Schipper, J. van Dalfsen, V. Vassilopoulou, Y. Issaris, L. van Hoof, E. Pecceu, K. Hostens, M.L. Pace, L. Knittweis, V. Stelzenmüller, V. Todorova, V. Doncheva, Maritime ecosystem-based management in practice: Lessons learned from the application of a generic spatial planning framework in Europe, Mar. Policy (2016).
[28] A. Schultz-Zehden, K. Gee, Towards a multi-level governance framework for MSP in the Baltic (2016), Bull. Marit. Inst. Gdań. 31 (1) (2016) 34–44.
[29] A. Schultz-Zehden, G. Kira, Toward Sectoral Stakeholder Involvement in a pan-Baltic MSP Bulletin of the Maritime Institute in Gdańsk (31(1): 34-44) (2015).
[30] A. Schultz-Zehdenn, G. Kira, Findings. experiences and Lessons from BaltSeaPlan, Berl.: S. Pro (2013) 148.
[31] C. Ehler, Conclusions: benefits, lessons learned, and future challenges of marine spatial planning, Mar. Policy 32 (5) (2008) 840–843.
[32] C. Ehler, F. Douvere, Marine spatial planning: A Step-by-Step Approach toward Ecosystem-based Management, IOC Manual and Guides No. 53 (Intergovernmental Oceanographic Commission and Man and the Biosphere Programme.), 2009.
[33] C. Curtice, D.C. Dunn, J.J. Roberts, S.D. Carr, P.N. Halpin, Why ecosystem-based management may fail without changes to tool development and Financing, BioScience 62 (5) (2012) 508–515.

[34] V. Stelzenmüller, J. Lee, A. South, J. Foden, S.I. Rogers, Practical tools to support marine spatial planning: a review and some prototype tools, Mar. Policy 38 (2013) 214–227.
[35] D.C. Rose, W.J. Sutherland, C. Parker, M. Lobley, M. Winter, C. Morris, S. Twining, C. Ffoulkes, T. Amano, L.V. Dicks, Decision support tools for agriculture: towards effective design and delivery, Agric. Syst. 149 (2016) 165–174.
[36] H. Coleman, M. Foley, E. Prahler, M. Armsby, G. Shillinger, Decision guide, Selecting decision support tools for marine spatial planning, Cent. Ocean Solut. (2011).
[37] K.G. Andreas Kannen, Nerijus Blazauskas, Roland Cormier, Karsten Dahl, Cordula, A.M. Göke, Antje Ross, Angela Schultz-Zehden, A catalogue of approaches and tools for MSP, Bonus Baltspace Deliv. 3 (2016) 2.
[38] M. Fetissov, R. Aps, M. Kopti, BaltSeaPlan Web - advanced tool in support of Maritime Spatial Planning, BaltSeaPlan Report 28, 2011.
[39] C. Göke, J. Lamp, Case Study: Systematic site selection for offshore wind power with Marxan in the pilot area Pomeranian Bight, BaltSeaPlan Report 29, 2012.
[40] S. Jörg, J. Lamp, Case Study: Site selection of fisheries areas for Maritime Spatial Planning with the help of tool Marxan with Zone in the pilot area Pomeranian Bight, BaltSeaPlan Report 30, 2012.
[41] Common Wadden Sea Secretariat, Wadden Sea Plan 2010. in: Proceedings of the Eleventh Trilateral Governmental Conference on the Protection of the Wadden Sea., Wadden Sea Secretariat, Wilhelmshaven, Germany. (2010).
[42] G.F.A.f.N.C. BFN, Marine Spatial Planning in the German Exclusive Economic Zone of the North and Baltic Seas, (2006).
[43] A. Rosenthal, G. Verutes, K. Arkema, C. Clarke, M. Canto, S. Rosado, S. Wood, InVEST Scenarios Case Study: Coastal Belize, Natural Capital Project, 2012.
[44] ESSIM Planning Office, The Eastern Scotian Shelf Integrated Ocean Management Plan, Fisheries and Oceans Canada (2007).
[45] Direction of the Galapagos National Park, Management Plan for Conservation and Sustainable Use of the Galapagos Marine Reserve, (1998).
[46] Norwegian Ministry of the Environment, Integrated Management of the Marine Environment of the North Sea and Skagerrak (Management Plan), Meld. St. 37 (2012–2013) Report to the Storting (white paper) (2012).
[47] S. Kidd, Rising to the integration ambitions of Marine Spatial Planning: reflections from the Irish Sea, Mar. Policy 39 (2013) 273–282.
[48] S. Kidd, L. McGowan, Constructing a ladder of transnational partnership working in support of marine spatial planning: thoughts from the Irish Sea, J. Environ. Manag. 126 (2013) 63–71.
[49] M.A. Vincent, S.M. Atkins, C.M. Lumb, N. Golding, L.M. Lieberknecht, M. Webster, Marine nature conservation and sustainable development - the Irish Sea Pilot, Defra by the Joint Nature Conservation Committee, 2004.
[50] S. Airamé, J.E. Dugan, K.D. Lafferty, H. Leslie, D.A. McArdle, R.R. Warner, Applying Ecological Criteria to Marine Reserve Design: A Case Study from the California Channel Islands, 13 Ecological Applications,, Ecological Applications, 2003.
[51] M.W. Beck, M. Odaya, Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico, Aquat. Conserv.: Mar. Freshw. Ecosyst. 11 (4) (2001) 235–242.
[52] I. Altman, R. Boumans, J. Roman, L. Kaufman, Multi-scale Integrated Model of Ecosystem Services (MIMES) for the Massachusetts Ocean (v 1.0):, (2012).
[53] Å. Andersson, S. Korpinen, A.-.S. Liman, P. Nilsson, H. Piekäinen, A. Huggins, BALANCE Technical Summary Report PART 3/4: Ecological coherence and principles for MPA assessment, selection and design, 2008.
[54] C.P. Barbanti A, F. Musco, A. Sarretta, E. Gissi, Developing a Maritime Spatial Plan for the Adriatic –I, 2015.
[55] S. Menegon, A. Sarretta, A. Barbanti, E. Gissi, C. Venier, Open source tools to support integrated coastal management and maritime spatial planning, PeerJ Prepr. 4 (2016) e2245v2.
[56] V. Stelzenmüller, H.O. Fock, A. Gimpel, H. Rambo, R. Diekmann, W.N. Probst, U. Callies, F. Bockelmann, H. Neumann, I. Kröncke, Quantitative environmental risk assessments in the context of marine spatial management: current approaches and some perspectives, ICES J. Mar. Sci.: J. du Cons. 72 (2015) 1022–1042.
[57] I. Galparsoro, P. Liria, I. Legorburu, J. Bald, G. Chust, P. Ruiz-Minguela, G. Pérez, J. Marqués, Y. Torre-Enciso, M. González, Á. Borja, A Marine Spatial Planning Approach to Select Suitable Areas for Installing Wave Energy Converters (WECs), on the Basque Continental Shelf (Bay of Biscay), Coast. Manag. 40 (1) (2012) 1–19.
[58] E. Glaas, A.G. Ballantyne, T.-S. Neset, B.-O. Linnér, Visualization for supporting individual climate change adaptation planning: assessment of a web-based tool, Landsc. Urban Plan. 158 (2017) 1–11.
[59] M.E. Watts, I.R. Ball, R.S. Stewart, C.J. Klein, K. Wilson, C. Steinback, R. Lourival, L. Kircher, H.P. Possingham, Marxan with zones: software for optimal conservation based land- and sea-use zoning, Environ. Model. Softw. 24 (12) (2009) 1513–1521.
[60] R. Costanza, R. de Groot, P. Sutton, S. van der Ploeg, S.J. Anderson, I. Kubiszewski, S. Farber, R.K. Turner, Changes in the global value of ecosystem services, Glob. Environ. Change 26 (2014) 152–158.
[61] A. Newton, M. Elliott, A typology of Stakeholdersand Guidelines for engagement in Transdisciplinary, participatory processes, Front. Mar. Sci. 3 (2016) 230.
[62] A. Meiner, J. Reker, Balancing the future of Europe's coasts — knowledge base for integrated management, 2013.
[63] J. Rice, M.dF. Borges, A. Grehan, A. Kenny, H. Loeng, F. Maynou, R.Serrão Santos, H.R. Skjoldal, O. Thébaud, V. Vassilopoulou, F. Volckaert, Science dimensions of an Ecosystem Approach to Management of Biotic Ocean Resources (SEAMBOR), 2010.