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Practical tools to support marine spatial planning: A review and some prototype tools

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ABSTRACT

Marine planners use spatial data to assess planning options. They need analytical approaches, methods, applications and practical software tools to enable assessment of the relationships between human uses and ecosystem components. Here the results of a two-stage process, aimed at developing practical and GIS-based tools for direct use by planners, are presented. First, some available tools for use in the early stages of plan development were reviewed; for example, to identify interaction between activities to reduce potential conflicts or assist in zone delineation, methods to facilitate a risk assessment of the cumulative effect of human pressures and tools offering decision support. Second, a stakeholder workshop was organised to identify routine marine planning tasks and the technical tools required to support those tasks. From the 39 practical tools reviewed, mostly published in peer-reviewed literature between 1998 and 2009, the majority have been applied in the marine environment in Europe, USA and Australia. It was observed that many of the tools are designed to be used by scientists, programmers or strategic planners with only a few that could be used by case officers (regulators). Together with the results of the stakeholder workshop a suite of prototype tools were developed that offer utility to marine planners. Thus the developed tools provide a solid basis for future development as they are a result of a transparent and participatory process.

1. Introduction

Worldwide marine spatial planning (MSP) is advocated as a promising tool to support the implementation of ecosystem-based marine management [1,2]. Marine spatial planning is defined as a public process of analysing and allocating the spatial and temporal distribution of current and future human activities in marine areas, to achieve ecological, economic, and social objectives that usually have been specified through a political process [3,4]. Moreover ecosystem-based MSP explicitly incorporates ecological principles which articulate the scientifically recognised attributes of healthy, functioning ecosystems into a decision-making framework [5]. Among the most important drivers for MSP in Europe are the Maritime Policy or 'Blue Book' [6] issued by the European Commission in the context of the EU Thematic Strategy and European legislation on nature conservation such as the Birds Directive [7] and the Habitats Directive [8]. Examples of national MSP implementation are the recent UK Acts to deliver a new marine planning system, which will enable the development of marine plans where the protection of the seas and the ability to balance pressures on them will be enhanced [9,10].

There is a growing body of literature regarding the underlying concepts of MSP [5,11,12], the processes involved in its implementation [13–15] and practical experiences [16–19]. Practical guidance for the development of spatial plans often describes a sequence of tasks within a planning framework. A prominent example is provided by the United Nations Educational, Scientific and Cultural Organisation, where worldwide MSP examples have been described and synthesised in a good practice guide for MSP [20]. Ten steps depict the cyclic process comprising scoping, setting of goals and objectives, initial assessment, plan development and implementation with strong stakeholder participation throughout, and a final adoption of the implemented plan, based on a performance assessment (see also [13]).

Whilst there is conceptual guidance for MSP, practical tools to support the implementation of the various steps are still scarce [5,21]. In general, such tools are manifold and can comprise frameworks, meetings, methods or technical solutions (see examples in EBM network toolbox; www.ebmtools.org). Furthermore, not all steps of such a planning process require underpinning science. Thus the main scientific input is required for the initial assessment, the development of spatial management scenarios and for plan performance assessment. Specifically, scientific

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information is the building block for the key tasks of data collection, analysis and the development and evaluation of spatial management options.

More precisely, the marine planning process requires an integrated assessment of (*i*) multiple objectives, (*ii*) conflicts and synergies of marine uses, (*iii*) the risk of cumulative effects of human activities, (*iv*) spatial zoning or management options, and (*v*) scenario testing. For this integrated assessment, marine planners and case officers (regulators) need practical tools which ultimately support marine planning in practice. These tools include risk assessment tools, forecasting and modelling tools and other decision support tools such as simulation models to facilitate 'what if' questions/scenarios from which planning options can be developed.

Inherent within the concept of marine planning is the requirement to process and analyse information with a spatial component and so there are obvious benefits to implementing marine planning within a Geographic Information System (GIS) framework. Practical tools should not only be useful in the preparation of the plans themselves, but may also assist regulators and case officers to put a plan into effect when making routine licensing decisions.

A process that has led to the development of some prototype planning tools designed to address this need for practical, easy to use tools to support the plan development by planners and decision makers, is described here. This three-part process comprised a review of existing planning tools, a stakeholder workshop on tool requirements for routine planning tasks, and the development of GIS-based tools. Only tools relevant to the initial development of plans (including examples from terrestrial planning) and the assessment and analysis of options were reviewed. Three categories of possible practical tools for MSP were distinguished: those that could be used for (*i*) identifying spatial interactions between activities; (*ii*) risk assessment of cumulative effects of human pressures (CEA); and (*iii*) decision support (DSS). In the second step, an expert workshop to determine the requirements for practical tools to support routine planning tasks was held. Based on the review and workshop results a suite of prototype tools, driven by spatial data and designed to simplify or automate routine procedures, was developed, thereby allowing maximum utility without the need for high levels of GIS technical expertise. These tools were developed using Visual Basic (http://vb.net/uk/index.html) within the Visual Studio development environment and were designed to be used with the ESRI ArcGIS software. The resulting toolbar provides additional functionality when enabled within an ArcGIS map document.

2. Material and methods

2.1. Review of practical planning tools

For each tool category available or published, practical solutions were reviewed and assessed against standardised criteria to ensure comparability. As the objective of this initiative was to evaluate the capability and practicality of a certain tool to aid the routine tasks of marine planners the aim of the tool and the associated references was reported. Further, the tools were classified using the following criteria: potential users (programmer, scientist, strategic planner, case officer, public), data requirements, purchase cost (commercial > £100, commercial ≤ £100), last update (date), marine use (yes/no), and location used (scale, country, case study). Since the results of this review have been used to define the gaps and consequently the needs for the development of prototype planning tools, a comprehensive assessment of the advantages and disadvantages of the use of a certain tool was not included. The background and reasoning for the review process for each tool category are briefly described below.

2.1.1. Spatial interaction between activities

Allocating space to particular activities within a marine environment poses challenges that are more problematic than in land-based planning. In the marine environment conflicts between users are more common and boundaries are more difficult to identify and enforce [3,4]. Spatial zoning can be used to separate potentially conflicting activities and may result in a particular sector being granted near-exclusive use of specific areas of the sea [22]. However, zoning often occurs following the development of a spatial plan, effectively becoming one of the tools used to implement the plan and usually as a component of a more comprehensive management strategy. An understanding of the extent and intensity of existing activities is necessary before zones can be established. Furthermore, zoning, or the development of spatial management options, requires that management objectives be clearly defined in conjunction with the indicators to assess achievement of those objectives. All of this information must be presented in a format that is easy to understand both by users of the marine environment and by those with a management remit [23]. A wide range of variables must be taken into account e.g., data describing the physical and biological characteristics of the area; user activity within the area; user values and perceptions; and an appreciation of conflicts between competing users and between users and the environment [13].

In land use management, current approaches for defining and assessing spatial management options encompass, for instance, multi criteria analyses (MCA) or spatial optimisation techniques such as Pareto optimality (see [24,25] and references therein). While the former approach requires a weighting of management objectives, for example using stakeholder opinions, the latter eliminates the need for a prior specification of weights and represents a more complex and computationally intensive approach. Multi criteria analysis comprises a series of methods allowing a comparison between alternative outcomes based on multiple factors. It includes techniques for structuring objectives, performing sensitivity analysis and enhancing presentation and visualisation of results [26,27]. Development of the criteria layers used to drive the MCA is an important component and can provide useful insight into conflicting activities within an area. Multi criteria analysis has been applied as an aid to zoning within marine protected areas [28], across national borders [23], in coastal areas [29] and for broad-scale marine management [17], with the sources of the criteria layers being many and varied. Only technical tools that facilitate the implementation of MCA in the context of zone delineation were reviewed, as the aim was to identify the gaps in exploratory tools to assist in the quantification of current activities, prior to the establishment of zones or spatial management options.

2.1.2. Cumulative effect assessment

Currently, the management of marine resources often follows a sector by sector approach, where each human activity, such as fisheries, energy production or shipping, is managed independently [30]. This sectoral approach to marine management makes it difficult to assess cumulative effects of multiple human activities and their associated pressures. Cumulative effects or impacts can be described as the combined effect of multiple activities over space and time [31]. A cumulative effect assessment (CEA) forms a part of a strategic environmental assessment and environmental impact assessment, where adverse effects on a resource or valued ecosystem component are assessed. Components of a CEA may include an initial scoping stage, the setting of spatial and temporal boundaries, the identification of valued components and indicators, the identification of the source of impact and the likely pathways of occurrence, and the assessment or prediction of impacts [32].

The determination of the impact from a particular human activity on a resource or valued ecosystem component within a spatial area requires both a method for translating human activities into ecosystem specific impacts, and spatial data describing the activities and ecosystem components [1]. Once the impact of a particular activity is defined the interaction between human activity impacts can be assessed. There are several ways in which human activities can interact. Individual events of a particular activity can result in (*i*) no cumulative impact, (*ii*) accumulative impact, or (*iii*) fully additive impact. While multiple activities can interact in four different ways: (*i*) dominance of one activity, (*ii*) pure addition of impacts, (*iii*) multiplicative impact that is larger than the sum of the single impacts, and (*iv*) mitigation of one activity by the impact of the others (see [30,33]). Thus currently available methods and approaches to assess cumulative impacts of human activities were assessed, but with an emphasis on ready-to-use software tools to facilitate the creation of data layers reflecting combined or cumulative impacts of human activity on sensitive ecosystem components.

2.1.3. Decision support systems

Decision support is a broad field comprising many aspects of planning and implementation. Accordingly, practical software tools were reviewed that can be used to support decision making in the planning process. Decision Support Systems (DSS) are

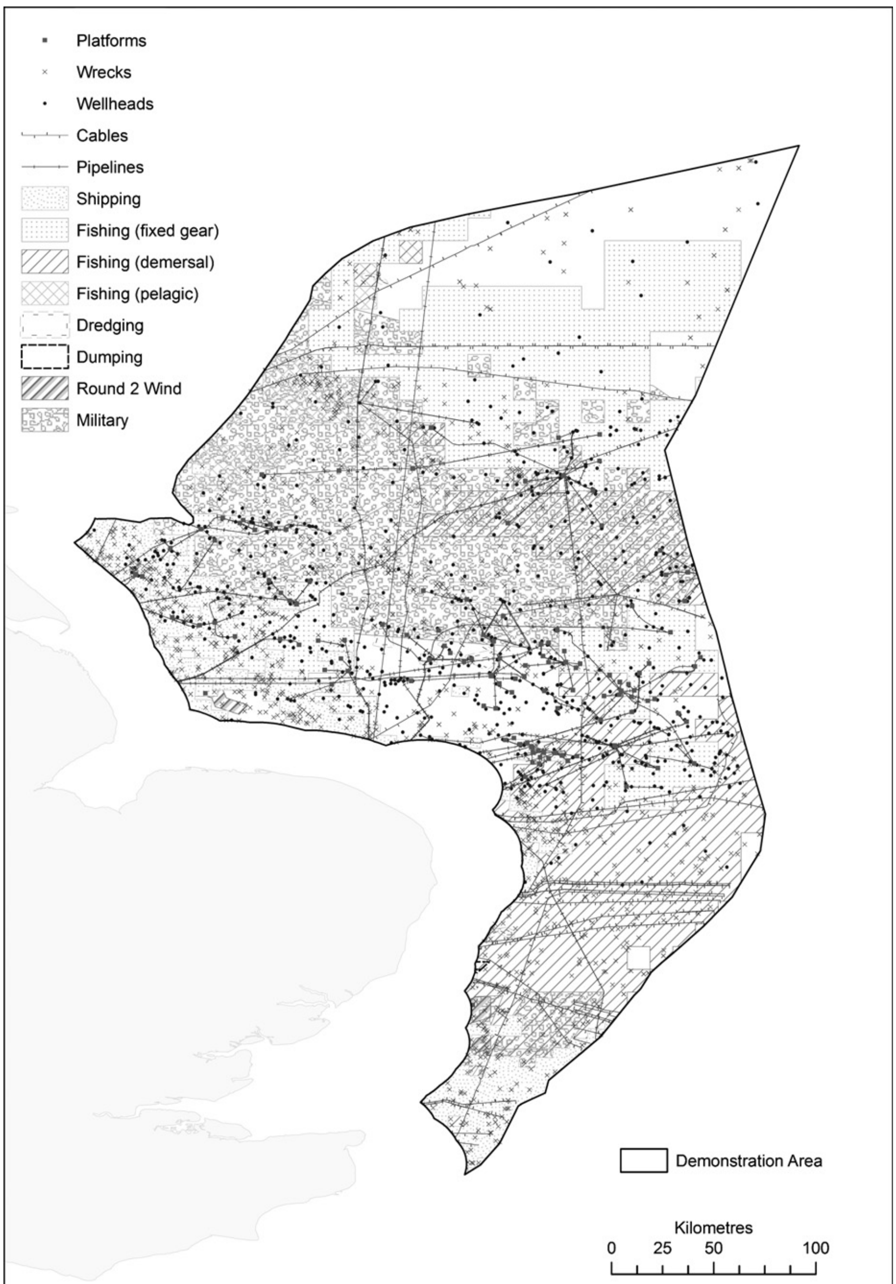

Fig. 1. Sample data used to develop prototype tools.

Table 1
Summary table of the reviewed practical tools for spatial allocation, cumulative risk assessment, and decision-support systems.

No.	Tool category	Tool name	What does it do?	Potential users	Data requirements	Costs	Last update	Marine use	Locations used	References
Tool nr.	Spatial interaction CEA DSS (analysis; data; communication; forecasting)	Tool name Publication title	Brief description of the aim of the tool and general methods	Programmer Scientist Strategic planner Case office Public	Short description on data requirements: GIS layer Expert group Model parameters	Commercial > £100 Commercial ≤ £100 Shareware Software free—support extra Freeware	Last update of software	yes no	Scale, country, case study name	Article website
C1	CEA	An approach to identify vulnerable areas	GIS-based model to assess the probability of disturbance of whales by considering combined stressors. Multiple stressors where added where each activity layer reflected probability of response.	Scientist	GIS layers on ecology and human pressures	–	–	yes	Regional, Canada British Columbia	[37]
C2	CEA	Global map of human impact on marine ecosystems	GIS-based ecosystem-specific spatial model to synthesize global data sets of human activity. Weighting of impact of particular activities per ecosystem.	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	Global scale	[30]
C3	CEA	Assessment of the intensity of human activities	GIS-based approach to map and rank the impact of human activities. Activities impacts were ranked and a stressor value beyond location of occurrence was created to account for spatial distribution.	Scientist	GIS layers on human pressures, expert group	–	–	yes	British Columbia, Canada	[16]
C4	CEA	Estimating marine cumulative effects	GIS-based approach to assess the yield based on the interaction of various activities	Scientist	GIS layers on human pressures, expert group	–	–	yes	Bay of Fundy, North America	[42]
C5	CEA	Marine Planning framework for South Australia	GIS approach within a marine spatial plan summarises the number of activities per planning unit.	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	South Australia	[17]
C6	CEA	MARA GIS tool	Development of a GIS tool to implement the MARA Framework	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	North Sea	MARA project
C7	CEA	ACEA GIS demo	GIS and remote sensing tools were used to provide the means for data and models integration, thus providing a technical foundation for characterizing environmental effects across the Denver metropolitan region.	Scientist, Strategic planner	GIS layers	–	–	no	Denver, USA	http://www.itre.ncsu.edu/ADC10/PDFs/2007_Winter_Conference/session585/Paper_(07–2611).pdf
C8	CEA	Ocean Communities 3E Analysis (OCEAN)	GIS toolkit. Perform overlays or spatial queries, perform statistical analyses, provide summary statistics resulting from real or hypothetical area-based management scenarios or optimisation analyses (such as cumulative weighting or simulated annealing)			Commercial ≤ £100	unknown	yes	USA	http://www.ecotrust.org/ocean/
C9	CEA	BALANCE GIS tools	GIS approach to predicting anthropogenic influence on coastal lagoons and large shallow inlets and bays.	Scientist, Strategic planner	GIS layers on human pressures	–	–	yes	Baltic Sea	www.balanceeu.org Balance Interim Report 28, pp66,
C10	CEA	Irish Sea Pilot	Collation of geodata and approaches to map human pressures	Scientist	GIS layers on human pressures	–	–	yes	Irish Sea	[43]
C11	CEA	GIS-based cumulative effects assessment	GIS approaches to assess environmental impact assessment	Scientist	GIS layers on ecology and human pressure	–	–	no	Colorado	[44]

Table 1 (*continued*)

No.	Tool category	Tool name	What does it do?	Potential users	Data requirements	Costs	Last update	Marine use	Locations used	References
C12	CEA	The practical implement-ation of MSP—under-standing and addressing cumulative effects	Framework for the practical implementation of CEA based on the outcomes of an expert workshop	Scientist, Strategic planner	(spatial and temporal data on human activities and environment)	–	–	yes	UK	[44]
D1	DSS analysis	Conservation Management System	A practical approach to management planning for sites of conservation and recreation importance - terrestrial	Scientist Strategic planner Case officer		Commercial ~£750. Would probably need modification for marine use.	2008	no	UK	www.esdm.co.uk/?tabid=63
D2	DSS data	SeaZone	Collation of data sources needed for MSP into one database.	Scientist Strategic planner Case officer	None, it provides data	Commercial > £100. Defra access agreement.	2008	yes	UK	http://www.seazone.com
D3	DSS communication	Fishermap (Finding sanctuary)	A web based mapping tool allowing fishers to enter areas that are valued by them.	Scientist Strategic planner Case officer Public	None as it is a data collation tool	free to users—modification would need payment to software company	2008	yes	UK	http://www.fs.no-ip.com/mainpage.aspx
D4	DSS forecasting	MARA, Marine Aggregate Extraction Risk Assessment framework	Performs structured probabilistic environmental risk assessments for aggregate extraction.	Programmer Scientist Strategic planner		Availability not clear, runs in ArcGIS.	2008	yes	UK	http://www.mara-framework.org.uk [45]
D5	DSS analysis	Marxan	Estimates efficient reserve networks by maximising estimated benefits and minimising estimated costs	programmer Scientist		Free Open source GIS interface coming soon	2008	yes	Australia Great Barrier Reef, California, Welsh inshore waters	http://www.uq.edu.au/marxan
D6	DSS analysis	Performance Assessment System and Marine Planning Framework	Evaluates the effectiveness of each marine plan by assessing the maintenance of ecosystem conditions.	Scientist Strategic planner Case officer		Not clear whether it has available software tools.	2008	yes	Australia Great Barrier Reef	http://www.environment.sa.gov.au/coasts/pdfs/mp_framework_pas.pdf [17]
D7	DSS forecasting	FLR—Fisheries Library in R	Fisheries stock assessment and management strategy evaluation	programmer	Model parameters	Free	2008	yes	UK, ICES, Canada etc.	http://www.flr-project.org/
D8	DSS forecasting	Ecospace	Spatial ecosystem model, predicts population dynamics into the future based on who eats who, can simulate closed areas.	programmer Scientist	Model parameters	Free	2008	yes	worldwide	http://www.ecopath.org/
D9	DSS forecasting	Isis-fish	A generic and spatially explicit simulation tool to evaluate the impact of management on fisheries.	Programmer Scientist	Model parameters	Free	2008	yes	France	http://www.ifremer.fr/isis-fish/objectivesen.php, [46]
D10	DSS forecasting	Fishing relocation model	To predict where fishing effort may be relocated if areas are closed.	Programmer Scientist		Not available	2005	yes	UK	[47]
D11	DSS analysis	CommunityViz	An advanced yet easy-to-use GIS software to visualize, analyse, and communicate about land-use decisions.	Scientist Strategic planner Case officer Public		Commercial. $750 US per annum incl. support. $300 software only + requires ArcGIS9	2008	no	US	www.placeways.com/communityviz/
D12	DSS analysis	Index				Commercial $1900 US	2008	no	US	www.crit.com/index/index.html

			Interactive GIS planning support tools for designing future scenarios and ranking by goal achievement.	Scientist Strategic planner						
D13	DSS Analysis	NatureServe Vista	DSS for conservation planning, tools for planners, resource managers and communities. Set up by NGO The Nature Conservancy.	Scientist Strategic planner Case officer Public		Free, but website wasn't always available		no	US	www.natureserve.org/prodServices/vista
D14	DSS analysis	Balance: MSP recipes for the Baltic (NOT operational software tools)	Comprehensive collection of recipes for MSP analyses.	Programmer Scientist		Free recipes that can be implemented in the GIS of choice.	2007	yes	Baltic	http://balance-eu.org/xpdf/balance-interim-report-no-28.pdf
D15	DSS forecasting	Atlantis	Ecosystem model to support strategic fisheries management.	Programmer Scientist	Model parameters	Not clear where available	?2005	yes	Australia, USA	http://www.csiro.au/science/ps3i4.html#1 [48]
D16	DSS analysis	Ecosystem Management Decision Support (EMDS)	Knowledge-based decision support of ecological assessments.	Programmer Scientist Strategic planner	Landscape data	commercial		no	US	http://www.fsl.orst.edu/emds/ http://www.institute.redlands.edu/emds/index.htm
D17	DSS analysis	Doris- Marine Protected Areas Decision Support Tool	Web-based application for designing, viewing and reporting on marine protected areas.	Scientist Strategic plannerCase officer Public		User password—not apparent how to obtain. Custom commercial software.		yes	California	http://marinemap.org/doris/ http://marinemap.org/mlpa/
D18	DSS analysis	Aries	Web tool for ecosystem service assessment and valuation. Appears to have straight-forward methods for looking at spatial distribution of activities.	Not yet available: Scientist Strategic planner Case officer Public		Not yet available. Freeware	n.a.	yes		http://ecoinformatics.uvm.edu/aries
D19	DSS analysis	OSS: optimisation support system	To identify comprehensive, adequate and representative locations for conservation planning.	Scientist		Not clear, links to ArcGIS & commercial optimisation software	2005	yes	Australia	[49] http://www.mssanz.org.au/modsim05/papers/crossman.pdf
S1	Spatial interaction DSS	Sketch Planning	The public accesses information, models, maps, plans, and computing methods available to the planners. Decisions are coordinated and innovations tested. Transformation of public hearing from confrontation into collaboration.	Programmer Scientist Strategic planner Case officer Public	Decision dependent. May be paper-based or digital.	If digital, requires significant investment: Commercial > £100	n/a	yes	U.S. (EPA) Smart Growth INDEX (SGI) model Univ. of Leed, Virtual Slaithwaite	[50]. http://www.epa.gov/dced/pdf/Final-print.pdf http://www.ccg.leeds.ac.uk/projects/slaithwaite/ppgis.html
S2	Spatial interaction	Expert Choice 11.5 'Comparison Core'	Web application for decision makers. Easy to use, intuitive workflow. Allows definition of decision criteria and identification of potential solutions. 'Comparison Core' tracks all participants' judgments, data, and comments allowing focus on objectives, analysis, and results.	Programmer Scientist Strategic planner Case officer Public	Expert defined objectives	Commercial > £100	2007	yes	Hawaii Norway Trinidad & Tobago	http://www.expertchoice.com/products/ec11.html [51–53]
S3	Spatial interaction DSS	Web-HIPRE	Web-based tool for public/stakeholder involvement in decision making: software for decision analytic problem structuring, multi-criteria evaluation and prioritisation based on value trees	Programmer Scientist Strategic planner Case officer Public	Expert defined objectives	Free, online	2003	yes	Lake Päijänne, Finland	http://www.hipre.hut.fi/ [54]
S4	Spatial interaction DSS	Optimisation Support System (OSS):Integer Programming coupled to GIS	Integer programming algorithms used to derive optimal solutions. Implemented in ArcGIS, uses commercial software (ILOG's CPLEX) for optimisation engine	Programmer Scientist	Environmental, social, cultural and economic datasets.	Commercial > £100	2008	yes	Encounter MPA, South Australia	http://www.ilog.com/products/cplex/ [49]
S5		MultCSync				Free, online	2004	n/a		

Table 1 (*continued*)

No.	Tool category	Tool name	What does it do?	Potential users	Data requirements	Costs	Last update	Marine use	Locations used	References
	Spatial interaction DSS		Software package designed to aid incorporation of multiple criteria into conservation planning	Programmer Scientist						http://uts.cc.utexas.edu/~consbio/Cons/MultCSync.pdf
S6	Spatial interaction DSS	Xplorah	SDSS for integrated assessment of socio-economic and environmental spatial policies. Effectively a weighted MCA application.	Programmer Scientist	Environmental, social, cultural and economic datasets	Free, online/CD	2007	no	Puerto Rico	http://www.riks.nl/projects/Xplorah
S7	Spatial interaction	Spatial Analysis: Boolean constraints	Identification of areas of exclusivity. Designation of 'no-go' areas. Usually a pre-cursor to multi-criteria analysis	Programmer Scientist Case officer (with some training)	GIS layers relevant to constraints	Commercial > £100	n/a	yes	Many and varied	[55]
S8	Spatial interaction	Spatial Analysis: Multi-criteria analysis	Identification of factors/costs/criteria Standardisation of data to single measurement scale. Combination of factors (may be weighted) to give total 'cost'. Zoning based on analysis of final 'cost' surface.	Programmer Scientist	GIS layers relevant to objectives	Commercial > £100	n/a	yes	Australia	[17,23,28,29,56–58]

variously defined and for this review the definition of an interactive computer-based system designed to help decision makers utilise data and models to solve unstructured problems (based on [34]), was adopted.

Decision Support Systems can be differentiated according to their focus on data, models, knowledge, or communication [35]. Most DSS allow users to enter options and then generate some form of result. In model-driven DSS the results are generated by a mathematical, simulation, or statistical model. Data-driven DSS do not require a model, but instead use data to generate the results. Knowledge-driven DSS use stored facts, rules and procedures to generate results. Communication-driven DSS facilitate the communication between different stakeholders in producing final outcomes.

Alongside functionality, the proposed user is a key attribute of a decision support tool, i.e., whether the scientist, the decision makers, or the tool itself, has responsibility for analysis, scenario generation, scenario ranking and decision making. Decision makers are most likely to require tools at the development stage of MSP is that enable them to work with data and test scenarios. The results of this review were used to assess the need to develop a new GIS-based software tool that implements weighted overlay analysis as a means of assisting the decision support process.

2.2. Development of prototype software tools

Having completed the literature-based review, a workshop on the development of practical tools for marine planning was organised. Three criteria were applied to select those attending the workshop: (a) practical experience in the use and/or application of the principles of marine or terrestrial planning and licensing; (b) policy interest in the development of planning; and (c) scientific or technical expertise with spatial data, GIS and models. This provided a broad mix of expertise in policy, data use, science, GIS, licensing, land planning and sustainability appraisal. Workshop participants were asked to identify practical tasks and tools for (i) planners who develop options for regional marine plans, and (ii) regulators who put such plans into effect.

The outcomes of the workshop, together with the review exercise, allowed the immediate identification of gaps where practical and easy to use GIS tools were required to support routine planning tasks. Using Visual Basic (http://vb.net/uk/index.html) a series of prototype software tools were developed to facilitate: (i) assessment of current activities, (ii) conversion of data on human activities to data on human pressures, (iii) assessment of impacts of those pressures on marine landscapes, and (iv) assessment of the risk of cumulative pressures. As outlined in detail in [36], human activities can be categorised into generic pressure categories. In order to conduct an assessment of impacts of human pressures on ecosystem components it is necessary to convert data describing human activities into data describing pressures from those activities. The theory and concept of cumulative impact analysis is also outlined in detail in [36]. For illustration purposes an offshore area to the east of England was selected and a spatial database was compiled describing human uses such as fishing, aggregate extraction, wind resource development, cables, pipelines, oil and gas infrastructure, disposal sites, and wrecks (Fig. 1) with which to assess the tools.

3. Results

3.1. Review of practical tools

The focus was on tools to support the process of plan development. A total of 39 practical tools that could potentially support the development of marine plans in UK waters (Table 1) were assessed. Under the pre-defined constraints eight tools have been found which related to spatial interaction between activities, 12 tools related to cumulative impact assessment, and 19 tools related to decision support. The majority of the reviewed tools have also been applied in the marine environment (30 cases) and most widely in Europe, USA and Australia (Fig. 2). Results showed that the majority of the tools could only be used by scientists, programmers or strategic planners. Only a few were suitable for use by case officers as the functionality of the tools did not aid the specific requirements, e.g., licensing processes (Fig. 3).

3.1.1. Spatial interaction between activities

From the tools reviewed, four are notable as representing excellent examples that facilitate the implementation of multi-criteria analysis in the context of zone delineation (Table 1; S8). The application by [28] defined protection levels/zones as the primary objectives. Data layers covering physical, biological, environmental and anthropogenic conditions were processed to provide five high-level variables expressing a value, such as natural value of the marine environment and natural value of the coastal environment. Weights were assigned to these variables and a range of scenarios were developed by combining the weighted value layers.

Another study [23] carried out similar process steps where three levels/zones of protection were explored: a fully protected marine nature reserve, a marine seascape reserve and a marine park. Four high level values were determined (natural marine value, commercial value, water-sport and recreational value and land use value) and described by means of eleven data layers. Stakeholder preferences were investigated and summarised by means of pair-wise comparison for each of the zoning options and suitability maps were derived based on concordance scores.

Other authors [29] presented a methodology for ranking coastal areas in the north east of the Island of Rhodes using a combination of MCA methods and GIS. The analysis comprised ten criteria based on economic, social and ecological data describing three zones. For each criterion, each zone was weighted against the other zones using pair-wise comparison and matrices were developed to indicate the relative importance of each zone.

Others [17] identified four ecologically rated zones ranging from those with highest diversity of marine, coastal and estuarine habitats, to zones where ecological health and biodiversity value could not be adequately assessed. These zones were determined based on an assessment of environmental, economic, social and cultural data layered within a GIS and analysed according to their presence/absence within the grid cells. In order to utilise these maps within the context of MSP they were accompanied by a series of maps illustrating present and potential (negative) impacts and guidelines for a performance assessment system. This system contains outcomes for each ecological variable linked to criteria, performance indicators, benchmarks and monitoring protocols.

3.1.2. Cumulative effect assessment

For the 11 practical tools within the CEA category the type of impact interaction and impact weighting matrix used was reported (Table 2). Results revealed that the majority of the existing practical solutions could only account for additive interaction of human pressures, where equal weight is allocated to the contributing pressure layers. A practical solution to assess cumulative effects of human pressures that is useful in the context of MSP was developed by [37]. These authors developed a GIS-based model to assess the probability of human disturbance of whales by considering multiple stress layers, representing the hypothesised likelihood of inducing a response. Further, the GIS approach adopted by [16] could also aid the development of MSP. A relative scale was used to rank both the impact of marine activities and the extent of stressors, and direct and indirect impacts were considered. The commercial GIS toolkit Ocean Communities 3E Analysis (OCEAN) (Table 1; C8) offered the most comprehensive approach as it allows the integration of cumulative effect assessment with scenario testing.

3.1.3. Decision support systems

The summary of potential decision support tools for marine spatial planning presented in Table 1 is the result of a time-constrained search of the literature and it does not reflect an exhaustive list. The majority of the tools reviewed fell within the

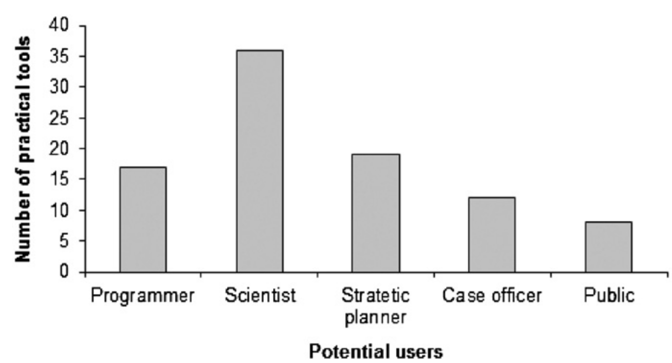

Fig. 3. The number of reviewed practical tools that can be used by programmers, scientists, strategic planners, case officers and the public. Note various tools can be used by more than one user group.

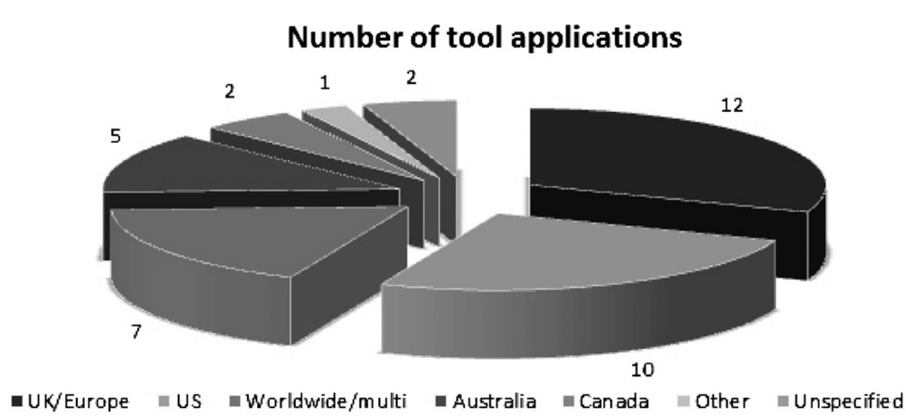

Fig. 2. Geographical application of reviewed tools.

analysis and forecasting categories. Within the forecasting category there were many tools that are highly specialised and only suitable for use by scientists. Whilst these tools are likely to feed into the management process they are unlikely to be of direct use to planners. Four tools most likely to be of use for MSP (with the caveat that the analysis has not been based on practical testing of each tool) were identified.

In the category of data-driven DSS, one of the most comprehensive sources of marine data for the UK is the SeaZone Hydrospatial product (Table 1; D2), which is likely to play an important role in decision support. This could be through a user front-end to the SeaZone data itself, or through incorporation of the database into other tools. The Conservation Management System (Table 1; D1) is a site-based tool used to support management of terrestrial conservation sites and is used by many UK organisations including Natural England and the Royal Society for the Protection of Birds. It allows records of management objectives, actions and direct connection to maps through an integrated GIS. To support MSP a more regional (rather than the site-based) tool would be required and further investigation would determine whether the existing tool could support this or whether modifications would be necessary.

In the area of communication-based DSS, and particularly with regard to stakeholder involvement, the "Fishermap" online mapping tool (Table 1; D3) developed by Finding Sanctuary was noteworthy. The tool allows fishermen to delineate areas on a map showing fishing grounds and known spawning/nursery areas. Attributes, such as gears used or frequency of use, can also be added. Finding Sanctuary is incorporating such data into MPA design using the conservation planning tool Marxan (Finding Sanctuary's December 2009 newsletter: http://finding-sanctuary.org/page/resources.html/).

For forecasting likely consequences of management actions in the marine realm, the Marine Aggregate Extraction Risk Assessment (MARA) framework (Table 1; D4) was the most comprehensive approach to tool development. The technical report is available from the MARA website (http://www.mara-framework.org.uk/Output.htm) with the developed software tool available on restricted access. The MARA framework is closely related to the Environmental Impact Assessment process in creating audit trails for evidence-based decision making, which could make it of use

Table 2
Interaction type of human activities, and the weighting scheme implemented in the practical tools for the assessment of cumulative effects (see Table 1 for details).

#	Type of interaction between human activities considered	Weighting of impact of activity used
C1	Additive	Equal
C2	Additive	Equal
C3	Additive	Relative scale to rank impact and extend (based on Jamieson and Levings 2001).
C4	Additive	Equal
C5	Additive (positive and negative interaction distinguished)	Equal
C6	–	–
C7	One activity layer	–
C8	Possible to integrate various layers	Various weighting schemes
C9	Additive	Equal
C10	–	–
C11	–	–

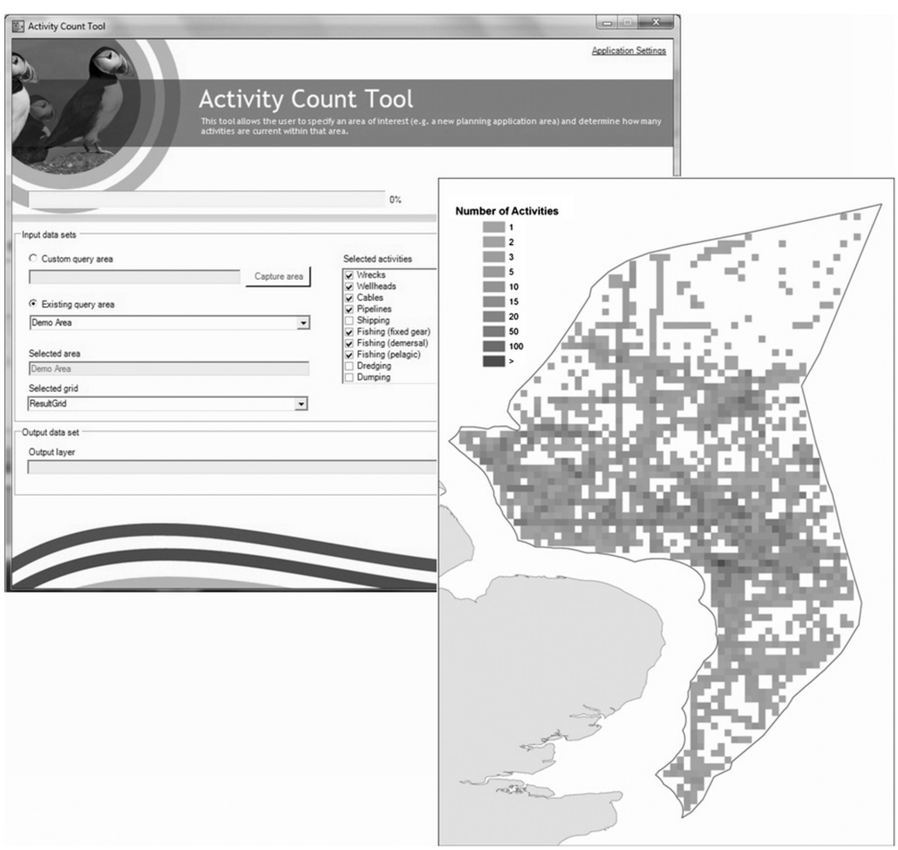

Fig. 4. Using the 'Count Activities Tool' to assess the density of activity. The output from the tool shows a count of the specified activities within each grid cell of the selected result grid.

for future planning processes. Although MARA is focussed on aggregate extraction activities, it may prove possible to incorporate other marine activities.

Fishing is another important activity for consideration. There are a number of tools to evaluate likely future state of fish stocks based upon management actions (e.g., Fisheries Library in R, Atlantis, Ecospace and ISIS-fish). These fisheries tools are complex and likely to remain in use by scientists rather than being directly used by the marine planners.

3.2. Prototype software tools

The stakeholder workshop provided a broader understanding of the current stage of the UK government in the planning process, and raised an awareness of the practical tasks that are still to be undertaken. In particular the workshop emphasised the need for practical solutions to planning tasks, and it was apparent that a range of experts was required to consider how data and tools could address these tasks. The most important task identified by the group was the assessment of conflicting human activities within an area, and the associated tools comprised a matrix that highlighted the possible interaction between activities, and guidance on how to prioritise particular uses. Furthermore, the setting of priorities and criteria was highlighted as an important task for those implementing the plan, but practical tools were not identified. Tasks and associated tools related to cumulative risk assessment were also considered important for regulators, although it is likely that they will be more effective during the preparation of the plan.

A suite of software tools to support planners and case officers in effectively analysing data and taking planning decisions was developed. Thus the capabilities of the set of prototype tools are of use for the routine planning tasks of (i) an assessment of the current activities within an area, (ii) conversion of data on human activities to data on human pressures, (iii) an assessment of impacts of those pressures on specific ecosystem components, and (iv) an assessment of the risk of cumulative pressures. The features of the tools are described as follows:

'Activity count tool'

Simply displaying features in a map can give a misleading impression of the 'busyness' of an area as the selected colours, line thickness etc. can distort the picture. The 'Activity Count Tool' produces an indication of the density of activities per unit area by adding the number of activities per grid cell (Fig. 4). The user can either digitise an area of interest or select an existing boundary file and can specify the activity data sets to be included in the analysis. The number of activities is summarised and stored as a new attribute column in the selected result grid. In the demonstration example the number of activities per unit area is shown in Fig. 4.

'Create pressure layer tool'

Human activities exert pressure on the marine environment and for the tool application, pressure is defined as the footprint and intensity of an activity representing the physical disturbance of the seabed. The 'Create Pressure Layer Tool' allows multiple activities to be processed in order to generate a pressure layer. In the example the location of cables, pipelines, wellheads and wrecks were aggregated, as these activities contribute to a generic 'obstruction' pressure [38] (Fig. 5). Although represented as points (or lines) within the database, in reality these features have a fixed spatial extent and therefore need to be buffered to represent the true extent of their obstruction. The tool allows multiple activity datasets to be buffered to differing extents and then amalgamated to determine a combined footprint. The proportion

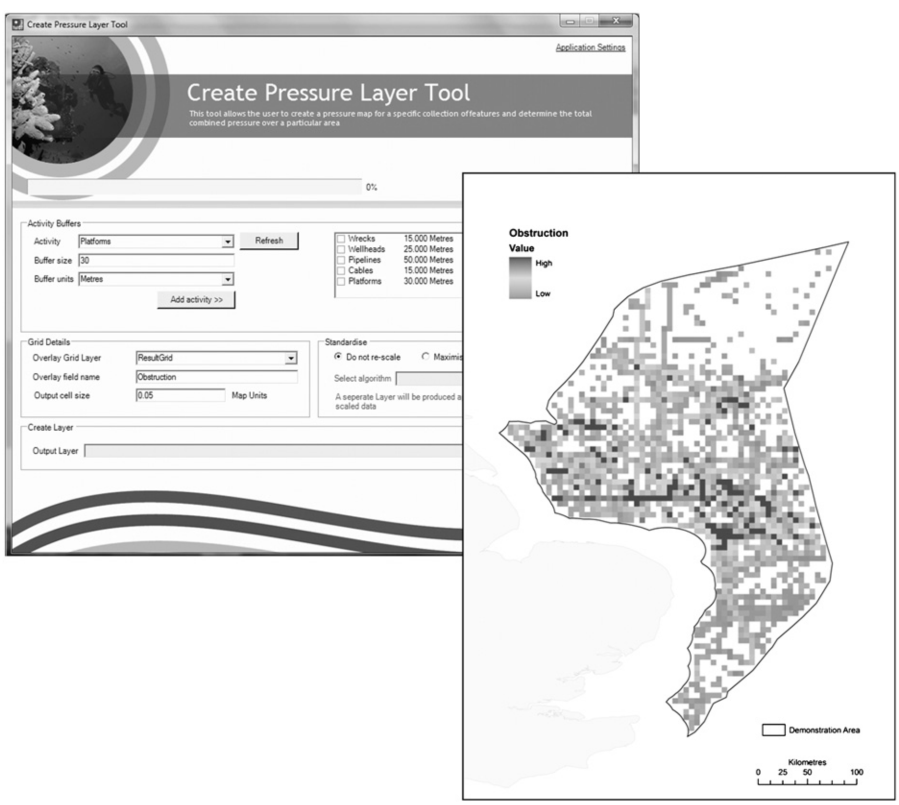

Fig. 5. Generating a pressure layer. The example shows how wrecks, wellheads, pipelines, cables and platforms are buffered and combined to represent an 'obstruction' pressure. The output from the tool shows the proportion of the result grid cell impacted by the pressure.

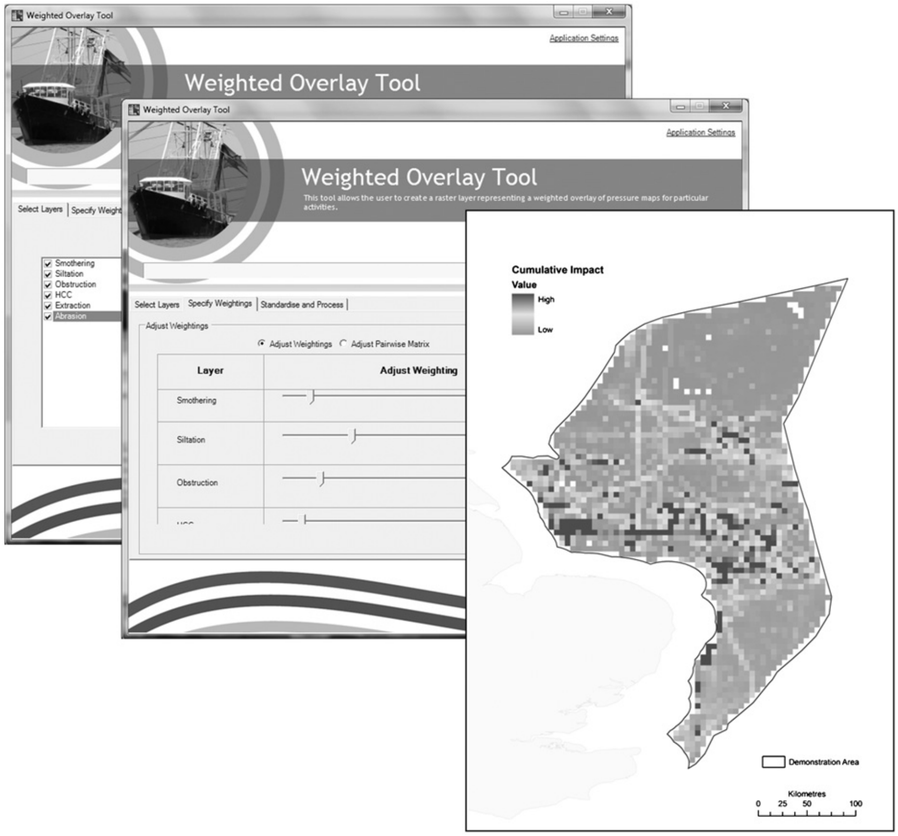

Fig. 6. Cumulative impact on the seabed predicted using the 'Weighted Overlay Tool'. The example shows how input layers are selected and weights assigned to each input layer. The output from the tool shows the summation of the combined weighted input layers.

of the grid cell impacted by this footprint is calculated to provide an indication of the pressure, with values stored as a new attribute column in the selected result grid.

'Weighted overlay tool'

The impact of a pressure is defined by its spatial and/or temporal overlap with the presence of sensitive ecosystem components. This tool allows assessment of a pressure data layer to be combined with a layer describing sensitivity to that pressure. The output is an impact layer for that pressure. The risk of cumulative impacts can also be assessed with the 'Weighted Overlay Tool' tool by combining impact layers (Fig. 6). The user can assign a weight to each input layer. The 'Pairwise matrix' tab facilitates the setting of weights by means of the user specifying the relative importance of each of the input layers when compared against the other input layers. As the data described by the input layers may be expressed in different measurement units the tool provides functionality to transform these layers into a common scale prior to their combination. Two linear scale transformation methods are available. The 'score range' method scales the input data values precisely in the interval 0 to 1 but does not retain the proportionality between values. The 'maximum score' method retains proportionality between the values but the transformed data may not cover the full range of values between 0 and 1.

4. Discussion

This study reported on the process of the development of a suite of prototype tools that offer utility in the area of MSP. This process coupled a selective review of available and practical GIS-based tools and methodologies with input from a stakeholder workshop on planning tools. The review exercise did not result in an exhaustive list of available practical tools as the search was constrained to tools for spatial interaction between activities, cumulative effect assessment and decision support. Although consultation tools and related approaches are crucial in a MSP process, these are addressed elsewhere [2,15]. Finally, with the help of the results of the stakeholder workshop a set of easy to use, generic and GIS-based tools was developed allowing the user to, (i) assess the occurrence of human activities in a given area, (ii) transform data on human activities in geodata of human pressures, and (iii) map the impact of single and/or combined pressures on specific ecosystem components.

4.1. Practical tools for exploring spatial interaction between activities

Practical tools to explore spatial interactions between activities, including the definition of zones, need to comprise multiple processes. The review revealed that GIS functionality was only partly required to assess interactions of human activities, often comprising tailored scripts to facilitate data manipulation or to automate repetitive routines. Although methods such as MCA have been applied many times in a GIS framework to implement zoning schemes (e.g., [28,29]), no practical tools were found which were designed to implement these methods fully. However, there are other approaches and GIS-based tools such as Marxan [39] that allow optimal locations to be identified, based on defined constraints and targets.

While not dependent on a GIS-based solution, one of the critical components is a clear definition of the objectives for the development of certain spatial planning options. Thus for MSP

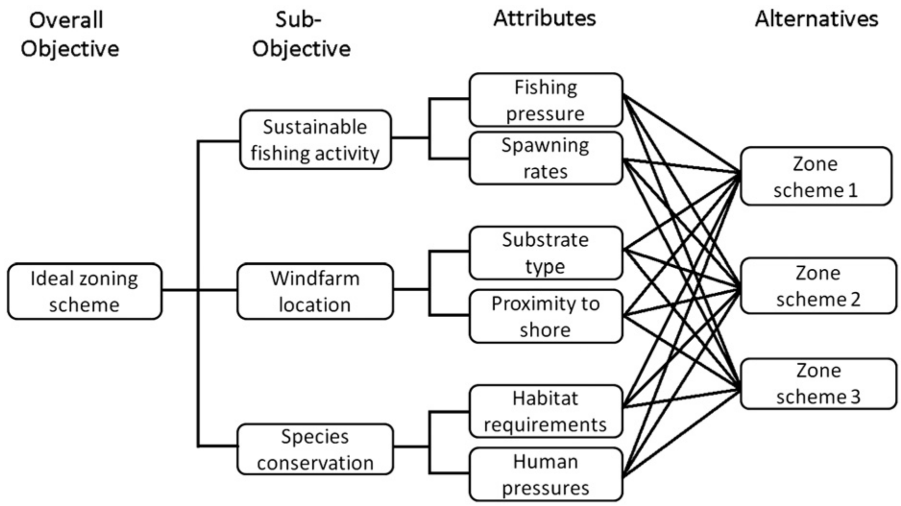

Fig. 7. A simple example of a value tree for marine zoning.

the use of value trees can be helpful in ascertaining the required criteria layers to be evaluated, where each objective is defined by sub-objectives or attributes. A simple example of a potential value tree to support spatial allocation in the context of MSP is synthesised in Fig. 7. Several layers of objectives, with associated attribution, are added under the lowest objective layer, with decision alternatives connected to the attributes. The overall objective (in this case to identify an optimal zoning scheme) is the highest level in the value tree. In order to achieve this objective it is necessary to conserve species, identify suitable sites for wind farms, and maintain a sustainable level of fishing activity. These objectives form the second branch of the tree. They are further disaggregated into measurable attributes enabling the quantification of the higher-level objectives. If an agreed value tree can be achieved then multiple stakeholders can value the sub-objectives in order to explore alternative scenarios.

Further tools may help in the identification and clarification of these contributing attribute data. Hence, under this theme the 'Activity Count Tool' was developed. It was designed to enable repeated assessment of the distribution and overlap of human activities in the planning processes and can allow the user to explore patterns of activity in different areas of interest.

4.2. Practical tools for cumulative effect assessment

The majority of the practical and GIS-based solutions reviewed do not allow the assessment of cumulative effects other than by the sequential addition of data layers describing the occurrence of human pressures. However, results of the stakeholder workshop revealed that a practical and simple tool to use in the context of marine planning would be desirable to allow the detection of multiple human activities. It was envisaged that a planner could then choose between differing types of interaction to provide an assessment of uncertainty when defining the risk for cumulative impact for spatial areas.

This would require the development of a weighting matrix associating the level of threat by each activity (impact weights) on sensitive ecosystem components within the planning area. A recent study [40] showed a comprehensive approach to ranking the impact of particular human activities by attributes such as spatial scale, frequency, taxonomic scale, and resistance and recovery time of an ecosystem. Practical solutions for a comprehensive assessment of cumulative effects of multiple activities need to have the functionality to assess variability in the results, caused by both the type of activity interaction and the weighting matrix applied.

The 'Create Pressure Layer Tool' and 'Weighted Overlay Tool' were developed to facilitate the conversion of human activities to pressures and enable mapping of the impact of single, or combined pressures on specific ecosystem components (see [36] for details on the methods). The latter has the capability to include data layers describing "sensitivity" to pressure and provides functionality for determining an appropriate weighting scheme. Thus such a high level of flexibility in assessing cumulative impacts supports a stakeholder engagement process as different views on the importance of pressures/impacts can be assessed and visualised.

4.3. Practical DSS tools to support marine spatial planning

Based on the reviewed practical tools to support the decision making process, none could be identified that could be directly used to assess candidate marine spatial plans. If a candidate plan consists of delineation of defined areas for particular activities it should be straightforward to quantify the effectiveness of that plan in terms of the compatibility of the overlap of activities and landscape elements. Impact matrices for different activities in the marine environment are available [41] and if these could be combined with matrices specifying the compatibility of different activities, scores for spatial plans could be calculated. It seems likely that such spatial overlap analyses are currently being carried out in other locations (e.g., Australia and California).

4.4. Development of GIS-based planning tools

The main criterion for the development of the prototype planning tools was a general applicability at any scale with any available GIS data, and ease of use for routine planning tasks requiring minor GIS expertise.

Some pre-processing of data may be required before the tools can be used, for example template results grids must be created at the required resolutions, while clipping of data to the required region or area of interest will improve processing times. The use of the tools requires basic knowledge of GIS functionality. However, a sound understanding of the environmental impacts of human activities is important as the flexibility of the tools places responsibility on the user for ensuring that appropriate data sets are used and that results are interpreted in an appropriate manner. There is scope for significant development of this toolkit as the requirements for marine planning continue to develop. One current area for development is the inclusion of an audit trail to document any processing carried out. This will detail the data layers input to a process, any weights applied, the date/time of processing, the user carrying out the processing and the location of any results generated.

5. Conclusion

The results reveal that some practical solutions are already available to support cumulative effect assessment, decision support and allocation of space, all of which form integral parts of the development of a regional spatial plan. However, the tools identified often represented tailored GIS solutions for individual case studies, rather than generic tools that could be applied directly in UK marine planning. Further investigation of the most promising tools identified in the review will be necessary to establish which can best contribute to future marine spatial planning in the UK.

This review exercise highlighted the usefulness of GIS for marine spatial planning, as many workflows can be translated into a connected series of process steps to produce a tool for use by planners. Many of the tools currently available and reviewed here are technically complex and could only be used by scientists or programmers. It can be concluded that the use of generic GIS software or in-house tools, and perhaps the development of custom tools would be best for future efficiency. Hence a suite of prototype tools was developed to promote discussion on the development of a generic spatial planning toolbox. However, care will need to be taken to ensure that any such development is appropriate to the technical ability of the user and the data available. The uncertainty of the outputs of such tools is a result of the quality of the data used and the assumptions made for the assessment. In conclusion, the developed tools provide a solid basis for future development as they result from a transparent and participatory process combining a selected review of tools with the views of stakeholders on the needs for practical tools to support routine tasks in the development of marine spatial plans in the UK and elsewhere.

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