Analyzing Tradeoffs: Barriers to Using Decision Support Tools for Marine Spatial Planning

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Abstract

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Although the literature surrounding the development of decision support tools (DSTs) has rapidly expanded in recent years, their use in marine spatial planning (MSP) processes remains limited. Tradeoff analysis is considered essential to the MSP process by most implementation guides, but the use of DSTs to conduct tradeoff analysis is rare. Here I identify the barriers to widespread use of DSTs for tradeoff analysis. To inform this objective, I conduct an independent assessment of three DSTs that have been used in MSP in order to identify the strengths and weaknesses of each. Based on this analysis, I identify weaknesses that may contribute to infrequent use in tradeoff analysis and MSP development. Ultimately, three major barriers are detected: 1) significant data requirements impede institutional capacity to use DSTs; 2) lack of sufficient documentation and information available to practitioners; and 3) outputs that can be difficult to interpret for stakeholders and decision-makers. Because of the barriers identified, practitioners may benefit from using simpler tools as part of a broader stakeholder process.

Keywords: decision support tools, marine spatial planning, tradeoff, Marxan, InVEST, MIMES

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1. INTRODUCTION

New and expanding uses of oceans have increased pressure on marine resources, driving the creation of policies to guide sustainable planning practices aimed at protecting these services for existing and future generations. Marine Spatial Planning (MSP), a policy tool to develop plans that integrate competing uses such as marine conservation, offshore energy development, and fisheries management (CEQ 2009, European Commission 2010) has gained international attention in recent years. By planning areas in ways that separate conflicting uses and combine complementary uses, MSP is used to prevent or reduce conflicts associated with marine resources and space (Ehler and Douvere 2009, CEQ 2009, European Commission 2010).

Global interest in MSP has spurred development of best practices and planning guides to achieve desired policy outcomes (Ehler and Douvere 2009, Manwaring and Orenstein 2011, Halpern et al. 2012, White et al. 2012). Among other objectives, these guides emphasize the importance of valuing and analyzing tradeoffs to develop and evaluate management alternatives. For effective MSP, it is important to consider the tradeoffs associated with management decisions to avoid detrimental impacts while increasing benefits. A community dependent on local fisheries, for example, may also have an interest in developing aquaculture facilities. To decide if aquaculture is a “good” idea for this community, it must determine the positive and negative effects of such development now and into the future. This is a tradeoff analysis, and is used to determine the alternative results based on the current and prospective needs of the community.

Tradeoff analysis for MSP is often complex. Because the ocean provides numerous services ranging from cultural significance of a place to carbon sequestration to a source of food, a variety of social economic and ecological data are needed to accomplish this type of evaluation.

Tradeoff analysis can be used to identify management decisions that are suboptimal and can reduce conflict among user groups by finding "win-win" solutions, e.g., by identifying services that can be maintained or increased without a cost to other services (Lester et al. 2013).

The near-term priorities include tailoring the valuation technique to each use or service (provisioning, regulating, cultural, and supporting) (Halpern et al. 2012, MA 2005). The step-by-step approach endorsed by United Nations Education, Scientific and Cultural Organization (UNESCO) also states the importance of defining and analyzing existing and future uses, and encourages mapping these uses to evaluate associated tradeoffs (Ehler and Douvere 2009). Because the data compilation and analysis associated with this type of use evaluation is complex, many are championing the use of new software programs to assist in tradeoff analysis (Stelzenmüller et al. 2013, White et al. 2012, Halpern et al. 2012, Guerry et al. 2012, Curtice et al. 2012).

Decision support tools (DSTs) have been developed to assist in achieving the priorities outlined in the MSP guides. These range from spatial cost-benefit analysis techniques (Naidoo and Rickets 2006) to GIS-based software models (Watts et al. 2009, Guerry et al. 2012). The MSP literature widely supports the use of DSTs to organize the collection and synthesis of data, and to analyze and map various uses, help communicate that information to stakeholders and decision-makers, and analyze tradeoffs (Ehler and Douvere 2009, Manwaring and Orenstein 2011, Halpern et al. 2012, White et al. 2012). DSTs may also increase the capacity of decision-making processes to include resilience, a concept often considered at odds with the more traditional planning goal of optimizing resource use (Johnson et al. 2013). Similarly, DSTs may help consider risk when predicting outcomes, which can complicate traditional tradeoff analysis (Cormier et al. 2013).

Despite the increasing availability and variety of DSTs, there are relatively few marine planning processes that have actually used available DSTs to analyze tradeoffs (Collie et al. 2013, Stelzenmuller et al. 2012). An examination of 17 MSP plans revealed only 6 used GIS-based mapping tools, and none employed a cost-benefit approach or a detailed tradeoff analysis (Collie et al. 2013).

Published literature on GIS-based planning tools is expanding rapidly, but there are relatively few tools capable of valuing and analyzing tradeoffs in a comprehensive, integrated and spatially explicit way (Bagstad et al. 2013, Stelzenmuller et al. 2012). Historically, tools were developed to evaluate only one use at a time (e.g., fishing or conservation), and therefore tools have developed only a primitive capacity to evaluate tradeoffs and the interactions between competing or complementary uses (Guerry et al. 2012). Many tools have been developed to evaluate tradeoffs for terrestrial planning and management, but most cannot account for the challenges associated with marine environments including more costly data collection and mapping difficulties (Guerry et al. 2012). In fact, it was not until fairly recently that developers began work on marine-based DSTs for the purposes of MSP.

Although development is ongoing, few DSTs are being employed to evaluate tradeoffs in planning processes (Collie et al. 2013, Stelzenmuller et al. 2012). There are likely a few important barriers associated with this limited use. Primarily, choosing a DST to evaluate tradeoffs may require wading through websites and published literature. No user-oriented filter or guide to assist in this process seems to exist. The Center for Ocean Solutions developed a guide that examined a limited set of tools for MSP (COS 2011), however it lacks information that is important for managers and planners attempting to choose a DST, including cost, data requirements, what types of uses are ideal, and expertise needed to use the DST.

The purpose of this investigation is to a) identify the DSTs currently available to value and analyze tradeoffs for MSP and b) examine the barriers inhibiting the application of these tools. Results are intended to provide information to DST tool developers to facilitate improvement of tools and to offer information for practitioners on how best to use DSTs in MSP processes.

2. MATERIALS AND METHODS

2.1 Selection Criteria

It was essential to this study that DSTs be comprehensive, able to consider both spatial and temporal perspectives, and suitable to planning projects that involve stakeholders. First, I developed selection criteria to classify DSTs according to my specific requirements, which are largely based on common attributes associated with MSP. DSTs must consider all coastal and marine uses, apply science to inform decisions, employ a strong spatial and multi-dimensional analysis, promote stakeholder engagement, include economic, ecological, and social objectives, and be forward-looking and adaptive (Wilkinson et al. 2013, Ehler and Douvere 2009, Menzel and Teng 2010, Foley et al. 2010). Based on these attributes, I developed a list of six criteria to screen DSTs for inclusion in this study. The DST must be: a) able to make the link between potential management actions and human well-being, b) adaptable to a stakeholder driven decision-making process, c) able to evaluate ecological, social, and economic trade-offs, d) previously applied in an MSP or similar marine planning process (preferably several), e) able to evaluate specific trade-offs between multiple services on a spatial and temporal scale, and f) predictive and forward-looking.

2.2 Selection of Relevant DSTs

With these selection criteria, I conducted a review of current literature on MSP, existing plans that used DSTs, and web based archives to compile a list of DST tools for consideration. A central web-based resource for this portion of the study was the EBM Tools Network, found at http://ebmtoolsdatabase.org/. Upon determining the universe of tools to consider, I developed a matrix with key information about each tool and then applied the selection criteria against each DST (Table 1).

	Links to human well-being	Is adaptable to a stakeholder process	Considers ecological, social, economic tradeoffs	Used in marine planning process	Performs spatial and temporal trade-offs	Is predictive
***ARIES**	✓	✓	✓		✓	✓
Atlantis	✓	✓		✓		✓
Audience Response/Keypad Polling Systems		✓		✓		
Coastal Resilience	✓	✓		✓		✓
Cumulative Impacts	✓	✓		✓		
Ecopath with Ecosim and Ecospace (EwE)	✓	✓		✓		✓
Habitat Digitizer Extension		✓		✓		
***Marine InVEST**	✓	✓	✓	✓	✓	✓
InVitro	✓	✓	✓			
Legislative Atlas		✓				
MarineMap	✓	✓		✓		✓
***Marxan with Zones**	✓	✓	✓	✓	✓	✓
MGET	✓	✓				✓
***MIDAS**	✓	✓	✓	✓		✓
***MIMES**	✓		✓	✓	✓	✓
MINOE	✓		✓		✓	
MMC	✓	✓		✓		
NatureServe Vista		✓				✓
Open OceanMap	✓	✓		✓		
Sampling Design Tool for ArcGIS		✓		✓		

Table 1. Evaluation matrix showing criteria and scoring by Project Team (source: EBM tools network http://ebmtoolsdatabase.org/). * indicates tools that met either all or most selection criteria.

Marine InVEST and Marxan with Zones met all selection criteria. The outputs generated by Multiscale Integrated Earth Systems Model (MIMES) have been difficult to convey to stakeholders in past processes (Napoli and Moura 2011). For this reason, it did not meet the criterion that tools be adaptable to a stakeholder-driven decision-making process. However, this hurdle was overcome in the Massachusetts Ocean Plan (MOP) MSP process by incorporating Marine Integrated Decision Analysis System (MIDAS) (Patel et al. 2011) as a front-end display tool. Based on this information, I elected to include MIMES with MIDAS in my review. Artificial Intelligence for Ecosystem Services (ARIES) also met nearly all specified criteria (Villa et al. 2009), but it was not used in a marine planning process and I therefore excluded it from the study.

3. RESULTS

Three tools were ultimately selected for review: Marine InVEST, Marxan with Zones, and MIMES with MIDAS. A literature review was conducted for each, which included a review of the published literature pertaining to selected DSTs, tool documentation from the developer, web-based descriptions and reviews, any completed management plans, and a review of case studies. I conducted interviews and corresponded by email with tool developers to clarify information from the literature review and to confirm my evaluation of the tools. I used this information to compile a brief summary of key features found in each tool, which is provided in Table 2. I then characterized the strengths and weaknesses of each of the three tools and used this analysis to identify potential barriers to broad DST use.

Tool	Developer	Release Year	Approach	Stakeholder Engagement	Use in Planning Projects	Data Requirements	Tradeoff Valuation Technique
Marine InVEST	The Natural Capital Project	2010	Ecosystem services and an ecological production function approach to determining efficiency	Very good – designed to include stakeholders in iterative process	Coastal Belize, WCVI	Varies depending on tiered models	Maps tradeoffs geographically using various valuation techniques. Also can use a production function model
Marxan with Zones	University of Queensland Australia	2009	Conservation zoning with an algorithm that sets targets as parameters for alternatives	Very good – data gathering, objectives setting, and model analysis involves stakeholders	Australia, South Africa, St. Kitts and Nevis, Philippines, Malaysia, Solomon Islands, Indonesia	Can accommodate different types of data and participant knowledge mapping has been effective in past projects	Monetary costs/values placed on geographic zones. A social participation component to further inform models
MIMES	Gund Institute, University of Vermont	2006	Ecosystem services and their connection to each other and human well-being; designed to be nearly comprehensive	Fair – concept map outputs are difficult to explain to stakeholders	Massachusetts Ocean Plan	Significant data required to accommodate the various sub-models	Various management actions are displayed in concept maps which show all services affected.

Table 2: Key features of the three DSTs selected for study.

3.1 Marine InVEST

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a modeling and mapping tool designed to aid in the process of MSP by valuing ecosystem services and modeling the effects of proposed management alternatives to help evaluate tradeoffs. InVEST was developed by the Natural Capital Project (a partnership organization between Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund) and designed with a public involvement component in mind, allowing stakeholders to develop management scenarios that can be modeled by the software program (Tallis et al. 2010). The terrestrial version of InVEST has been used in multiple international management projects to evaluate tradeoffs for spatial planning, strategic planning, and environmental impact assessments (Yukuan et al. 2010). The marine version of this tool was developed recently and was piloted on a planning project on the West Coast of Vancouver Island (Guerry et al. 2012).

InVEST is based on an ecological production function approach, which is adapted from traditional economic principles for modeling utility. This approach is intended to demonstrate the causal linkages between management inputs and ecological outputs, i.e., tradeoff evaluation (Wainger and Boyd 2009). Although InVEST can be used to identify an efficiency frontier, where the biological and economic utilities are used to plot management alternatives (Figure 1) (Polasky et al. 2008), it is generally used to model a limited number of scenarios identified by stakeholders. This allows users to identify each scenario's effects on ecosystem services which permits decision-makers to weigh tradeoffs among scenarios (Guerry et al. 2012).

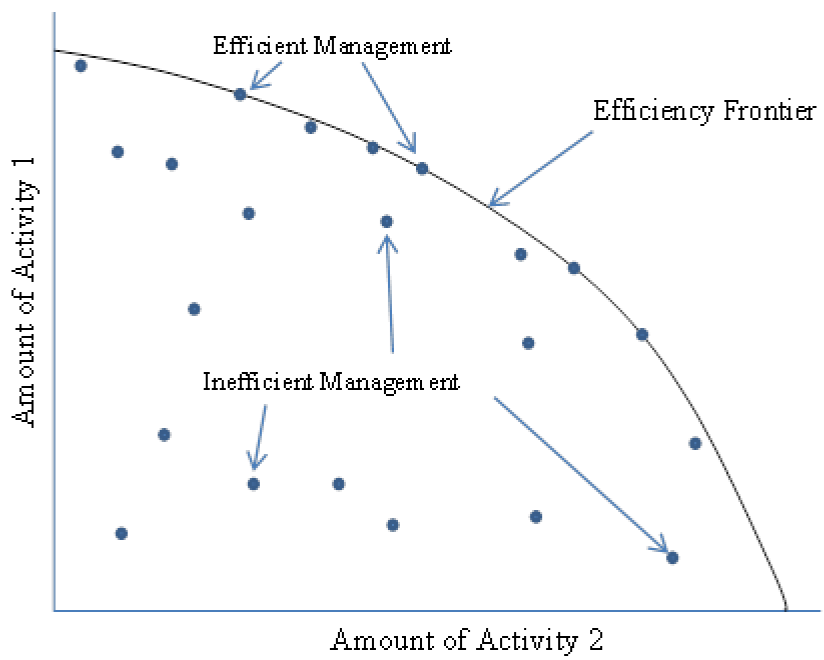

Figure 1. Example efficiency frontier graph. Management actions plotted on the curve are efficient, while actions plotted within the curve are inefficient (adapted from Polasky et al. 2008).

This approach addresses the difficulty in valuing non-economic services for use in tradeoff analysis. Aesthetic quality, for example, is of great importance to those that live or recreate in coastal areas, but placing a monetary value on this attribute can be difficult and may be contrary to the way many people think about the natural environment (Daily et al. 2009). By mapping important aesthetic areas and identifying the management alternatives that will affect these views, InVEST overcomes the rigidity of traditional economic valuation models and allows stakeholders, planners and decision-makers to reach their own conclusions without a production function model (Daily et al. 2009, Guerry et al. 2012). Involving stakeholders throughout every stage of the process is fundamental to the InVEST model (see Figure 2), which is reflected in the tool design. By communicating tradeoffs that could ensue from particular management actions, the goal is to facilitate more informed policy decisions.

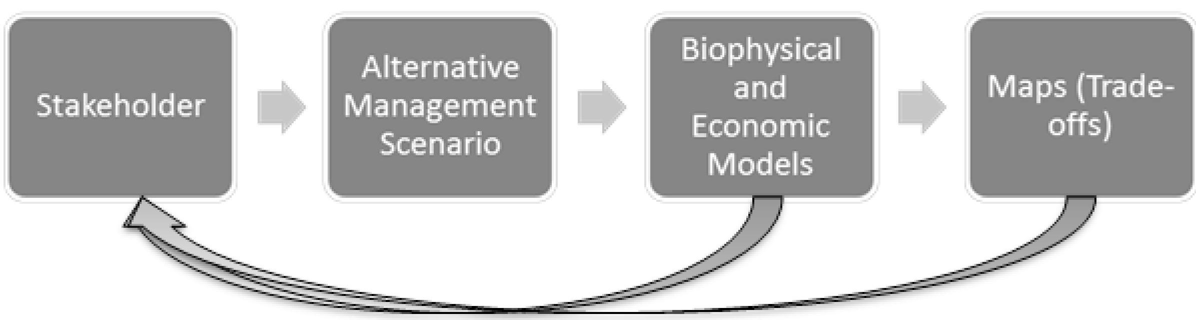

Figure 2. InVEST process design, adapted by Kirsten Nelsen from Marine InVEST software documentation (National Capital Project 2011).

InVEST is specifically designed to model how a change in one service due to human impact or climate change can affect the utility of other ecosystem services for human well-being. A tiered design allows users to combine models with differing complexities based on project needs and data availability (Tallis et al. 2012). There are currently two tiers in the InVEST suite. Tier 0 models are the simplest and can be applied in processes with relatively few available data (Tallis et al. 2012). No actual valuation is performed in tier 0 models. Rather, tier 0 models map ecosystem services or other attributes associated with an area, such as which coastal areas are susceptible to erosion, marine habitat risk assessment, and overlap analysis between fisheries and recreation (Tallis et al. 2012). Tier 1 models identify tradeoffs more accurately, but also require more data to run (Guerry et al. 2012). Models from different tiers may be used together to provide a more complete picture of the tradeoffs and conflicts that should be considered in a region (Guerry et al. 2012). The marine InVEST DST is capable of modeling nine use categories: marine-based renewable energy, food from fisheries, food from aquaculture, coastal protection, aesthetic quality, recreation, marine carbon, water quality, and habitat risk (Tallis et al. 2012, Guerry et al. 2012). Each model is built based on supply and valuation of that service, which varies depending on the management scenario (Guerry et al. 2012).

3.1.1 InVEST WCVI Case Study

Communities on the West Coast of Vancouver Island (WCVI), located in British Columbia, Canada, depend heavily on marine resources. In the mid-1990s, a team of community leaders came together to identify key issues ranging from pollution to declining fish stocks to lack of legitimacy in government (Okey and Loucks 2011). To help address some of these problems, the West Coast Aquatic Management Board (WCA) was developed. The WCA is a co-management organization with sixteen members from local, provincial, and federal government, WCVI First Nations, and other community stakeholders (Arbour et al. 2008).

The WCA is currently engaged in a regional, ecosystem-based MSP process to help address resource and planning issues identified (Espinosa-Romero et al. 2011). Three management plans are being developed: one for the entire WCA jurisdictional area, and one each for the Clayoquot and Barkley Sound subareas, (Figure 3) (Espinosa-Romero et al. 2011). Several competing marine uses are being considered in the process, including current uses such as commercial aquaculture, commercial fishing, recreation and tourism, First Nation subsistence and ceremonial uses, and emerging uses such as wave energy facilities (Guerry et al. 2012). There is also an emphasis on aesthetic, spiritual, and cultural benefits for residents and First Nations, which are traits not easily standardized with monetary values. The goal of MSP in this case is to manage these competing uses sustainably for the benefit of current and future generations (Guerry et al. 2012).

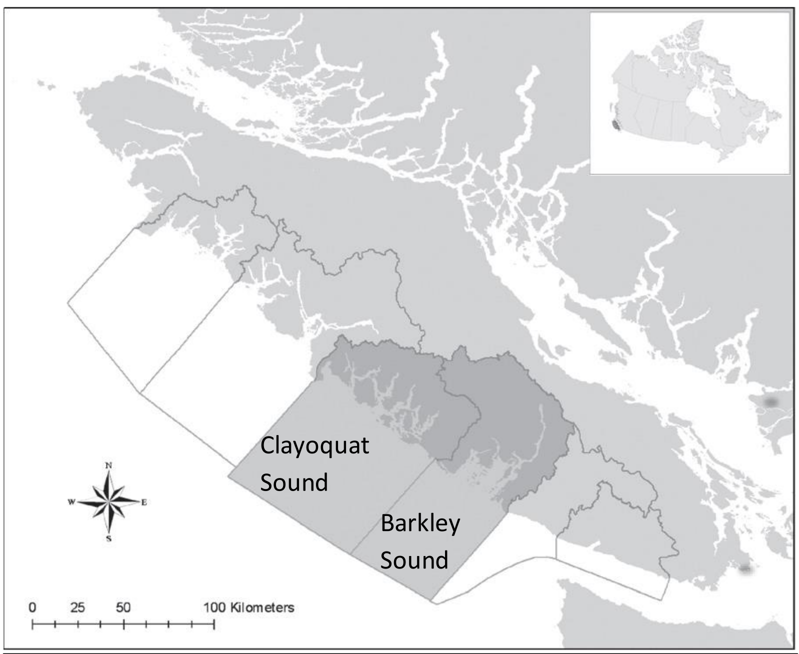

Figure 3. Map of the WCVI. Outlined area is within the jurisdiction of the WCA. (Source: Espinosa-Romero et al. 2011)

The WCVI project is still in progress, but a case study reviewing the Lemmens Inlet subsection near Tofino, British Colombia has been published (Guerry et al. 2012). The WCA began by administering stakeholder interviews to identify the community's key issues, values, and visions.

Based on this information, the WCA worked with developers at the Natural Capital Project to develop three management scenarios that could be analyzed by the InVEST model: 1) a 'baseline' scenario reflecting current uses, 2) a 'conservation' zoning arrangement that would allow a combination of low impact and no-take uses, and 3) an 'industry expansion' scenario that would allow more shellfish aquaculture and float home leases (Guerry et al. 2012).

Using a combination of tier 0 and tier 1 models, InVEST was able to communicate information about the three management scenarios. It was determined, for example, that the 'conservation' scenario would result in a spatial increase of 57% in kayaking routes based on general preference to kayak in more protected areas, an increase of $98,998 in the value of shellfish harvest from increased oyster growing area, improved habitat and water quality, and an overall decrease in the number of float homes by 4 within the inlet (Guerry et al. 2012). Different metrics were incorporated, e.g., currencies versus values, and did not present a problem for stakeholders and decision-makers analyzing tradeoffs (Guerry et al. 2012).

The use of InVEST models was also noted to have an impact on stakeholder discussions and on the relationship between the WCA and the broader community. By identifying management scenarios and using an impartial modeling tool to predict potential impacts of those scenarios, some discussions became less polarized, which helped to expedite the process (Guerry et al. 2012).

3.2 Marxan with Zones

Marxan (marine reserve design using spatially explicit annealing) was designed specifically to aid managers and decision-makers in planning marine protected area (MPA) implementation. Since its inception in 2003, Marxan has been used worldwide by 1500 organizations in 110 countries, including the large-scale re-zoning of the Great Barrier Reef (Watts et al. 2009, Segan et al. 2009). The newest version, Marxan with Zones, was released in 2009 by the University of Queensland in Australia (Watts et al. 2009). Marxan with Zones was developed to account for a significant limitation present in the previous Marxan tool (Watts et al. 2009). Marxan could only consider two types of zones at a time, e.g., either an MPA or not an MPA, but could not apply more specificity to zones, e.g., no-take versus partial take MPAs. This restricted the scope of management options and was shown in a zoning study conducted in northern California to result in disproportionate and inequitable impacts to various uses and industries (Klein et al. 2009). By creating a tool that allows different types of MPA zones and more specific constraints, the developers hypothesized that more equitable outcomes could be achieved (Klein et al. 2009).

Marxan with Zones was specifically designed to be used as part of a stakeholder-driven planning process. The program interacts with GIS tools, which are often used to map alternatives in spatial planning, to design clumped reserve systems that lend well to practical management applications for policymakers and planners (Ball et al. 2009). Furthermore, outputs can be modified in an iterative fashion to reflect stakeholder input or preferences (Grantham 2011). Unlike the other tools reviewed here, Marxan with Zones does not apply an ecosystem services model to conservation. Instead it is based on an algorithm, or a defined set of targets and rules, which allows the tool to search for solutions within certain parameters based on the data.

Data requirements are largely dependent on project needs, but a few key pieces of information are necessary to run the model including data points designating the parameters of potential zoning areas, costs of implementing MPAs in those areas, and conservation features prominent in particular zones (Watts et al. 2009). The user must decide what types of zones to include, e.g., conservation zones or extractive use zones, and then decide on targets for uses such as habitat protection (Watts et al. 2009). Information for this type of analysis can be gathered using a variety of data collection methods, including social survey data, expert or community working groups, as well as from more traditional sources of data like government studies (Grantham 2011).

Marxan with Zones attempts to identify the zoning alternatives that fulfill the greatest number of targeted objectives identified by the user throughout hundreds of simulated runs. It accomplishes this by running the model multiple times as different target objectives are specified and expert knowledge is incorporated. The two main outputs produced are “selection frequency,” i.e., the number of times a particular zone is selected across multiple runs, and the “best solution,” i.e., the alternative that accomplishes the most objectives (Grantham and Possingham 2010).

3.2.1 Raja Ampat Case Study

Raja Ampat is an archipelago of islands and submerged coral reefs located on the northwestern tip of Papua in eastern Indonesia (Grantham and Possingham 2010). The islands and surrounding waters have become a global and Indonesian conservation priority because of their support of coral species, coral reef fish, and many species of marine megafauna, including 16 species of cetaceans, dugongs, and three important turtle species (Grantham et al. 2012). Many local villages are reliant on small scale commercial and subsistence fishing for food security (Grantham 2011). A strong indigenous culture has contributed to the maintenance of healthy ecosystems and a strong connection to marine resources (Grantham 2011). However, climate change, illegal, unreported, and unregulated (IUU) fishing of anchovies, and a growing population are putting increased pressure on marine resources (Grantham 2011).

The Raja Ampat regency government partnered with The Nature Conservancy (TNC) and Conservation International (CI) to engage in an MSP process, using Marxan with Zones to inform development of a network of seven MPAs in Raja Ampat (Grantham 2012). A four-step process was used to create a zonal MPA network: 1) determine planning objectives and identify data needs, 2) collect data and develop a database, 3) analyze data using Marxan with Zones, and 4) incorporate results into the data plan (Grantham 2011). First, the project team worked with the local community to develop planning objectives and identify data requirements to meet those objectives. Goals for the project included developing spatial plans that achieved biodiversity and conservation with no-take zones, maintaining sustainable use zones with access to fishing areas, and also allowing other activities such as tourism and aquaculture to continue (Grantham 2011).

The second step involved collecting existing data and conducting participatory expert mapping workshops to compile and then improve necessary information. Initially there was no central source for spatial data, which resulted in some preliminary challenges for the project team. Data were collected from various sources including several NGOs, the Indonesian government, and universities. Using these incomplete data as a starting point, the team used participatory mapping to fill gaps (Grantham and Possingham 2010). By consulting stakeholder groups, including local communities, NGOs, and government, this method worked to both efficiently gather data and also to include stakeholders early in the planning process. Overall, the team spent close to a year gathering, translating, and analyzing data (Grantham and Possingham 2010).

After data were collected using a combination of techniques, the Marxan with Zones tool was used to identify solutions that considered multiple planning objectives. This was step three of the zoning process (Figure 3). Targets for conservation and fishing were developed depending on the MPA type being considered in a given area. In no-take MPAs, for example, 30% of each

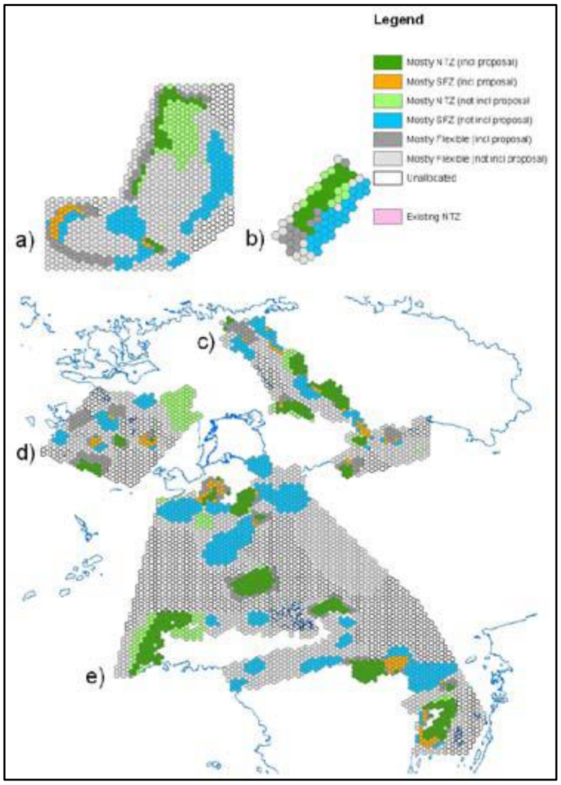

Figure 4. Zoning in Raja Ampat by workshop participants. Color indicates areas best suited to fulfill different management objectives (Grantham 2011).

different habitat type was specified and the baseline target for species of concern was set at 30%. Each zone was also assigned cost layers, which showed the value lost for fisheries and other uses. After running the model, a few zones stood out as most suitable for either no-take MPAs or sustainable fishing zones, meaning they met most or all targets set for both conservation and socioeconomic vitality. Based on the specific targets set by modelers, Marxan with Zones identified areas that exhibited win-win solutions, while considering damaging tradeoffs.

Upon development of alternatives for MPA siting, stakeholder input was again incorporated into the analysis to determine the best overall solution. This was step four, incorporating results of the model runs and stakeholder input into development of the zoning plan. By comparing proposals developed by local stakeholders and NGOs to the Marxan with Zones algorithm, the project team was able to determine overlap between the results (Grantham and Possingham 2010). This method of comparing algorithm outputs with stakeholder preferences illuminated deficiencies in the model caused by holes in data that may have otherwise gone unnoticed.

3.3 MIMES with MIDAS

The Multiscale Integrated Earth Systems Model (MIMES) was developed to allow planners and managers to understand the dynamics of ecosystem services, how these services are linked to human well-being, and the potential for change in service value and function under various management scenarios (Videira et al. 2012). Model outputs from MIMES take the form of complex concept maps. These proved to be difficult for stakeholders to understand and presented a challenge when attempting to communicate model results (Napoli and Moura 2011). MIDAS (Marine Integrated Models of Ecosystem Services) was used to interpret models and analysis developed by MIMES. Using MIDAS to display information from the MIMES models based on user preferences provided clearer, more intuitive results and contributed to stronger stakeholder engagement (Napoli and Moura 2011).

Developed by the Gund Institute at the University of Vermont in 2006, MIMES is based on ecological economics (Costanza et al. (1997) and on the ecosystem services concept developed by the Millennium Ecosystem Assessment (MA) report (MA 2005). The MA report classified ecosystem services by spatial characteristics, e.g., carbon sequestration is global in scale, while water purification from estuaries may be a local characteristic. According to this framework, MIMES models are organized into five different “spheres”: anthroposphere (human dimension), atmosphere (earth energy and gases), biosphere (attributes of the earth’s surface), hydrosphere (water by reservoir), and lithosphere (rocks and ore) (Figure 4) (Boumans and Costanza 2007). Designed to model the entire earth system by dividing information and data into five “spheres”, MIMES shows the potential results of management actions and the flow of ecosystem services.

MIMES model outputs are meant to contribute to a more complete understanding of tradeoffs and the interfaces between ecosystem functioning, ecosystem services, and human well-being (Boumans and Costanza 2007). The model uses this information to assess the likelihood of future scenarios and to educate users about alternative management options (Boumans and Costanza 2007). An animated feature within the MIMES software can demonstrate the impacts of management decisions over time (Boumans and McNally 2011). MIMES can function as a data clearinghouse and is intended to grow as more information is discovered about the natural or human environment.

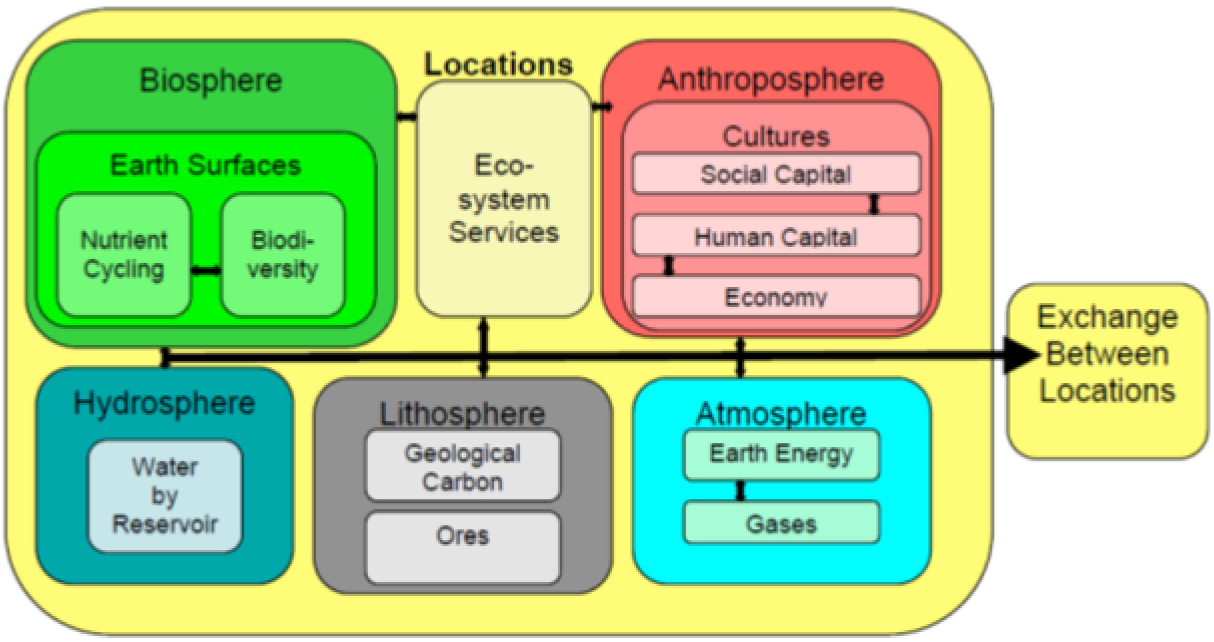

Figure 5. MIMES framework (Boumans and Costanza 2007).

MIDAS was used as a front-end tool in the Massachusetts MSP process to address the issue of complexity in MIMES models for stakeholder engagement (Napoli and Moura 2011). MIDAS models a set of outcomes based on socio-economic, governance, and ecological factors and then outputs are mapped in GIS (Patel et al. 2011). A user friendly and graphically appealing tool, MIDAS is intended for non-technical users with no prior training (Patel et al. 2011). Instead of facing the large amount of information provided by the MIMES concept maps, MIDAS allows users to limit the information that they want, which is then displayed graphically. MIMES and MIDAS were linked for the purposes of the Massachusetts MSP process so that changes made by participants to the MIDAS outputs are reflected in the MIMES model. Therefore, MIDAS is a helpful front-end visualization tool to interpret MIMES outputs into maps and models appropriate for stakeholder use.

3.3.1 Massachusetts Ocean Plan Case Study

After a private offshore wind energy firm proposed the development of a facility in Nantucket Sound between Martha's Vineyard and Cape Cod in 2001, the local community voiced opposition because of the potential for negative effects on the environment, recreational boating, the fishing industry, and, aesthetic views (Firestone and Kempton 2007). Eventually this stalemate led to passage of the Massachusetts Oceans Act in May of 2008, which mandated development of a plan to manage issues related to offshore renewable energy development, fishing, maritime shipping, recreation, and conservation (MRAG 2009).

An advisory body, the Massachusetts Ocean Partnership (now Sea Plan), was tasked with developing this multiple use zoning plan. It was clear that tradeoffs existed between natural resource preservation, traditional uses, and new development. Sea Plan's overall goal was to develop equitable management alternatives as defined by the Massachusetts Oceans Act (Executive Office of Energy and Environmental Affairs 2009). This included balancing and protecting natural, social, cultural, historic, and economic interests, protecting biodiversity and ecosystem health, supporting the wide use of marine resources and sustainable uses, and to continually incorporate new knowledge as the basis for adaptive management over time

(Executive Office of Energy and Environmental Affairs 2009). The controversial nature of offshore wind energy development within the surrounding community stemmed mainly from the potential reduction in aesthetic quality in this vacation destination. The community perceived that the development of a wind farm would result in decrease in property values associated with the compromised view. This opposition to development provided strong incentive to include stakeholders in the planning process.

Sea Plan began its process by identifying prohibited areas, renewable energy areas, and multi-use areas as the three zoning categories to be considered. It also identified specific performance standards, e.g., proposed uses will avoid special, sensitive or unique marine life and habitats (Douvere and Ehler 2011). It engaged in large-scale data collection, compilation and publication, which resulted in an integrated data network of ocean and coastal data for Massachusetts, i.e., Massachusetts Ocean Resource Information System (MORIS). Once data were collected and organized, Sea Plan intended to employ DSTs to help inform the decision-making process. Sea Plan decided upon two different tools to analyze tradeoffs for the MOP (Moura 2012).

The more complex modeling approach, MIMES, was developed and applied to this case by scientists from multiple universities including the Gund Institute at UVM (Napoli and Moura 2011). MIMES is data intensive and has the ability to create complex, nearly-comprehensive models of the earth systems (Boumans and Costanza 2007). These complex models require substantial amounts of data, leading to high costs associated with employing MIMES. The MIMES DST worked with the Massachusetts MSP process, however, partly because of the significant time spent on information gathering early in that process.

4. DISCUSSION

The fundamental conclusion of this analysis is that there is a general lack of access to tradeoff DSTs. Specifically, DSTs evaluated here have only been used with a high level of involvement from the entities that developed them. More broadly, it appears that few organizations or governments have the data capacity or organizational capability to use these DSTs without significant funding and guidance from development teams, universities, and nonprofits. This indicates that instead of projects seeking out the use of tradeoff DSTs, tool developers are actually seeking out projects to pilot their tools. The possible exception is Marxan with Zones, which has been used in many MPA planning projects worldwide.

To increase the accessibility of DSTs, there are three issues that would benefit from further consideration: a) significant data requirements, b) lack of documentation and information aimed at practitioners, and c) model outputs are either not comprehensive or are difficult to interpret.

4.1 Data Requirements Inhibit Use

DSTs require significant data to run effective models, and these data may be lacking for most marine planning processes. The time and cost required to collect the data will likely limit the use of DSTs in the decision-making process (Bagstad et al. 2012). Marine InVEST, for example, claims that its tiered modeling system can accommodate different degrees of data complexity and it is therefore adaptable to multiple processes (Guerry et al. 2012). However, the InVEST tool has only been used by projects that team up with the Natural Capital Project, which provides funding for data collection and modeling guidance. This indicates that InVEST presently is less accessible to MSP processes that do not have the backing of InVEST developers. Although tier 0 models can be generated with minimal data, the WCVI case study used a combination of tier 0 and tier 1 models to conduct a tradeoff assessment. These efforts required scientific data on habitat and water quality, and stakeholder interviews to collect recreational and float home data (Guerry et al. 2012). Aside from the information required to run the models, an MSP process would need a staff person proficient in GIS and/or experienced in modeling to ensure proper tool function.

Similarly, MIMES requires significant data to accommodate its complex modeling system. Although data availability was not an issue in the Massachusetts MSP process, it also had the support of a number of modelers from universities and a sizeable grant from the Moore Foundation, which likely contributed to its ability to employ the MIMES model and gather adequate data. The extensive breadth of data used could prove unrealistic for projects with a larger spatial scale, shorter time-line, and/or tighter budget for data collection, effectively preventing the tools from use in most U.S. MSP processes currently in development and projects in developing countries.

Complexity can also be an advantage, however, and the MIMES tool is designed to account for externalities in its analysis of potential management actions by applying various spatial and temporal sub-models at global, regional, and local levels (Videira et al. 2012). Compared to the other tools examined here, MIMES has the ability to provide a more complete account of potential effects management actions could have on human well-being and the future utility of ecosystem services. Depending on the scope and scale of the planning process and the availability of data, MIMES may contribute significantly to a well-informed decision-making process.

Marxan with Zones seemed relatively flexible in its data requirements. It has also been used in far more marine planning processes than the other tools. The participatory nature of Marxan with Zones and the ability to include different types of data into the models is an attractive feature for MSP. A participatory approach was used where limited data were available in Raja Ampat and that was essential to the success of the project (Gratham and Possingham 2010). By combining the objective modeling software with more subjective community input, the project team was able to compare information and results for a more informed and accepted planning process. There are many projects that have run the Marxan with Zones software either with local knowledge mapping incorporated into the model or compared against local knowledge mapping to determine optimal alternatives (Agostini et al. 2010, Game et al. 2010, McConney and Chuenpagdee 2011). Developers of Marxan with Zones both encourage the use of these methods and also acknowledge that unique challenges to blending science and community input result in a need to tailor to each specific project (Grantham and Possingham 2010, Klein et al. 2009, McConney and Chuenpagdee 2011). However, Marxan with Zones is specifically targeted at for MPA designation and zoning for conservation purposes and may not be effective at comprehensive multiple use zoning of an area.

Overall, data requirements, and the time, cost and feasibility associated with data collection, seemed to be the greatest barrier to widespread use of tradeoff tools.

4.2 Lack of documentation and information aimed at practitioners

MIMES is the most comprehensive model, but has the least developed software documentation of all three tools reviewed. It comprises some “case examples” listed on the MIMES website and a Google Code site (http://code.google.com/p/mimes/ last accessed March 26, 2014) where users can add information about their experience using the tool. Development and further improvements to MIMES and associated software documentation is part of a broader web-based collaborative process, including interested users and developers from universities, government organizations, NGOs, and software industry (Boumans and Costanza 2007). It is possible that the lack of concrete information and user-friendly instruction is a result of, and a potential flaw in, this collaborative development model.

Most tools reviewed at all stages of this analysis lacked direct and comprehensive information that could be used by practitioners to decide between DSTs. This may be a significant barrier to use in MSP processes.

4.3 Model outputs are either not comprehensive or are difficult to interpret

The limited model categories currently contained in the InVEST suite, i.e., nine use categories, could inhibit analysis of a use outside of the already programmed model. In the WCVI case study, the Natural Capital Project developers had to tailor broad recreation models to display information about use categories not included in the original model: kayaking and float homes (Guerry et al. 2012). This tailoring worked in the WCVI case (Guerry et al. 2012). However, if a programmer is less familiar with the software, this may prove a more difficult task.

Marxan with Zones is effective at considering human preference and zoning areas for conservation, but the tool was not designed for comprehensive MSP and may fall short if used in this way. Although used in multiple MPA designation and zoning projects, Marxan with Zones has not yet been used to develop optimal zoning configurations for a variety of uses like offshore energy development and shipping. It does have the potential to estimate tradeoffs between multiple uses if the benefits and cost could be represented statistically and targets set. However, this is a potential limitation when deciding on a DST that fits the practical applications of a MSP process.

The MIMES tool uses concept maps as outputs, where different ecosystem services and human uses are connected with lines and arrows. Although an effective way of describing relationships, this can hinder a stakeholder participation process because MIMES outputs can be difficult to understand without training or modeling expertise (Napoli and Moura 2011). This may limit access to the tool, especially on projects where a large budget and extensive personnel are absent.

Finally, it is no surprise that no model is capable of providing an accurate representation of all real-world attributes. The models chosen for review here are intentionally complex, but even models that attempt to account for externalities, are only as comprehensive as the breadth of data available. Further, it is especially difficult to program models to accurately reflect the diversity of human values and preferences, especially related to non-economic goods (Lester et al. 2013; Ruiz-Frau et al. 2013). Therefore, it is essential to treat DSTs as a tool that can inform, but not decide, a stakeholder-driven planning process. Because uncertainty in model inputs is always a reality, model outputs must be analyzed through a human lens and adjusted to reflect practical knowledge and user perspectives (Klein et al. 2008). DSTs can increase the transparency of a process because clarity in data is required to produce models and model outputs are generally designed to communicate data to appeal to a broad range of stakeholders. However, planning teams should take care to clearly communicate the process by which tools can support, not make, decisions to avoid skepticism and concern over lack of transparency in decision-making.

4.4 Another Perspective on DST Limitations

More funding and advanced development of DSTs like the three reviewed here is advocated byCurtice et al. (2012). They confirm that tools are not widely applied to planning process and identify some of the same barriers reported here, e.g., lack of documentation, difficulty of use (Curtice et al. 2012). Nearly all tools developed for natural resource planning and management are free to download and are generally developed by academic or non-profit organizations. Often, EBM and MSP processes are conducted by government and nonprofits, which cannot afford fee-based software. This creates a disincentive for software developers to invest in DST innovation, although they are perhaps better equipped to design highly-functional, well-documented tools. Ultimately, Curtice et al. (2012) provide recommendations to alleviate funding constraints for tool development.

Although it is clear that DSTs lack application and perhaps funding, the assumption that further development of these DSTs will increase application may be misleading. This assertion assumes that organizations interested in DSTs have adequate infrastructure and data capacity to use these tools. However, as shown in this review, few planning processes had sufficient readily available data required for effective model use. Some processes, such as the Raja Ampat zoning process, underwent a year of data collection and used participatory mapping to fill in data gaps, which was a relatively inexpensive, time consuming, yet productive method of information gathering (Grantham and Possingham 2010). To support the highly complex DST, MIMES, the Massachusetts MSP process required a multi-year data gathering process (Napoli and Moura 2011). Based on these findings, it is unclear whether further tool development would have the desired increased use in EBM and MSP processes identified by Curtice et al. (2012).

5. CONCLUSION

To effectively conduct MSP, it is important to consider the tradeoffs between multiple competing and complimentary uses, and DSTs have been developed to aid in this complex endeavor (Ehler and Douvere 2009, Halpern et al. 2012). Upon analysis of the various tools designed to analyze these tradeoffs, I found that there are few examples of DST use in actual MSP processes. Three significant barriers to DST use were identified: 1) significant data requirements impede institutional capacity to use DSTs, 2) DSTs lack documentation and information aimed at practitioners, and 3) model outputs either lack comprehensiveness or are difficult to interpret. Despite these challenges, there are perceived benefits to using tradeoff tools to supplement a stakeholder-driven decision-making process (Grantham et al. 2012, Guerry et al. 2012). Mapping and modeling tools can help to collate large amounts of information for visual representation. This can work to identify the specific tradeoffs that exist in a particular zone and can illuminate complimentary solutions. DSTs can also help bring stakeholders together and can move dialogue ahead by presenting a variety of management alternatives. If fully used, tradeoff tools can enhance a planning process and can lead to more effective collaboration and understanding between diverse stakeholders.

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