CHAPTER 2

What GIS Experts and Policy Professionals Need to Know about Using Marxan in Multiobjective Planning Processes

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Abstract

Decision support tools are increasingly becoming part of marine conservation planning, and a body of case studies and good practices is growing around their usage. Nevertheless, misconceptions persist among managers and stakeholders about what these tools can provide, and among technical experts, who question how the tools may offer an advantage in planning processes. This chapter provides a summary of these issues with a focus on challenges and problems faced in real-world marine conservation planning. The popular decision support tool Marxan, designed to inform multiobjective spatial conservation and resource-use planning decisions, provides a good example of decision support tool applications and lessons over two decades of use. Marxan helps select networks of areas that represent target amounts of features at minimal "cost." Many challenging decisions and considerations are inherent in solving this problem, including setting targets, determining appropriate socioeconomic values, and interpreting and communicating results. In the end, however, handling relationships with stakeholders and managers in a planning process can make or break acceptance of the tool and the use of its results.

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Introduction

Marine protected areas (MPAs) have become an increasingly applied tool yet remain a controversial issue in spatial resource management. In part, this is because of the lack of a systematic process and clear definition and implementation of planning criteria, as well as heavy emphasis on placement of MPAs to avoid conflict with existing human uses (Devillers et al. 2014). However, specific elements have recently been identified to explain the success, failure, and indifference of many MPAs to biodiversity and resource enhancement (Edgar et al. 2014). Just as these common elements should aid development of effective MPA networks, recognizing themes of successful multiobjective tool use should help guide the process of meeting MPA network criteria. Although this chapter focuses largely on experiences gained through marine conservation planning, we believe that much of its content is also applicable to marine/maritime spatial planning (MSP) and multiobjective resource planning in a broader sense.

To meet a range of conservation and other planning objectives, a systematic approach has taken the place of the ad hoc, site-by-site approaches of the past that resulted in overrepresentation of certain habitats or ecosystems at the expense of others (Pressey et al. 1993; Simberloff 1998; Possingham et al. 2000). The process of systematic conservation planning (SCP) was developed to describe the location, design, and management of areas that comprehensively represent regional biodiversity and targeted resources (Margules and Pressey 2000; Margules and Sarkar 2007; Moilanen et al. 2009). A clear set of objectives, incorporation of the best available information, the inclusion of stakeholders, transparent analysis and reporting, and iterative decision-making all characterize good SCP practices. However, the full promise of SCP has remained elusive because of emerging complexities such as proper accounting of the costs associated with proposed solutions and appropriate use of available decision support tools (McDonald 2009; Ardron et al. 2010).

The Role of Spatial Tools in a Systematic Planning Process

Decision support tools (DSTs) are designed to benefit planning processes by assisting with complicated problems that are beyond human intuition or conventional approaches. Conservation-focused DSTs are software programs that (1) guide decisions intended to promote protection of biodiversity, ecological structure and function, ecosystem services, and/or scenery; and (2) at minimum, identify either sets of complementary sites needed to achieve quantitative targets for biodiversity features or the complementary contribution that individual sites make to conservation within a region (Sarkar et al. 2006).

In recent years, DSTs that help guide ecosystem-based management, integrated ocean management, adaptive management, MSP, and SCP processes have proliferated. Many of them are free or inexpensive to use, but a commonly associated problem is a lack of dedicated maintenance and/or adequate user support, often making the tools unreliable and difficult to use (Curtice et al. 2012). In some cases, proper usage and good practices are documented (Watts et al. 2009; Ardron et al. 2010; Fulton et al. 2011; Guerry et al. 2012). However, there are few published examples that compare functions and features of these tools (cf. Sarkar et al. 2006; Coleman et al. 2011; Rozum and Carr 2013). Rarer still is discussion of how DSTs have been effectively used in the broader context of SCP or MSP processes. Many of the most informative published studies present results from multiobjective analyses and tend to feature the spatial planning tool Marxan (e.g., Chan et al. 2006; Klein, Chan, et al. 2008; Klein, Steinback, et al. 2008; Ban, Picard, et al. 2009; Christensen et al. 2009; Grantham et al. 2013). Considering the broad experience that has been built in terms of planning contexts and study locations, this chapter focuses on Marxan; however, lessons discussed here can often apply to the broader use of multiobjective planning tools in general (e.g., Zonation from Moilanen 2014, ConsNet from Ciarleglio et al. 2009, and C-Plan from Watts et al. 2014).

With more than 9,000 downloads from users in at least 140 countries over the past four years alone (M. Watts, personal communication, June 2014), Marxan has become the most popular tool of its kind. It was developed to address the “minimum-set problem” of protecting at least a set amount of conservation features for the minimum cost (McDonnell et al. 2002). Over the past 15 years, experience in implementing Marxan results has shown that part of its success comes from the ability to help practitioners adhere to the stages of SCP (box 2.1), which promotes a comprehensive, flexible, complementary, repeatable, and efficient process (Possingham et al. 2010). For example, using Marxan to plan a network of protected areas requires users to set explicit targets for species and habitat inclusion (stage 4 of the SCP process), a potentially politically charged consideration that can be too easily deferred or neglected in planning situations without tools that require this difficult, yet essential, discussion to occur (Lieberknecht et al. 2010).

Box 2.1. Stages of SCP

Systematic conservation planning can be described in 11 key stages, based on guidelines presented by Pressey and Bottrill (2009) and including feedback between stages. This set is meant to be indicative and should not be considered definitive (for example, Possingham et al. [2010] propose an eight-stage approach):

1. **Scope and budget the planning process** to make decisions about boundaries, the planning team, budget, necessary additional funds, and how each step in the process will be addressed, if at all.
2. **Identify and involve stakeholders** (those who will influence, be affected by, or implement actions) from the start of a planning process to encourage information exchange, enable collaborative decision-making, foster buy-in, and increase accountability. Different groups of stakeholders will need to be involved in different ways in specific stages of planning.
3. **Describe the context for conservation areas** in terms of social, economic, and political factors. Identify the types of threats to natural features that can be mitigated by spatial planning and the broad constraints and opportunities around conservation actions.
4. **Identify clear goals and objectives** to articulate priorities for protection and restoration/enhancement of biodiversity (e.g., representation, persistence) and socioeconomic interests (e.g., ecosystem services, livelihoods).
5. **Collect spatially explicit data on socioeconomic variables and threats**, including human uses, tenure, extractive uses, costs of conservation, constraints and opportunities to which planners can respond, and predictions about the expansion of threatening processes.
6. **Collect spatially explicit data on biodiversity and other natural features**, including representation (e.g., vegetation types), focal species, habitat types, biodiversity proxies, ecological processes, and ecosystem services.
7. **Establish targets** by interpreting goals/objectives to quantitatively specify how much of each feature to protect within the network, and establish design principles to influence the geographic configuration (including size, shape, number, and connectivity of sites) of the network.
8. **Review current achievement of objectives** and identify network gaps (often through remote data and field surveys) to determine the extent to which targets are already met.
9. **Select new conservation areas** (often with stakeholders) from multiple location and configuration options that complement existing protected areas for cohesive networks that meet targets and design criteria. Factors that influence decisions usually include costs, constraints, and opportunities for effective conservation.
10. **Implement conservation action** by making decisions on fine-scale boundaries, appropriate management measures, institutional arrangements, implementation sequencing priority, and other site-specific considerations to ensure that selected areas are given the most feasible and appropriate management and that areas are prioritized for action when resources are limited.
11. **Maintain and monitor** the protected area network to evaluate whether management is effectively preserving ecological integrity and long-term persistence in the context of original goals and objectives.

Strengths and Limitations in the Use of Decision Support Tools such as Marxan

When used correctly, planning tools such as Marxan and its expansion, Marxan with Zones, save users time and resources, act as a guide for moving from data to decision-making, build on past work rather than repeating it, reduce the need for human expertise, help explore a wider range of alternatives and trade-offs, document decisions about inputs and parameters, and help integrate planning across diverse sectors (Curtice et al. 2012; Possingham et al. 2010). However, these benefits cannot be realized if DSTs are used without the proper data, as detailed in the following.

The use of tools such as Marxan is seldom a quick process, and we caution that it comes with an initially steep learning curve. Furthermore, using Marxan is not recommended in regions where data is inconsistent (patchy) and/or scarce, as the tool will simply highlight the few areas that contain the most data, and cannot take into consideration features for which there is no data. This uneven and/or inadequate coverage of a planning region may miss important ecological features or socioeconomic information that could dramatically influence site selection results. In such cases, it can be beneficial to incorporate facilitated and structured discussion, which for "simpler problems" (i.e., those with few data layers and associated targets and costs) can often lead to similar results with less time and technical effort (Ban, Hansen, et al., 2009; Ardron et al. 2014). In such situations, if planners decide to also use a DST, the tool should play a secondary role in the decision-making process.

In many data-poor situations, it is possible to address some deficiencies, especially at coarse scales, using surrogates. For example, if species occurrence data is unavailable, climate profiles and other environmental parameters may be appropriate surrogates for developing predictive habitat models. Models can be updated or later replaced in the analysis if and when more data becomes available (e.g., Sarkar et al. 2005). Likewise, socioeconomic information such as fishing effort can be approximated by data that is more easily collected, such as boat counts (Weeks et al. 2010). Also, surrogates such as sea surface temperature variation can be used to inform the selection of suitable future habitat to protect a range of management options that account for climate change (Makino et al. 2014).

In general, more data is often available than may be first thought. Various institutions often hold a number of different datasets that describe an area at global, regional, and national scales. Taking stock of these various data sources is one of the first and often most time-consuming tasks in SCP, and is necessary regardless of whether a DST is ultimately used or not.

How Marxan Can Fit into a Systematic Planning Process

Marxan is freely available, spatially explicit software hosted by the University of Queensland, Australia, to support spatial planning. Commonly, practitioners use Marxan analyses to protect at least a certain percentage (termed a *target*) of each representative habitat type, endangered species, climatic zone, and so forth (the *features* of an analysis). The site selection process involves (1) collecting planning units that contain at least the targeted amount of features, while (2) minimizing the sum of selected area perimeters, and (3) avoiding socioeconomically important areas (termed *costs*, for which high values make a planning unit less efficient to include) where possible. Marxan allows flexibility in aspects of an analysis such as the number and types of features included, the target that is set (or not set) for each feature, whether any planning units have a preexisting status (e.g., necessarily included or excluded from all network configurations), and the cost of including each planning unit in the reserve network. Variable emphasis can also be placed on the importance of meeting specific targets and on clumping sites together versus creating a dispersed network (more information available in Ardron et al. 2010). For example, figure 2.1 shows the powerful effect that calibration can have on results through the boundary length modifier (BLM) setting (PacMARA 2012).

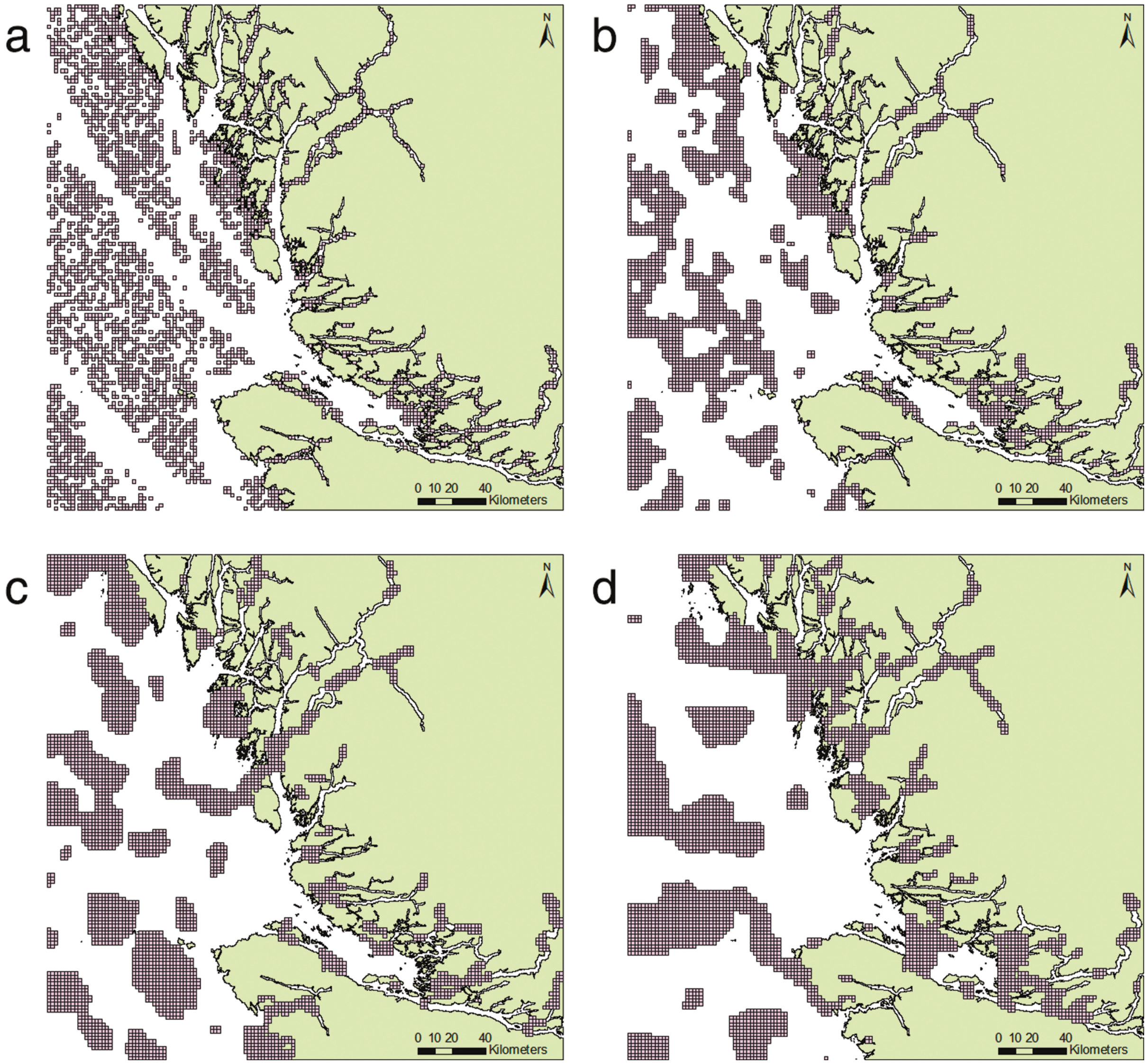

Figure 2.1. Results of a demonstration Marxan analysis used for Pacific Marine Analysis and Research Association training courses that describes hypothetical planning along the central coast of British Columbia, Canada. Purple shading indicates areas selected as part of a complementary network for each scenario. With all other parameters held constant, (a) shows no weighting of boundary length (BLM = 0); while (b), (c), and (d) show increasingly strong influence of total boundary length minimization (BLM = 0.1, 1, and 10, respectively) on network configuration. Data source: British Columbia Marine Conservation Analysis Project Team. 2011. *Marine Atlas of Pacific Canada: A Product of the British Columbia Marine Conservation Analysis*. Available at www.bcmca.ca.

Although initially conceived in the context of marine conservation planning, Marxan is also applicable to freshwater, terrestrial, or a combination of systems (Tallis et al. 2008; Ball et al. 2009; Beger et al. 2010; Hazlitt et al. 2010; Makino, Beger, et al. 2013; Klein, Jupiter, and Possingham 2014; Klein, Jupiter, Watts, et al. 2014). Marxan has also been used in a variety of ways other than developing recommendations for new conservation sites (for example, considering existing networks [Stewart et al. 2003; Fuller et al. 2010], examining the efficiency of ad hoc planning processes [Klein, Chan, et al. 2008; Mills et al. 2012], and planning for persistence in the face of climatic change [Game et al. 2008; Makino et al. 2014]). Other examples of innovative Marxan uses include optimizing a measure of ecosystem services in addition to biodiversity (Chan et al. 2006; Luck et al. 2012); prioritizing a network of fishing sites to maintain viability of the industry (Ban and Vincent 2009); and using conservation priority as the cost for industrial site selection, and vice versa, to inform potential conflict analysis (PacMARA 2012).

In perhaps the best-known case worldwide of MPA creation involving Marxan (e.g., Ecology Centre of the University of Queensland 2009), the Australian government cosponsored an analysis using stakeholder engagement to inform protected area designation in the Great Barrier Reef (GBR). Substantial stakeholder involvement in planning promoted impartiality in the recommendations that Marxan returned, and the resulting maps comprised an effective platform for communication and compromise when used iteratively to zone the GBR (Lewis et al. 2003; Davis 2004; Pattison et al. 2004). However, by systematically avoiding areas of high human "cost," the GBR zoning plan has recently come under criticism (Devillers et al. 2014). This emerging controversy highlights the tendency of DSTs to simply "do as they are told," and stresses the need to address larger questions over the objectives and trade-offs that arise in planning processes.

Marxan with Zones has since been developed to more efficiently allocate zones to meet multiple objectives and has been used to inform planning in many regions globally (e.g., Makino, Klein, et al. 2013). Marxan with Zones is based on the same software as Marxan (akin to layers of Marxan nested within one another) but benefits from the use of more data (i.e., zone-specific datasets) to operate at its full potential. Creating Marxan with Zones scenarios also involves more variables to control and requires more explicit judgments, which complicates usage but allows more flexibility and range of options than using Marxan alone. The contribution of zones to different targets, the costs of implementing different zones in different locations, and the interactions between zones are all considered with this advanced tool (Watts et al. 2009). Marxan with Zones makes it possible to create a range of conservation schemes, from "no-take" to allowing only certain types of extractive activities, depending on the designation (Klein et al. 2009).

Both programs help users evaluate how well each scenario meets conservation and socioeconomic objectives, thereby facilitating the exploration of trade-offs. However, Marxan with Zones has the distinct advantage of allowing what would be treated as *cost layers* in Marxan (e.g., a specific fishery) to be separate features within the analysis, with specific targets set for each associated zone (e.g., multiple use, specific industry access, indigenous access). This functionality allows users to avoid a major shortcoming of Marxan, which is requiring that all cost data be combined into a single value for each planning unit. However, the greater power of Marxan with Zones leads to fundamental questions regarding the efficacy of different management treatments (e.g., differing levels of restrictions) in different zones, or *zone effectiveness* (Makino, Klein, et al. 2013), and their effects on biodiversity, which can be difficult to predict.

Lessons Learned

Further recommendations on the use of Marxan, including the topics briefly mentioned in this section, are covered in detail in the *Marxan Good Practices Handbook* (Ardron et al. 2010), as well as in two workshop reports on the topic (PacMARA 2008; BCMCA and PacMARA 2010). Following, we expand upon considerations that have emerged as central in the course of technical and managerial DST trainings through our involvement in the Pacific Marine Analysis and Research Association (PacMARA). PacMARA is a charitable organization based in British Columbia, Canada, that is dedicated to building capacity in marine and coastal planning internationally. The organization provides facilitation, training, analysis, and support for the ocean planning community, both within and external to planning processes, through workshops, courses, symposia, and spatial planning research case studies. In addition to our own work, we have learned a great deal from participants while leading hands-on and conceptual capacity-building courses throughout the world (PacMARA has held 40-plus courses and workshops for 800-plus participants from 50-plus countries).

In the following sections, we focus on insights that we believe to be relevant to practitioners who want to understand how spatial tools and their outputs fit into the larger context of systematic planning. These are, for the most part, personal observations; however, although many of these "tips" are Marxan-specific and unpublished, they are often similar to good practices that have been highlighted in the marine planning and GIS literature more generally (e.g., Mitchell 2001; Ehler and Douvere 2009). In addition, there are good practices in cartography and the display of quantitative information that deserve close attention; however, these practices are amply covered in the existing literature (e.g., Monmonier 1996; Tufte 2001) and are not addressed further here.

Asking the Right Question

For a spatial planning tool to appropriately prioritize areas for protection, practitioners must be cautious to ensure that they are asking the right question of the tool. Game et al. (2013) elaborate on this issue with several valuable insights, and here we highlight a few practical considerations. Marxan and Marxan with Zones can be used in a seemingly endless variety of ways (Watts et al. 2009; Martin et al. 2010); however, the value of their outputs will depend in large part on whether they address the legal and policy requirements of a particular audience and planning process. For example, although displaying the results of an MPA network that protects 20% of a region can have heuristic value, the usefulness of implementing such a network will be limited if governing bodies are interested in meeting only lesser targets (e.g., the Convention on Biological Diversity [CBD] Aichi Target 11 of 10%) (CBD 2011). Likewise, study areas that mismatch or fall outside the jurisdiction of a given planning process, even if they make more "ecological sense," will have little value in terms of the planning process's mandate.

Common Misconceptions

The original and rewritten Marxan manuals explain the algorithm and its objective function (Ball and Possingham 2000; Game and Grantham 2008). However, the explanation is necessarily technical with some mathematical notation.