Marxan Good Practices Handbook

Version 2

20 July 2010

Editors

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PacMARA
Pacific Marine Analysis & Research Association

Suggested Citation:

Ardron, J.A., Possingham, H.P., and Klein, C.J. (eds). 2010. Marxan Good Practices Handbook, Version 2. Pacific Marine Analysis and Research Association, Victoria, BC, Canada. 165 pages. www.pacmara.org.

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Foreword to the Second Edition

It has been two years since we released the first edition of this handbook. With nothing like it previously published, we were tentative in our initial findings and made sure that a disclaimer was prominently displayed to invite comments and criticisms. While we still welcome comments (to jardron@pacmara.org), the intervening two years have made us perhaps a little bolder. Much of what was written has demonstrated its pertinence in practice, and moreover, no one has written to dispute the suggestions of our original 25 authors and three editors, except for some technical corrections.

However, that is not to say that the first edition was beyond criticism! The comments we received generally pointed out issues that were not addressed in the first edition; i.e., gaps rather than errors. Therefore, we have added seven text boxes to augment the first edition, discussing such relevant issues as dealing with differently sized planning units (trickier than previously assumed) and detecting edge effects.

I would like to acknowledge in particular the British Columbia Marine Conservation Analysis (www.BCMCA.ca) for sharing their insights, questions, and lessons learned at a workshop that PacMARA and BCMCA co-hosted last year in Vancouver, Canada. Special thanks go out to Dave Nicolson and Karin Bodtker of the BCMCA, who respectively wrote the 2009 workshop report and many of the text boxes to this revised edition that ensued. (That workshop report contains many additional discussions and possible solutions to issues that arose, and provides good food for thought for all users. It is available on the PacMARA Marxan Resources and Training wikisite: http://www.pacmara.org/tikiwiki.) Thanks also to Natalie Ban for her additional insights. As always, it is hard-earned practical experience that is the most valuable!

In addition to the BCMCA contribution, thanks go out to George Wilhere who contributed two text boxes concerning the setting of targets and penalties.

I would like to thank Heather Coleman of PacMARA who has been responsible for the many small corrections as well as the larger additions that have made this second edition one revision closer to comprehensive good practices.

While some gaps have now been filled, others still remain. A large gap that we have decided to leave open for now is regarding good practices in the use of Marxan with Zones. It was felt that the tool is still too new, with too few practical applications, to yet be able to discern good practices. To that end, we once again reach out to you, dear readers, to send us your experiences unique to Marxan with Zones, as well as any other insights you might wish to share about the use of Marxan generally. As these intervening two years have demonstrated, there are still a lot of issues lurking about needing better attention.

Jeff Ardron, Washington, D.C., 13-June-2010

Foreword to the First Edition

When learning to apply a new tool or new approach, it is inevitable that mistakes will be made and hard lessons learned. Such was the situation about ten years ago when Marxan was still in its infancy and systematic conservation planning was a good idea, but rarely followed. Since then, the experiences have been piling up... A few years ago, I began to see repeating patterns. Many of us were tackling the same issues, learning by doing, over and over again. The time had come to begin learning from one another, what works and what does not, and to develop preferred approaches –*good practices*.

In the fall of 2006, the Pacific Marine Analysis and Research Association (PacMARA) began to research good practices in the use of Marxan. Beginning with an on-line questionnaire (led by Natalie Ban, see *Appendix 1: Results of Marxan User Survey*), Marxan users could express what they saw as its strengths and weaknesses, as well as areas where they would have liked further guidance. One result was a clear need for better materials to get users started; this led to the re-writing of the Marxan manual (a collaboration between PacMARA and the University of Queensland), which was released in February 2008. The questionnaire results also highlighted other issues requiring consideration. To delve into these, PacMARA organized two back-to-back workshops in Vancouver, Canada, in April 2007. The first two days included about 120 international participants discussing the proper use of tools like Marxan in conservation planning.[1] The second two days involved 30 experts who split up into sub-groups discussing particular topics, sharing good practices and drafting chapter outlines.

One year later, through the collective efforts of 25 authors and three editors, after many edits and internal reviews, the handbook is now ready for your thoughts. Between now and December 2008, we invite comments, praise and criticisms, with the aim of publishing a final version in 2009. In the meantime, we hope this review-version will still be helpful in providing guidance leading to more robust and defensible results.

This handbook is a result of the hard work, reviews and revisions of its authors, particularly the chapter leads. My co-editors, Hugh Possingham and Carissa Klein, spent long hours sifting through hundreds of pages of manuscripts in various forms of completion, offering valuable insights and suggestions. With authors spread out across the globe, Carissa also had the joyless logistical task of coordinating their submissions, comments, and (re-)revisions. PacMARA provided unwavering administrative support, especially Kyira Korrigan and Michele Patterson. The Gordon and Betty Moore Foundation provided the oh-so-necessary funding. Thank you all.

Jeff Ardron, Rügen, Germany, 12-May-2008

[1] Results from the first two days are summarised in a workshop report that can be downloaded from www.pacmara.org

1 Introduction

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ABSTRACT

Marxan is software that delivers decision support for reserve system design. *Marxan was initially designed to solve a particular class of reserve design problems known as the* minimum set problem *(see Box 1.1) where the goal is to achieve some minimum representation of biodiversity features for the smallest possible cost. Marxan helps users to determine the possible contribution of individual areas and whole networks towards meeting their objectives. Users may use Marxan to explore and propose possible network configurations, to facilitate collaborative network design, or to guide their own land acquisition / marine zoning. Marxan is not designed to act as a stand-alone reserve design solution. Its effectiveness is dependent upon the involvement of people, the adoption of sound ecological principles, the establishment of scientifically defensible conservation goals and targets and the construction of spatial datasets. Marxan should be used as part of a* systematic conservation planning *process (outlined in this chapter) and in collaboration with other forms of knowledge. These other forms of knowledge are essential to the refinement of Marxan inputs, the interpretation of Marxan outcomes and the precise placement of final reserve boundaries. Because it seeks spatially efficient solutions, based on a defined problem, Marxan represents a significant step forward from earlier approaches of scoring sites. Nonetheless, there is a significant amount of uncertainty in selecting sites, which is but one aspect of systematic conservation planning, the final step of which is monitoring to evaluate whether the sites make meaningful contributions to the network.*

1.1 OVERVIEW OF SYSTEMATIC CONSERVATION PLANNING

1.1.1 What is systematic conservation planning?

World-leading conservation planning processes, both marine and terrestrial, are employing an approach known as systematic conservation planning (Pressey et al. 1993, Noss and Cooperrider 1994, Davey 1998, Pressey 1999, Margules and Pressey 2000, Groves 2003, Noss 2003, Leslie 2005). Systematic conservation planning focuses on locating, designing and managing protected areas that comprehensively represent the biodiversity of each region (Mace et al. 2006). This approach to planning involves proceeding through a transparent process of selecting and designing a system of protected areas that function together to meet clear region-wide conservation goals. Systematic protected areas planning is a means toward ensuring the integrity of the broader ecosystem by meeting big-picture, regional-scale goals while allowing local needs and conditions to influence the management and governance of each individual site in aspects such as size, shape, use, zoning, and regulation, as appropriate (Smith et al. 2006).

Systematic conservation planning is a departure from ad-hoc, site-by-site approaches that have been used to select protected areas in the past. An ad-hoc approach is one in which site selection is driven by conservation urgency, affinity, scenery and ease of designation, often avoiding areas that are politically or economically costly. Most areas now thought of as protected areas for "conservation" were not chosen to meet specific biodiversity objectives (Possingham et al. 2000). Many existing protected areas were selected because they are favoured vacation spots, or located in places that are unsuitable for other purposes such as agriculture or urban development (Pressey et al. 1993). Other areas have been selected to protect a few charismatic flagship or umbrella species (Simberloff 1998) without any guarantee that they will adequately conserve regional biota. This approach has resulted in a legacy of fragmented collections of sites in which some habitats or ecosystems, like the "rock and ice" of high mountain areas, are overrepresented, while others, such as low-lying fertile plains, are rarely conserved (Pressey et al. 1993, Soulé and Terborgh 1999).

1.1.2 Eight stages of systematic conservation planning[2]

Systematic conservation planning involves eight key stages.

1. **Identify and involve stakeholders.** Effective conservation planning requires the involvement of stakeholders from the onset of the planning process. Engaging stakeholders encourages information exchange, enables collaborative decision-making, fosters buy-in by increasing stakeholders' understanding of decisions made, and increases the accountability of those leading the planning process. Potential stakeholders include levels of government, industry, traditional owners, land holders and concerned community members.
2. **Identify goals and objectives.** The definition of clear goals and objectives for a comprehensive network distinguishes systematic conservation planning from other approaches. Conservation goals articulate priorities for the protection and restoration of biodiversity, whereas socio-economic goals seek to protect and enhance the social and economic interests of the region and the people living in it. For example, the establishment of the Great Barrier Reef Marine Park, Australia

[2] This list of steps was developed from a number of sources: Department of Conservation and Ministry of Fisheries (New Zealand) 2005; Mace et al. 2006; Margules and Pressey 2000; Pressey 2005; Smith et al. 2006; Tear et al. 2005; WCPA/IUCN 2007.

involved a balance between protecting the ecological integrity of the park while minimising the cost to industries, such as fisheries and tourism, which are dependant on the reef.

3. **Compile Data**. In order to design a network that embodies these goals and objectives it is necessary to understand and map the *conservation features* (features to be conserved in the network). In addition it may be useful to map human uses, threats and land tenure. Assembling the best available ecological, socio-economic and cultural data will require evaluating existing data, identifying gaps, and may involve the collection of new data to fill these gaps. Conservation features may be areas of importance to certain species, classifications that describe the different habitat types of a region, or physical proxies for the distribution of biodiversity; maps of human uses may depict places of high value for fishing, mining or forestry; threats may include highly developed areas or point sources of pollution; and tenure could include lands held in fee-simple (free-hold), licences (leasehold) and claims for resource extraction, and traditional ownership or stewardship by indigenous people.

4. **Establish conservation targets and design principles.** Conservation *targets* specify how much of each conservation feature (such as species and habitat types) to protect within the network. Design principles exert influence over the geographic configuration of the network, addressing factors such as size, shape, number and connectivity of sites, with the goal of ensuring persistence and ecological integrity in a truly cohesive network. Conservation targets may be statements such as "protect 20% of each bioregion" or "at least 10 turtle nesting sites;" design principles may include "design a network with sites no smaller than 20 km^2," "select between 7 and 12 sites," or "keep the edge to area ratio of the network low."

5. **Review existing protected areas and identify network gaps.** Most protected area networks do not begin with a "blank slate." Typically, there will be existing protected areas to build on. Once features are mapped and targets set, it becomes possible to review existing protected areas to determine the extent to which they already encompass conservation features, meet conservation targets, and provide meaningful protection toward network goals. In some cases, existing protected areas can contribute to goals and targets with enhanced management.

6. **Select new protected areas.** This step addresses the task of filling in the gaps identified in the previous step. Alternative designs are generated for complete network configurations, laying out options for a cohesive network that meets conservation targets and the design criteria. From the range of possible network configurations, new sites will be selected for protection. It is in this step that decision-support tools like Marxan are most helpful.

7. **Implement conservation action**. The implementation of conservation measures involves decisions on fine-scale boundaries, appropriate management measures, and other site-specific considerations. In cases where all sites in the network cannot be

protected at once it may be necessary to implement interim protection and set priorities for sequencing of implementation.

8. **Maintain and monitor the protected area network.** Once a network is in place, the original goals and objectives will inform management and monitoring necessary to evaluate whether management is effectively preserving ecological integrity, and whether the site makes a meaningful contribution to the network.

1.1.3 Why use a systematic approach?

Systematic conservation planning is widely considered "good practice" because it facilitates a transparent, inclusive and defensible planning process. In addition it embodies fundamental planning principles: comprehensiveness, *efficiency*, spatial arrangement, flexibility, complementarily and *selection frequency* (see *Chapter 3: Key Concepts,* for discussion of each of these principles).

Transparency refers to how well people understand the decision-making procedures and output products. A well-defined process with clear goals and objectives allows stakeholders to participate in the planning process knowing the criteria and "rules of the game." Systematic conservation planning requires clear choices about the values and features we want to protect and the goals we set for their protection. Setting clear goals forces planners to be open and specific, which may be important for stakeholders who will be affected by conservation decisions. Once clear goals, objectives, and design criteria are established and agreed, sites can be selected in a fair, logical and transparent way using explicit and consistently applied methods supplemented by pragmatic judgment and consultation. Highly transparent planning processes tend to increase the accountability and credibility of decision-making.

Inclusive planning processes better reflect the concerns of citizens and help to reduce conflicts between interests. This, in turn, results in stronger, more widely accepted decisions. In addition, inclusive processes ensure stakeholders are involved in the decisions that affect them directly. Finally, the relationships established through inclusive planning processes often contribute to ownership amongst the groups involved. Systematic planning processes support the incorporation of input, information and values from a wide variety of interested stakeholders (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*).

The **defensibility** of the planning process and its results is supported by the ability to report on how much of a particular ecological or cultural feature has been protected in a particular network design option and to document reserve design characteristics (perimeter, area, number of patches, *compactness*). Once the objectives are set it is then good practice to transparently report on how well a reserve network achieves those objectives. One of the most significant benefits of a systematic approach to conservation planning is its ability to explicitly consider how well a particular configuration meets conservation and socio-economic objectives and reserve design criteria.

Systematic conservation planning can become complex when there are multiple objectives and design criteria. To help address this challenge, specialised methodologies and tools have been developed (Evans et al. 2004, Pattison et al. 2004, and Margules and Sarkar 2007 provide reviews of such tools). Marxan has become the most widely used of these decision-support tools for network design.

1.2 WHERE MARXAN FITS INTO SYSTEMATIC CONSERVATION PLANNING

Marxan can be used for a variety of purposes at a variety of stages in the systematic conservation planning process (see *Section 1.1.2 - Eight stages of systematic conservation planning*). Marxan was designed primarily to help inform stage 6, the selection of new conservation areas. Marxan identifies sets of areas that meet conservation targets for minimal *"cost."* It also helps users evaluate how well each option meets conservation and socio-economic objectives, thereby facilitating the exploration of trade-offs. Marxan can also be used to highlight those places that occur in a large number of solutions, which can help set priorities for conservation action. Marxan has also been used in stage 5 of the systematic conservation planning process to measure the achievement of targets in existing conservation areas (Stewart et al. 2003). In stage 7, implementation, Marxan can be used to help prioritise conservation measures, and to develop management/zoning plans for selected sites.

It is important to understand that the appropriate role for Marxan, as with other *decision support software*, is to support decision-making. Marxan will not produce a final reserves network and computer-generated options will inevitably be fine-tuned to yield a final plan that considers the full range of political, socio-economic and practical factors.

<u>Box 1.1</u>: Minimum set reserve design problem

Marxan was developed to solve the minimum set reserve design problem: "What is the minimum number of sites, or minimum total area, necessary to represent all species?" In operations research, this problem is known as the *set covering problem* and solutions are found using *integer programming (IP)*, a well-known class of mathematical optimisation model from operations research (Possingham et al. 1993).

Such models are termed *integer programs* because "yes" or "no" decisions – in this case, whether to select a site or not – are represented by 1 and 0. Solutions to IP problems can be found using commercially available programming software that can be run on personal computers. Integer programming had actually been applied to reserve selection several years earlier with the "integer goal program" model of Cocks and Baird (1989), but it was the minimum reserve set IP that firmly established the link between reserve selection and operations research. (Williams et al. 2004).

The other broad class of reserve network design problem is called a maximum coverage problem which attempts to maximise the biodiversity benefit of a reserve network for a fixed total cost (Possingham et al. 2006).

1.3 WHAT IS MARXAN?

Marxan is software that delivers decision support for reserve system design. Marxan was initially designed to solve a particular class of reserve design problem known as the minimum set problem (see Box 1.1), where the goal is to achieve some minimum representation of biodiversity features for the smallest possible cost (McDonnell et al. 2002). In these problems the objective is to minimise costs and biodiversity enters as a constraint (Possingham et al. 2000). Marxan minimises the cost (see *Chapter 6: Addressing Socioeconomic Objectives* for discussion of "cost") while meeting user-defined biodiversity targets (Ball and Possingham 2000, Possingham et al. 2000). One possible biodiversity target could be to ensure at least 30% of every vegetation type is represented in a protected area network. In this case, a planner might ideally prefer to minimise the total monetary cost required for purchasing and managing land that meets this constraint. Where information on cost is not available, reserve area can be used as a surrogate for cost, based on the assumption that the larger the reserve size the more costly it will be to implement and manage, although this is not always the case. Cost can also be set to any other relative social, economic or ecological measure.

Box 1.2: Marxan, is it an algorithm, decision support tool, software, or a model?

Marxan is software used to support decisions. It is not a model, in that it is not attempting to mimic ecosystems or some of their processes. The optimisation algorithm within Marxan attempts to find good systems of sites through simulated annealing (see Marxan User Manual), whereby different sets of potential conservation areas are compared with user-defined targets and costs, and the set of areas that achieves its objective most efficiently is determined.

The number of possible solutions from a Marxan analysis is vast (for 200 *planning units* there are $2^{200} \sim 1.6 \times 10^{60}$ possible reserve networks) and because the problem is too complex for the human mind, computer *algorithms* have been developed. An algorithm is a process or set of rules used for problem solving. Two general types of reserve design tools have been devised to efficiently solve reserve design problems: exact algorithms and *heuristic (non-exact) algorithms*. Exact algorithms, such as integer linear programs (ILP) (see Box 1.1), are primarily designed to find a single optimal solution, whereas heuristics provide a number of good, near-optimal solutions. Because most reserve design problems consider a large number of sites and features, it is difficult, and often impossible, to find an optimal solution in a reasonable amount of time using an exact algorithm (Possingham et al. 2000, Cabeza 2003). Currently, heuristics are preferred over exact algorithms because they provide timely solutions to complex reserve design problems, and they offer a range of near-optimal solutions for planners and stakeholders to consider (Possingham et al. 2000, McDonnell et al. 2002, Cabeza 2003). Marxan finds a range of "good" solutions using *simulated annealing* (see Box 3.2). The user can also invoke a variety of less sophisticated, but often faster, heuristic algorithms (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*).

<u>Box 1.3</u>: Brief History of Marxan

The Marxan software is primarily a product of Ian Ball's PhD thesis (Ball 2000) that was supervised by and funded through Professor Hugh Possingham while both were at the University of Adelaide. Marxan was built on the reserve design software SPEXAN. An early version of SPEXAN was the site selection algorithm used within the Environment Australia planning software, REST. Both Marxan and SPEXAN are basic extensions of a FORTRAN77 program SIMAN, which contained the main concepts but not in a fashion that was easy for non-experts to use. Marxan represents an upgrade of SPEXAN developed under a small contract to the Great Barrier Reef Marine Park Authority. New versions of Marxan continue to be developed at The Ecology Centre, University of Queensland with partial support from a variety of sources.

One of the most useful outputs from the decision support software is the selection frequency output. This output shows how often each planning unit is in one of the good networks – i.e., those networks that solve the problem very well. Assuming all is running as it should, planning units that are selected more than 50% of the time can be thought of as being important for efficiently meeting biodiversity goals. Sites that are rarely selected can be ignored. This concept is inspired by, but different from, Pressey and Ferrier’s notion of *irreplaceability* (Pressey et al. 1994).

While Marxan was originally designed to ensure species and ecosystem representation in biodiversity conservation planning, and has primarily been applied to that field, it has proven applicable to a broad range of planning challenges rooted in a spatially-explicit minimum set design problem. In the field of coastal and marine natural resource management, Marxan has been employed to support multiple-use zoning plans (e.g., Fernandes et al. 2005). Marxan has been used to account for multiple objectives in a single planning process, balancing goals of fisheries, transportation and conservation. Chan et al. (2006) used Marxan to optimise a measure of ecosystem services as well as biodiversity. Ban et al. (2008) used Marxan to determine a network of fishing sites needed to sustain the industry (with the remaining sites left open for protection).

<u>Box 1.4</u>: Moving Beyond Scoring

The first quantitative methods for systematically identifying "good" reserve sites were developed in the mid 1970s and used numerical scoring to rank candidate sites in terms of multiple criteria such as species richness, rarity, naturalness, and size (Smith and Theberge 1986). Many organisations continue to use this approach today. Using scoring, an appropriate subset of reserve sites – usually those with the highest scores – is recommended. This approach often requires an unreasonably large number of sites to represent all species or other features, because the top-ranked sites frequently contain similar sets of species while missing others; one might need to go far down the ranked list of sites before all species are represented (Williams et al. 2004). In contrast to scoring systems, Marxan allows users to ask the question: What is the minimum number of sites needed to represent all conservation targets? Because scoring systems are not designed to solve a well defined problem, ignore the vast literature on mathematical programming, and struggle to deal with complementarity (see *Section 3.5 - Complementarity*) or spatial design criteria, we urge reserve network designers to ignore them.

1.4 GLOBAL USE OF MARXAN

Marxan was initially created as a modification of SPEXAN for use by the Great Barrier Reef Marine Park Authority, and has since been used by other protected area authorities and government agencies to design and prioritise their conservation networks. Since the release of Marxan in 1999, the use and application of the tool has grown exponentially. Currently, there are over 1500 Marxan users from over 80 countries. A recent survey of 77 Marxan users (see *Appendix 1: Results of Marxan User Survey*) indicates that Marxan has been used primarily in terrestrial (68%) versus marine (51%) and freshwater (22%) applications. The survey results also report that most Marxan projects were conducted at a regional scale (74%), with fewer at national (21%), international (16%) or local (13%) scales.[3]

Many non-governmental organisations (NGOs) with a focus on biodiversity conservation have turned to Marxan as a tool for evaluating representation and comprehensiveness. Marxan enables users to determine the contribution of individual areas and whole networks towards their objectives of ensuring sound management is extended to the full suite of biological and ecological resources. Users may use Marxan to explore and propose possible network configurations, to facilitate collaborative network design, or to guide their own land acquisition.

Ecoregional Assessments spearheaded by NGOs have led to advancement in efforts to ensure conservation of biodiversity. In many cases, governments and private land

[3] Note that percentages will add up to over 100% because respondents were able to tick more than one box.

managers have responded to the priorities identified through a Marxan process and extended their management activities to include Marxan portfolio designs. Increasingly, Marxan is now also being used independently by governmental bodies and their contractors.

The text boxes that follow demonstrate three examples of the use of Marxan. Others can be found through the Marxan web site: http://www.ecology.uq.edu.au/marxan.htm.

Box 1.5: Use of Marxan for planning MPAs in the Channel Islands National Marine Sanctuary

By Satie Airamé, Marine Science Institute, University of California, Santa Barbara

An intensive, systematic planning process in the marine area around California's northern Channel Islands culminated in April 2003 with the establishment of a network of ten fully protected marine reserves and two marine conservation areas that allow limited fishing. The involvement in the planning process of state and federal agencies, scientific and stakeholder advisory panels, and decision support tools including Marxan, facilitated a rigorous, flexible and repeatable process.

Conservation features were developed jointly by scientists and stakeholders and included a portion of marine habitats (such as kelp forests, seagrass beds, rocky reefs, and sandy bottom habitats), as well as breeding grounds for seabirds and haulouts for marine mammals in each of two major biogeographic zones. The scientists recommended setting aside at least 30 to 50 percent of each conservation feature in order to achieve the goals of biodiversity protection and sustainable fisheries.

An early version of Marxan was used to identify five representative alternative configurations that met conservation targets. By refining these outputs based on the ecological guidelines developed by the science advisory panel and their own knowledge of the area, the stakeholders created alternative network designs that minimised impacts on resource users. The selection frequency surface, generated by overlaying the top 100 Marxan solutions, was particularly useful for advancing discussions about where to establish protected areas. A computer planning tool called the Channel Islands Spatial Support and Analysis Tool (CI-SSAT) supported this process by helping stakeholders to view data and evaluate potential sites. Ultimately, the stakeholders were unable to come to consensus on a single preferred alternative, requiring state and federal agency staff to develop a compromise between the two network designs favoured by stakeholders. Many of the planning units that were selected in the majority of Marxan solutions were included in the final network of marine protected areas.

Box 1.6: Use of Marxan

The Nature Conservancy (TNC), the world's largest biodiversity conservation organisation (www.nature.org), has been designing and implementing Ecoregional Assessments in terrestrial, freshwater and marine ecosystems for over 10 years. The objective of conducting an Assessment is to characterise the biodiversity and human footprint in regions where the Conservancy is engaged in an effort to help guide strategic conservation action. TNC has completed more than 80 Assessments globally in collaboration with hundreds of local and regional partners.

Marxan is a commonly used decision support tool within the Assessment process for assisting in the identification of regional, place-based priorities. TNC uses Marxan primarily to sift through large ecoregional databases to design alternative site selection scenarios that are then used at peer review and expert workshops. Marxan is not used to find "the answer" to where conservation action should be taken, but to present these alternatives to multiple stakeholders across management sectors. As part of a larger decision support system, the spatially-explicit nature of Marxan and its representative goal-setting parameters allow the Conservancy to analyse large land and seascapes in an objective, transparent and repeatable fashion.

Both the Conservancy and World Wildlife Fund (WWF) have formed a collaboration to implement common methods for regional planning, and have agreed to employ tools that help design ecoregional conservation portfolios. Marxan is a commonly used tool in both organisations' conservation planning toolboxes in order to execute the principles of efficiency, representation, irreplaceability and functionality.

<u>Box 1.7</u>: Use of Marxan in rezoning the Great Barrier Reef Marine Park

In 2001 the Great Barrier Reef Marine Park Authority (GBRMPA) initiated the Representative Areas Program (RAP), a rezoning of the Park with the primary goal of better protecting biodiversity through the implementation of "representative" examples of 70 bioregions within no-take Green Zones. A representation target of 20%, among other biophysical operating principles, was recommended by a scientific advisory committee. Informed also by social, economic, cultural and management principles such as the guidance to, as far as possible, minimise impacts on current users, distribute impacts equitably, and create reserve networks that are practical for users and managers, the site selection problem faced by planners became complex and computationally large in a planning area of more than 16 000 planning units.

The approach taken to identify options for no-take area networks used a combination of expert opinion, stakeholder involvement and analytical approaches. Modifications to SPEXAN commissioned by GBRMPA and carried out by Ian Ball and Hugh Possingham gave rise to Marxan, and the program was used to support the design of a series of draft zoning plans that were ultimately revised and refined through an iterative process of expert input, public consultation and post-hoc analysis of the Marxan outputs. Early in the process GBRMPA learned that planning without an explicit socio-economic cost layer meant that Marxan was indecisive – that is a vast number of reserve networks were almost equally good.

Planners involved in the process have identified the use of Marxan as one of the factors that made the outcomes of the RAP more explicit, transparent and acceptable to all stakeholders, including scientists. Marxan helped facilitate a systematic approach supported, but not controlled, by science (Fernandes et al. 2005).

2 Is Marxan the Right Tool?

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ABSTRACT

Before embarking on a journey with Marxan one needs to define the problem at hand. Marxan is best known for its ability to solve the minimum set reserve design problem: "What is the optimal selection of planning units to meet our objectives for a minimum cost?" (see Box 1.1). Its use assumes that there are too many considerations for the solution to be readily obvious. Marxan allows for the transparent use of targets and other parameters, and solves this problem in an efficient manner using an optimisation technique called "simulated annealing." Its success, as measured by the implementation of a conservation plan that resembles a Marxan output, depends on the support of stakeholders in this wider planning process. There are ecological and social issues that Marxan cannot address, however, and other tools and/or approaches could be used in tandem. Often very different costs (constraints) have to be considered together, and putting these into a single cost function can be difficult and must be done with care.

2.1 WHY USE MARXAN?

2.1.1 Questions Marxan can help answer

Marxan was created to help determine how to design a reserve network that achieves conservation objectives for the minimum "cost" as defined by the user – often socio-economic. Marxan allows the user to vary many aspects of the problem: the number and types of conservation features included in the analysis, a target for each conservation feature, how important it is to meet targets for these conservation features, the status of planning units and the cost of each site that could be in the reserve network. The evaluation of multiple scenarios is one of its major strengths.

In the context of systematic conservation planning, key questions that Marxan can help answer include:

- Where are the current gaps in our existing reserve network?
- How efficient is the existing reserve network, or a proposed network, at meeting conservation objectives?

- What are the priorities and options for filling these gaps? For example, the selection frequency output conveys information about frequently selected sites, which normally would be a priority for conservation.
- How much more area is needed to conserve to achieve the conservation objectives and where are these areas located?
- How comprehensive is the network in relation to the conservation targets?
- What is the socio-economic cost of meeting different conservation targets, or in other words, how efficient is the reserve network?
- How will trade-offs between socio-economic and conservation targets impact different stakeholder groups (e.g., fishers, foresters, farmers)?
- Where will the focus of conservation effort be located in a particular region/tenure?
- How should zoning proceed to maximise conservation for minimum socio-economic impact?

While the core functionality of Marxan is directly relevant to systematic conservation planning, the tool has also been applied in the following contexts:

- prioritising areas for land acquisition by trusts and conservancies;
- critiquing an existing proposal or existing reserve network;
- providing a means for diverse stakeholder groups to develop proposals that represent their own interests at a planning table;
- investigating the scope and scale of possible designs for effective broad-scale networks in advance of multi-stakeholder planning processes;
- determining where to focus conservation efforts and further research;
- as "proof of concept," to demonstrate the feasibility of a systematic approach to conservation planning; and,
- as a research tool to investigate conservation planning questions from an applied and theoretical perspective.

2.1.2 Questions Marxan cannot answer

It is tempting to think that once Marxan is employed, it will solve all of our problems. Marxan will not tell you how to set conservation objectives, engage the appropriate stakeholders, or whether its input data are reliable. The definition of the problem, establishment of objectives and targets and data quality control are all part of the wider planning process and occur outside of Marxan (see *Chapter 1: Introduction*).

Marxan does not:

- model the persistence of species or ecological and evolutionary processes;

- determine what and how much of a conservation feature to represent or to protect (the user must define these objectives);
- recommend management designations or determine the level of protection a site requires;
- determine ecological irreplaceability. Marxan calculates the selection frequency of a site (see *Chapter 8: Ensuring Robust Analysis*) or in other words, how frequently a site is selected within the different good solutions that Marxan finds;
- deliver a single optimal solution. Marxan determines multiple "near optimal" solutions;
- ensure species viability or sustainability;
- categorise data into biophysical units, e.g., different marine habitats;
- tell the user how to integrate "costs" with different "currencies." While Marxan can include costs with different currencies, all of these costs must be integrated into a single cost surface layer before Marxan is used (see *Chapter 6: Addressing Socioeconomic Objectives*). The integration of this information is not straightforward and requires much thought and sometimes sophisticated socio-economic methods; and,
- manage data. Data acquisition, quality assurance, data preparation, and data management are the responsibility of the user.

Box 2.1: Using other tools in conjunction with Marxan

Population viability analysis (PVA) can be used in conjunction with reserve selection algorithms to produce reserves that are more biologically adequate (Noss et al. 2002, Carroll et al. 2003). For example, Noss et al. (2002) combined PVA models created using PATCH (program to assist in tracking critical habitat) with reserve design software in their multicriteria assessment of sites in the Greater Yellowstone Ecosystem. PATCH projects temporal changes in populations of terrestrial vertebrate species using habitat maps for an individual population, specifications for habitat use (such as territory size), vital rates (survival and reproduction) and descriptions of a species' movement ability (USEPA 2004). Other ecosystem models like Ecospace (Walters et al. 1999) could be used to test the ecosystem-level consequences of a particular Marxan reserve network.

2.2 Advantages of Using Marxan

Marxan is the most widely used systematic conservation planning tool in the world and is based on a well-defined problem (see Box 1.1). Given that the spatial data exist, Marxan can be used to help solve any spatial allocation problem (e.g., where to fish, cut trees, grow food, conserve species). Marxan can support broad, multi-objective decision-making and has the computational capacity to solve complex reserve design problems involving large amounts of data in a timely manner. One of the most significant benefits of Marxan is its ability to generate reserve configurations that meet stated conservation targets and in doing so find multiple near optimal solutions to these problems.

Using Marxan enhances the rigor, transparency and repeatability of processes that are inherently complex and potentially subjective. It enables the production of spatially efficient reserve network options that meet explicit representation and economic targets; e.g., 30% no take area. It ensures targets for conservation features are met for a minimum "cost" – be that monetary, area, or other socio-economic factors defined by the user.

Marxan provides a flexible environment in which to design protected areas. Marxan can consider simultaneously a broad set of conservation targets at multiple levels of biological organisation from bioregions to species to genotypes. It is also amenable to non-biological spatial data (e.g., economic, traditional and expert knowledge). Users can experiment with different conservation and management options (e.g., include existing protected areas or exclude private land). Marxan accounts for spatial contiguity and incorporates spatial considerations into the reserve design process (e.g., compactness, minimum patch size, *separation distance*).

Within Marxan, targets for conservation features, penalties (weightings) of conservation features and costs can all be varied easily, allowing for iterative solutions. Marxan produces a range of reserve configurations that meet conservation objectives increasing the chances of finding solutions that maximise conservation interests while minimizing negative economic, social or cultural impacts and can lead to the identification of unforeseen solutions. Marxan also has the flexibility to support participatory planning processes and to help negotiate acceptable outcomes amongst multiple stakeholders (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*).

Marxan is available free of charge and is easily downloaded from http://www.uq.edu.au/marxan. With a large and growing user community, technical support through a list-serve, the documentation of successful applications, a new manual including a Spanish translation, and of course this handbook, Marxan is becoming increasingly accessible to users world-wide. To aid the preparation of input files and in the visualisation of outputs within a *geographic information system (GIS)*, several front-ends have been developed (e.g., CLUZ, PANDA See *Appendix A2-3 Some Online Resources*).

2.3 Limitations of Marxan

Key limitations of Marxan can be divided into analytical and operational. With respect to analytical limitations there are three main points. First, Marxan is unable to easily integrate stochastic or temporally dynamic data. While most data are to some degree subject to stochastic processes, data used in Marxan represent either a snapshot in time, or an aggregation of various such snapshots. Second, within Marxan only a single "cost" surface can be employed. In other words, if the user would like to include different types of costs (e.g., land acquisition cost and opportunity cost) these costs must be combined outside of Marxan and then included as a single cost surface (see *Chapter 6: Addressing Socioeconomic Objectives*). Third, Marxan can only deal with binary problems or two planning zones, e.g., a planning unit is either in or out of the reserve. Marxan with Zones (a new product being tested at the time of writing) will deal with multiple zones.

Marxan has several operational limitations. Like any type of support tool, the quality of solutions is a reflection of the quality of data that are used. Terminology can be counter-intuitive or confusing, e.g., "cost," "*boundary length modifier (BLM)*" (see Marxan User Manual). Marxan can, like other tools, be misused and its outputs misinterpreted. While the use of Marxan as a decision support tool can facilitate stakeholder engagement, it is not a magic bullet for participation and acceptance of the planning process. Marxan does not alleviate contextual issues, or pre-existing stakeholder and political conflicts. Finally, preparing datasets and Marxan input files, as well as learning its proper use, takes time – more time than is normally recognised at the outset.

2.4 TIME REQUIRED TO USE MARXAN

Getting Marxan up and running can take several days to weeks. Time is required to understand the software program and the terminology it employs, to learn how to use the different input parameters appropriately, to create the different input files and to interpret the results. That said, it is data compilation, management and preparation that are typically the most time-consuming aspects; i.e., not actually using Marxan (or a similar tool) itself, but rather all the tasks associated with collecting and cleaning the necessary data. Data quality should be assessed, data gaps identified, and surrogates developed as required (see *Chapter 7: Assessing and Managing Data*). Data preparation can take several months, depending on the availability and quality of the data. Data preparation is essential regardless of the approach to reserve network design.

Understanding how Marxan responds to a range of key parameters (e.g., the boundary length modifier, planning unit "cost") takes time and experimentation. Users should conduct thorough sensitivity analyses to test the influence of input parameters on Marxan outputs (see *Chapter 8: Ensuring Robust Analysis*). Thorough sensitivity analyses are important because each reserve design problem involves a different study area, and no two problems are alike. In other words, parameters that work for one study will not necessarily translate to another study.

Marxan is one component of a larger planning process and the time it takes to use Marxan will be a function of this process. Ultimately, the financial and time commitment required to use Marxan effectively will depend on the level of expertise, data availability, amount of data, format of data, number of practitioners and the planning context, and the degree of stakeholder involvement and public consultation. Building in time for analysis and thoughtful communication of the results is crucial.

2.5 MARXAN REQUIREMENTS BEYOND THE TECHNICAL MINIMA

The minimum requirements for using Marxan successfully extend beyond the technical requirements (as outlined in the Marxan User Manual) and reach into the planning and organisational set up. The success of a process using Marxan extends beyond technical considerations and requires the willingness and commitment of the stakeholders to the process (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*). Not only the participants, but also all of the involved institutions need to accept the process, support usage of the tool and have a willingness to seriously consider the final product.

To use Marxan effectively requires an in-depth conceptual and methodological understanding of both Marxan and GIS. Clear, well-defined goals are needed at the outset. A successful Marxan project requires technical and planning expertise, as well as available time and money to carry out all the required steps (see Box 2.2, and *Chapter 5: Reserve Design Considerations*) and will benefit greatly from previous GIS and data management investment, and related infrastructure.

If the project under consideration does not have much readily available spatial (GIS) data, then approaches other than using spatial optimisation programmes such as Marxan should be considered. For example, a “Delphic” approach using experts familiar with the area could be a better investment of time and money, although such processes tend to bias site selection to areas where people have knowledge.

Box 2.2: Steps in running a Marxan analysis

Running a Marxan analyses is an iterative process involving many steps. Typically, steps include: (1) dividing the study area into planning units; (2) creating a GIS database of conservation features; (3) preparing the Marxan input files; (4) running Marxan simulations and scenarios; (5) reviewing and analysing the results; (6) consulting with stakeholders; (7) adding new information; (8) refining input parameters; (9) re-running Marxan; (10) printing maps; and (11) communication of the results. More information on these steps can be found in the Marxan User Manual.

3 Key Concepts

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ABSTRACT

There are a range of fundamental conservation planning principles and terms. In this chapter we define these principles and terms predominately using ideas in Margules and Pressey (2000) and Possingham et al. (2006). The ways in which these principles and terms are relevant to Marxan are then discussed. Two principles – comprehensiveness and efficiency - are the most central to our understanding and use of Marxan because they are embedded in the minimum set problem (see Box 1.1), which is what Marxan is primarily designed to solve. It is pointed out that a single planning unit does not by itself have an intrinsic constant value, but rather its value is a reflection of its contribution to the network's overall objectives, and thus can change depending on various network configurations.

3.1 COMPREHENSIVENESS

In simple terms, a comprehensive reserve system is one that contains every feature of biodiversity interest that occurs within a particular region. It should ideally take into consideration biodiversity composition (genetic, species and community diversity), structure (physical organisation, e.g., woody debris in woodlands) and function (ecological and evolutionary processes, e.g., reproduction, recruitment and the provision for shifts in habitat preferences of species at different life stages) (Noss 1990). A comprehensive reserve system is not technically possible because spatial data on all aspects of biodiversity are not available for any region. The hope is that if certain features are comprehensively represented (e.g., habitat types, vascular plants, birds or biophysical domains) then they will act as reasonable surrogates for the rest of biodiversity (Rodrigues and Brooks 2008).

Comprehensiveness is a fundamental principle embedded in the problem that the Marxan tool attempts to solve (see Box 1.1). Usually Marxan is used to find solutions that contain a set amount / percentage of every feature of interest for which the user has data, for the least possible cost. In some situations, this may not be possible; however, usually adjustment of the "*species penalty factor*" will ensure that each reserve network meets the pre-specified constraints ("targets"). (See Marxan User Manual and also *Chapter 4: Addressing Ecological Objectives through the Setting of Targets.*)

3.2 Efficiency

An efficient reserve network is one that meets the conservation objectives for the least possible cost. Efficiency is important because it facilitates future expansion of a reserve system through the resourceful use of funds (therefore potentially allowing more to be gained for the same cost) and is more likely to be defensible in light of competing interests.

Marxan finds solutions to the minimum set problem where the objective is to minimise the cost of the reserve network while meeting all the biodiversity constraints (see Box 1.1). Hence efficiency is a core objective of Marxan. From a practical perspective, the user needs to assign a cost to each planning unit. In a standard application of Marxan, the cost of a planning unit could represent the cost of its purchase and/or management, or the costs associated with lost economic development/use (Naidoo et al. 2006). In more theoretical applications of Marxan, area has been used as a surrogate for cost. In some cases the cost of a planning unit has been used to reflect broader issues such as threat. Either way, Marxan will try to avoid costly planning units, if alternatives are available. However, sometimes costly planning units that are essential for meeting the conservation objectives cannot be avoided.

3.3 Spatial Arrangement: Compactness and / or Connectedness

A compact reserve system is one with a low edge to area ratio. By reducing the edge to area ratio of a reserve network, there are multiple benefits: a smaller number of reserves, lower management and transaction costs, and potentially more viable populations and ecological processes. Reserve networks with fewer reserves and a shorter total boundary with non-reserve areas will also invariably be easier and less expensive to manage. In general, edges between terrestrial reserves and cleared areas are unfavourable ecologically, although for some species of conservation concern, edges are favourable. The fact that spatial arrangement is important is one reason why – in reserve network design – "the whole is more than the sum of the parts" (see Box 3.1). The Marxan parameter, boundary length modifier (BLM), permits the reserve designer to place more or less importance on the compactness of the reserve system relative to its cost (i.e., to influence the direction of design towards the "single large" and away from the "several small" design principle).

Connectivity is often an important consideration for conservation planning. While Marxan does not directly incorporate connectivity, the boundary length modifier can be used to achieve some forms of connectivity (Klein et al. 2008) (see *Chapter 5: Reserve Design Considerations)*.

<u>Box 3.1</u>: The whole is more than the sum of the parts

The most conceptually important flaw of scoring methods for designing reserve networks is that they do not deal with the concept that for reserve networks – the "whole is more than the sum of the parts". However, Marxan does. In essence, a site cannot be valued in isolation (which is what scoring systems do) – the contribution of a site to the reserve network can only be valued when we know what other sites occur in the reserve network. This occurs for two main reasons. First, we are interested in reaching targets for different conservation features. If a network already meets all the targets for all the features in a specific site, that site will add little. Second, we are interested in compact reserve networks. Hence, the value of a site will be larger if lots of its neighbours are already in the reserve network. An isolated site is less valuable, unless its neighbours are ultimately going to be included. It is critical to understand that sites, alone, have no well-defined value – but the whole system does have a well-defined value according to various criteria. This is true in many situations in life – for example when choosing a sporting team (a soccer team needs defenders, midfielders, and strikers that complement each other), or when buying the weekly shopping (bread may be the cheapest form of carbohydrate and protein, but people can not live on bread alone).

3.4 FLEXIBILITY

Conservation planners generally need to evaluate a range of solutions that are reasonably good from an ecological perspective in the context of other considerations, such as economics, political expediency, and social dimensions (Possingham et al. 2000). Flexible solutions provide planners with options to achieve the conservation objectives in a number of ways. Flexibility might be useful to take account of opportunities, or conversely respond to lost opportunities. The greater number of networks and planning units that can be appraised, the more likely the planner will find one which not only satisfies the conservation objectives, but also contributes to other goals. It also gives scope for sensible resolutions of resource-use conflicts (Kelleher and Kenchington 1992). Flexibility is reduced, however, when planning units with rare features are lost from the process, for whatever reasons.

Flexibility is a characteristic of Marxan because the most commonly used algorithm inside the tool, simulated annealing, finds many good solutions to large and complex problems. Additionally, because simulated annealing can generate these solutions quickly, it can be used to explore a variety of scenarios with differing constraints and parameters.

3.5 COMPLEMENTARITY

Planning units complement each other well if the species or habitats they contain are quite different, so their identification provides a combination of planning units that together achieve the ultimate goal of comprehensiveness in the most efficient manner (Justus and Sarkar 2002). Consequently, the process of planning reserve systems should be informed by what is already contained within the existing reserves (Kirkpatrick 1983, Vane-Wright et al. 1991, Pressey et al. 1993). The principle of complementarity is also important because the conservation value of every planning unit is dynamic and will change as the reserve system is established (Margules and Pressey 2000, Stewart et al. 2003).

The algorithms that Marxan uses to find good solutions to the reserve design problem use the principle of complementarity, which in reserve network design is another reason why "the whole is more than the sum of the parts."

3.6 Selection Frequency versus "Irreplaceability"

Broadly speaking, the irreplaceability of a planning unit reflects how important its inclusion is in the reserve system to meet conservation objectives. For example, if a planning unit is essential for a comprehensive reserve system because it contains a unique occurrence of a feature, and/or is essential to meet the pre-specified target for a feature, then that planning unit might be considered irreplaceable.

Pressey et al. (1994) first defined the irreplaceability of a planning unit as the fraction of all the feasible solutions that require that planning unit. However, this formulation was restricted to small datasets due to computational constraints. Later, Ferrier et al. (2000) developed a predictor of irreplaceability for large datasets. Irreplaceability is often a number between zero and one. If a planning unit is essential for a comprehensive reserve system because it contains a unique occurrence of a feature or the only remaining area left to achieve targets for that feature then its irreplaceability will be one.

Leslie et al. (2003) argues in relation to irreplaceability analyses that "such an analysis offers an effective way to glean valuable information about priority areas, while acknowledging the uncertainty inherent in the delineation of targets, model assumptions, and other parameters… An analysis like this can be used to prioritise marine conservation planning and implementation activities across a broad region, indicating which areas within the region consistently contribute to meeting the conservation goals."

In prudent applications of Marxan the user generates many good solutions to the minimum set problem using simulated annealing. Using all of these good solutions one can calculate the frequency with which any planning unit is selected – henceforth referred to as selection frequency. This is not exactly the same as irreplaceability as defined above, although it has in the past been called "summed irreplaceability." It tells us what fraction of the good solutions that are identified are lost if a site is no longer available for conservation. For example, if half the good solutions Marxan found to the minimum set problem (see Box 1.1) contain a particular planning unit then this planning unit will have a selection frequency value of 0.5. This is further discussed in *Chapter 9: Interpreting and Communicating Outputs*.

3.7 REPRESENTATIVENESS

There is much confusion about the term representativeness and its relationship to comprehensiveness. Ideally, the parts of each biodiversity feature (e.g., species or habitats) protected inside a reserve network should be representative of each feature and therefore cover the range of variation in each feature. We define it here is a reserve network that captures the (often unmapped) variation within a feature (Possingham et al. 2005).

Representativeness is closely related to the idea of comprehensiveness because if we define biodiversity at a finer scale (e.g., classify a habitat into its component types), then comprehensively sampling the finer habitat types is equivalent to representing the coarser habitat type. The ability to achieve representativeness is important to consider in the data collation phase.

A basic Marxan analysis does not typically deal with the issue of representativeness within a given feature layer. One simple way of representing features better is to subdivide those features into several sub-features – each of which may be geographically or biophysically defined. For example the northern end of a species' range could be one feature, and the southern end another feature. Similarly the wet end of a species' range could be one feature and the dry end another. This is discussed further in *Chapter 5: Reserve Design Considerations*.

Another feature of Marxan is that it can ensure a minimum separation distance between parcels and this might help to maximise the chances that a reserve network represents geographic variation in each feature. This is discussed further in the Marxan User Manual as well as in *Chapter 5: Reserve Design Considerations*.

3.8 ADEQUACY

Ideally, any selected reserve system will be adequate to ensure the persistence of all features contained within. This involves consideration of the concepts of population viability, ecological processes and the interaction between species, ecosystems, and landscape dynamics. Adequacy is also affected by the size and spatial arrangement of the reserve network. Typically reserve networks should be configured so that component sites interact in a positive fashion. Reserves located at sink populations are likely to depend upon replenishment from elsewhere, thereby diminishing prospects for long-term viability if connectivity, or source populations, are lost (Pulliam and Danielson 1991, Roberts 1998). Spatial design criteria can be either generic or species-specific and potentially informed by metapopulation theory, population viability analysis, biogeography, and landscape ecology (Pressey et al. 2007).

Adequacy is one of the most fundamental concepts of reserve network design and conservation biology in general, but while information on adequacy can be used in Marxan, such information is generally unavailable and uncertain. Adequacy can be considered in Marxan in several ways though it is not a major strength of the tool; e.g.:

- Setting a target population size for populations of a species based on the results of population viability analyses (Noss et al. 2002).
- A minimum patch area can be specified.
- The boundary length modifier can be used to clump planning units and create reserves with low edge to area ratio.
- Geographic spacing and risk spreading can be ensured through replication and the minimum distance function in Marxan.
- The planning unit status can be used to lock in areas that are 100% critical to species persistence (e.g., sources, wildlife staging areas, breeding areas, etc.) and lock out areas that are highly threatened by unmanageable threats to the persistence of biodiversity (e.g., areas with high density of invasive species).

3.9 Optimisation, Decision Theory and Mathematical Programming

Optimisation is a process whereby we try to find the best, or very good, solutions to a well-defined problem. There is a large body of mathematical techniques that can deliver optimal or near optimal solutions. Decision theory is any mathematical, economic or social science that helps us make decisions. Roughly speaking, mathematical programming fits inside the field of optimisation, and optimisation inside the even broader field of decision theory. Simulated annealing (see Box 3.2) is the algorithm inside Marxan that is used to find good solutions to the minimum set problem (see Box 1.1) and is a mathematical programming algorithm.

Box 3.2: What is simulated annealing?

The term *simulated annealing* comes from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce the prevalence of defects. Heat causes the atoms to become unstuck from their initial positions (a *local minimum*) and wander randomly through states of higher energy; the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one and hence fewer defects. By analogy, each step of the simulated annealing algorithm replaces the current solution by a random "nearby" solution, chosen with a probability that depends on the difference between the corresponding *objective function* values and a global parameter termed *temperature*, which is gradually decreased. The current solution changes almost randomly when the temperature is large, but increasingly only good solutions are accepted as the temperature approaches zero. The allowance for the selection of bad moves saves the method from becoming stuck at local minima—which is the problem associated with greedy methods of reserve selection (Kirkpatrick et al. 1983).

More on simulated annealing can be found in the Marxan User Manual, as well as the CLUZ website: http://www.mosaic-conservation.org/cluz/marxan1.html

4 Addressing Ecological Objectives through the Setting of Targets

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Abstract

Central to meeting the ecological objectives of a reserve network is that its spatial conservation targets are adequately determined and met. There are a number of approaches to setting conservation feature targets in Marxan, dependent on the ecological objectives and the available information. Often, it is appropriate to set broad scale representation targets for habitat or biotope classifications that cover the entire region (the coarse filter), and then set additional targets for spatially discreet individual features (the fine filter). Proportional targets for coarse filter features, such as habitat classifications, can be set the same for all classes for the feature (e.g., 10%), or can be scaled depending on the overall abundance of each feature class, with rarer ones given higher proportional targets than more abundant ones (see Box 4.1). For individual fine filter features, minimum viable population sizes and species/area curves can help define targets, when such information is available (see Section 4.3.2). Higher targets should be set for features of particular conservation concern (defined using explicit criteria such as rarity, decline, and threat). Existing protection measures (spatial and non-spatial) should influence how targets are set, and existing legal frameworks and political commitments may contain general targets as a required starting point. A trans-regional perspective will often influence targets, e.g., a feature that is rare in one planning region might be common in an adjacent region, and therefore be treated differently from a feature that is globally rare. In almost all cases, expert knowledge and opinion will be valuable in helping to define those targets or target ranges that are most likely to achieve ecological objectives (see Section 4.3.3 and Box 4.2). Where there is some uncertainty on this matter, it can be helpful to explore a range of targets to develop different scenarios.

4.1 Introduction

Good systematic conservation planning requires explicit objectives formulated into a well-defined problem (see *Chapter 1: Introduction*). In the context of Marxan, this chapter discusses the development of feature targets based on such ecological objectives. This is but one, albeit very important, aspect of translating Ecological goals into objectives which can then be quantified. In subsequent chapters, there is an outline of how other settings can be used in Marxan to address other design considerations (see *Chapter 5:*

Reserve Design Considerations); and, how to incorporate socio-economic objectives (see *Chapter 6: Addressing Socioeconomic Objectives*).

Broad goals and specific objectives[4] of a project should be stated at the outset, and then used to formulate the conservation planning problem. Moving from general goals to quantifiable specific objectives is an important step in using Marxan, which can deal with some specific objectives explicitly and exactly, but others require interpretation, or require some imagination. Central to this problem specification is the determination of feature targets.

4.2 CONSERVATION FEATURES AND TARGETS

A conservation feature is a measurable, spatially definable component of biodiversity that is to be conserved within a reserve network. Conservation features can be defined at different levels of ecological scale, e.g., it is possible to protect species, communities, habitat types, populations, and genetic subtypes. In a Marxan analysis, each conservation feature is given a target, which is the amount of the conservation feature to be included within the reserve network, e.g., 10 000 ha of a habitat, or 30% of its original extent, or one occurrence.[5]

How conservation features and targets are incorporated into a Marxan analysis is a reflection of the ecological objectives of the reserve network. For example, if there is a representation objective to include the full regional range of habitats within the network, then a regional habitat classification layer would be included in the analysis with each class incorporated as a specific conservation feature, for which targets would be set (e.g., 10% of each habitat type (see Box 4.1). If another objective is to adequately protect a particularly endangered mammal, then the species itself might be included as an additional conservation feature, with the minimum viable population size as a target. Alternatively, it might be more appropriate to use a habitat of importance to the species as a conservation feature (e.g., foraging habitat), and set a target of a given number of hectares.

How conservation features are selected, and their targets set, will depend on the type, scale, quality and quantity of the available ecological datasets that relate to them. In practice, the availability of good quality spatial data will often limit what conservation features and targets can be used. Ecological datasets come in many forms: point samples of species occurrences, observation records, abundances, species distribution maps (binary maps or probability of occurrence maps), habitat maps, habitat suitability maps,

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[4] Note that there is some semantic confusion in the literature about *goals* and *objectives*. In this handbook, goals will be considered as broader and more general, while objectives are more specific and quantifiable.

[5] These terms are not to be confused with terminology used by The Nature Conservancy, which uses the word *target* to mean the term *conservation feature* as used in this handbook.

numbers of individuals or numbers of species recorded on grid squares, probability of occurrence, etc. Perhaps one of the greatest challenges is integrating and pre-processing the various available data, so each conservation feature is summarised in a single unified dataset, associated with the planning units (see *Chapter 7: Assessing and Managing Data* and *Chapter 8: Ensuring Robust Analysis*). If a probability surface is used, the probability values can be used as a surrogate for abundance, with total "abundance" being the sum of the probability surface in the study area. A good practice is to document not just the conservation features and targets that are used, but also the rationale(s) behind their selection.

4.3 SETTING MEANINGFUL TARGETS

4.3.1 How coarse and fine filter targets work together

Coarse filter features are those that cover most or all of the planning area and usually represent habitats, biomes, or higher level species communities. For example, a representation target of, say, 25% for a vegetation class may protect an estimated 75% of all species found within this vegetation class. This is a coarse filter, as it is not considering any single species, per se, but rather a general grouping that usually occur together. The further inclusion of targets for fine scale or point locality data for selected species or habitats, refines this coarse filter approach, to include those critical areas where taxa of particular conservation concern are known (or likely) to occur. Criteria to select fine filter conservation features are various, and can include conservation features with special habitats not adequately represented through a coarse filter, such as rare, threatened or endangered species; keystone or umbrella species; endemic species; or species which have a disproportionate influence on their surrounding environment.

In some cases, coarse filter features are distributed across a study area with a broad range of sizes. For example, a seabed habitat classification might include large swathes of sandy areas, punctuated by small patches of rocky reef. In such instances, if targets of equal proportions are applied to all features, then the network can become dominated by vast swaths of common, likely less threatened features, and protecting such large common features may not be the best use of limited conservation resources (see Box 4.1).

Box 4.1: One approach for scaling coarse filter targets

Protecting 30% of a habitat covering 1 000 000 hectares is a considerably larger undertaking than protecting 30% of a more unusual habitat covering 1000 hectares, Ideally, adequacy data (e.g., species-habitat curves – see below) should be used to select appropriate percentages. However, for coarse filter features, these data are seldom if ever available, particularly in the marine environment. In such cases, other approaches should be explored to scale proportional targets based on the overall abundance of the conservation features.

One approach to contending with multi-scalar features is to normalise the spatial data using a square root transformation (just as species populations can often be normalised using a logarithmic transformation), and then scaling representation targets roughly in proportion to the square-root of the ratio of representative features' overall areas. Thus, within a given feature class (e.g., benthic habitats, or marine biomes), for any two features (x & y), protection would be such that:

$(x_p / y_p) \approx (x_t / y_t)^{0.5}$

...where the subscript "$_p$" represents the area protected of a given feature and the subscript "$_t$" represents the total area of a given feature in the network. Put another way, the distribution of targets for multiple representative features of the same general kind should fall within a continuum roughly proportional to the square root of their respective total areas.

In the above example, if 30% of the 1000 hectare feature is protected (i.e., 300 ha) then according to the formula, we would expect about 9500 hectares of the common one million hectare feature to be protected,[6] which works out to be about 9.5%. So, perhaps a 10% target would be set for the larger feature and a 30% target for the smaller one. Statistical assumptions behind this concept are discussed by Ardron (2008).

Whether it is appropriate to scale representation targets, such as suggested here, will depend on the ecological objectives of the network. For example, Johnson et al. (2008) point out that marine species associated with more common habitats will likely recruit from protected as well as unprotected sites, but that those associated with less common habitats will be more reliant on the dispersed "stepping stones" of protected areas, and thus proportionally more of those less-common habitats should be protected. Likewise, if a greater emphasis is put on protecting rare or unusual features, or if it is pragmatically unrealistic to protect very large areas, then scaling the targets could be appropriate. On the other hand, if the representation objective is to faithfully reflect the natural relative abundances of all representative features across the network, then it may not be appropriate to include a higher proportion of rarer features.

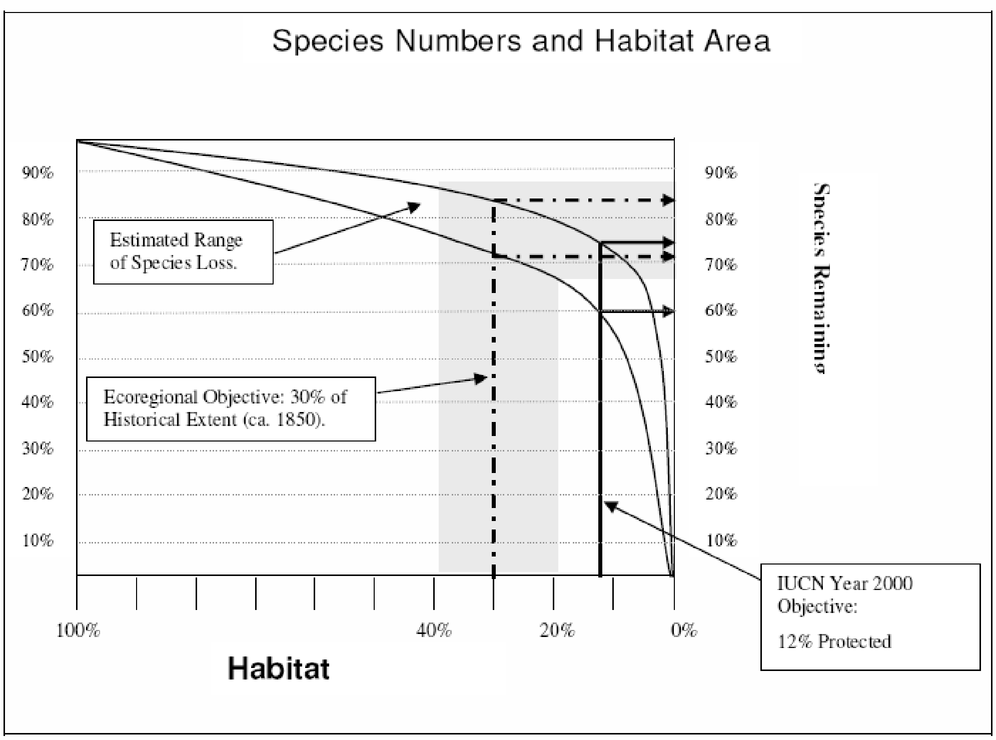
[6] That is, 300 ha * $(1\,000\,000/1000)^{0.5}$ = 9487 ha.

4.3.2 How much is enough? Viability assessments, species-area curves, and expert opinion

Ideally, we would inform minimum targets for individual species using detailed viability assessments – e.g., a reserve system should include enough habitat for 1000 Mountain Zebras (Ferrar and Lötter 2007). For individual species, the absolute values of targets may be guided by knowledge on minimum viable population sizes (MVPs).

Where available, species-area curves can be helpful guidance in the setting of targets for the required areas of different communities / habitats / biomes to be placed under protection (Desmet and Cowling 2004, Pryce et al. 2006). The principle is that enough area should be protected to ensure that the characteristic species of a community or biome are likely to be included; however, the details of implementation can be complicated (Tjørve 2003), and the way that a curve was developed will influence how it should be used (Scheiner 2003). Generally, as more area is set aside, the rate of increasing ecological benefits for the given species community or biome will begin to flatten (see Figure 4.1), and somewhere in this flattening section is where a target should be set. One "rule of thumb" is to locate the region of the curve where 1/10 increase in area gives 1/10 increase in species (Cain 1938). Other related curves consider larval dispersal, pollination distances, species range, and so forth.

<u>Figure 4.1</u>: Species area curve (from Pryce et al. 2006)



Unfortunately, especially in the marine realm, such data are usually unavailable and expert opinion is often the only substitute. In discussions with experts, it is helpful to understand what is considered to be a minimum viable patch size, and what would be considered a minimum network size to ensure ecological goals such as genetic diversity. Spatially relevant issues such as patch separation, terrestrial corridors / marine larval dispersal distances, and life history stages should also be discussed and translated into spatial targets, if known and when appropriate (see *Section 4.3 - Setting Meaningful Targets* and Box 4.1).

4.3.3 Expert advice and peer review

The choice of ecological targets used in an analysis could have far-reaching implications, and will have to be defended, perhaps in a court of law. The initial selection of ecological targets by the analysis team should incorporate expert and sometimes also stakeholder input (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*). Box 4.1 shows the questionnaire that was used in a series of expert workshops to inform marine conservation planning processes in British Columbia (BC), Canada. Good practice is to aim for agreement on a *range* of plausible target values. However, many experts are not comfortable with the use of numerical target values, and/or tend to overvalue their own particular areas of research. Thus the task of balancing the numeric values for all ecological targets in the analysis may ultimately reside with the core analysis team.

During refinements, it can be very helpful to consider the *relative target values* of conservation features as a related set rather than absolute values for individual features. In earlier BC analyses, protection targets for features were first ranked relatively using quantitative terms (low, mod-low, moderate, mod-high, high, very high) and then afterwards various numerical targets were applied to these terms in different scenarios (Ardron et al. 2000, Ardron 2003, 2008).

Box 4.2: Expert workshops to assist in setting targets

The British Columbia Marine Conservation Analysis (BCMCA, www.bcmca.ca) has taken an expert-based approach to selecting features and setting targets. To do this, the project team organized one-day themed expert workshops (for ecological themes including seabirds, marine plants, fishes, invertebrates, and marine mammals). After an introduction to the project, each workshop was dedicated to filling out worksheets based on the questions listed below.

SECTION 1 - FEATURES	
Marine Feature	**Rationale**
List the unique species/ecological features from this dataset (e.g., species, families, groupings of species or of species habitats) that require individual consideration in the BCMCA. You may also wish to delineate features by season/ region or both.	*Justification for classifying features or treating them separately.*

SECTION 2 - ECOLOGICAL TARGETS		
Measure	**Target (range)**	**Comments/ Justifications**
The type of measure that will be used to capture the marine feature (e.g., Percent of current extent of feature in study area, percent of current population, number of occurrences).	*The amount of the feature required for meeting the BCMCA's 4 ecological objectives: (1) Represent the diversity of BC's marine ecosystems (2) maintain viable populations of native species; (3) sustain ecological and evolutionary processes; (4) build a conservation network that is resilient to environmental change. Ranges should span minimum to preferred amounts.*	

SECTION 3 - ECOLOGICAL CONSIDERATIONS				
Minimum Patch Size	**Replication**	**Separation Distance**	**Other Ecological Considerations**	**Comments**
Minimum size of patch/population needed to ensure population viability.	*How many unique patches are needed to ensure long-term population persistence/to safeguard against disturbances?*	*The minimum distance that distinct patches of a feature should be from one another (consider dispersal distances).*	*e.g., connectivity, ecosystem linkages, dynamics, special management considerations.*	

SECTION 4 - SOURCES OF FLORA DATA AND PRE-PROCESSING					
Dataset/Layer	**Description**	**Geometry**	**Provider, Custodian**	**Extent**	**Key Fields/ Attributes**
Spatially georeferenced data that captures the location of the features. Preference will be given to digital data. This list need not be inclusive but should represent the best available data for science-driven analyses.	*Brief description of dataset.*	*Geometry type (point line or polygon)*	*Data provider/ reference*	*Geographic Extent of Database*	*Descriptive information stored with the spatial data.*

SECTION 5 - PRE-PROCESSING
Pre-Processing
How should this dataset (or combined datasets) be processed/prepared for use in Marxan?

Box 4.3: Lessons from the expert workshops

By Karin Bodtker, BCMCA

The BCMCA found that completing worksheets (see Box 4.2) worked better in some workshops than others. In general, they had greater success completing the worksheet under these conditions:

- Features were relatively easy to itemize on a species–by-species basis.
- The range of experts in attendance covered the full range of species groups being discussed.
- The experts in attendance either held the data they were recommending for the BCMCA project or they had good knowledge of them.
- There were no prior misconceptions about Marxan.

The BCMCA found that even though they had developed clear ecological objectives for Marxan scenarios, many experts were uncomfortable recommending target ranges for features because they usually had little or no evidence to support their recommendations. In hindsight, these three suggestions may help to solicit clearer responses from experts:

- Develop materials on examples of real-world Marxan analyses. From these, discuss a range of scenario objectives, itemized features, targets and results.
- Acknowledge that peer reviewed science that prescribes targets based on specific objectives largely does not exist and in order to move forward the project is trying to ascertain reasonable target ranges based on expert knowledge of the relevant ecological features.
- Emphasize that a range of targets will be explored, acknowledging that a single "right" number probably does not exist.

Furthermore, BCMCA held workshops at different times with different attendees and facilitators over a ten month period. While the format for the workshops was the same (large group plenary and small group break-out sessions with 4-6 experts in each small group), there were different approaches taken by different groups for identifying features or targets, possibly the result of "group-think."

<u>Box 4.4</u>: An alternative to expert workshops to assist in setting targets

Dave Nicolson, Black Coffee Consulting

An alternative approach to workshops with worksheets would be to hold a workshop focused on identifying features and data sources to populate those features, and introducing the topic of targets, followed by a Delphi survey/questionnaire to help set targets for each of the features. Invited experts would independently assign targets for all identified features, then be shown the average target and range of targets from all experts and be given an opportunity to revise their responses. Benefits of this approach include:

- reduced group-think bias;
- experts know the metrics that the data support prior to assigning targets;
- efficient use of participants time; and
- all experts have equal opportunity to contribute.

Difficulties of this approach include:

- low response rate when soliciting expert feedback by questionnaire;
- time lapse between explanation of targets and request for target recommendations (i.e., experts forget or are unsure and do not respond as a result); and
- Opinions on features and targets beyond participant expertise.

4.3.4 Conservation status as a proxy for target-setting

The conservation status of species and habitats (e.g., IUCN, or national red lists, globally or regionally at risk) can be used to inform priorities and set targets for individual features. Criteria that are commonly used to develop these lists include threat, recent or historical declines, rarity, endemism, or proportional importance, and features that fall into these criteria sometimes receive higher percentage targets. Where species or habitats have declined in extent, data on historic distributions may be available. These can be used to guide setting targets for what remains, as a proportion of its historic abundance. Knowledge on the causes of declines can also help inform target setting. For example, where estuary fish populations are threatened by river obstructions, the ecological objective may be to protect one whole un-dammed river length from catchment to sea, and the target would be a specified length of unaltered aquatic habitat containing headwater, tributary and mainstream elements.

The use of conservation status to direct fine filter targets risks that the emphasis of fine filter protection could rest on rare and threatened features, and these alone are very unlikely to ensure a healthy functioning ecosystem. Therefore, good practice dictates that other considerations such as ecological significance (e.g., keystone species for fine filter targets) and representativity (for coarse filter targets) are also quantified.

Box 4.5: Tracking "optional features" in the analysis

Sometimes there may be features of possible secondary interest that are not directly relevant to the declared ecological objectives of the analysis. These can still be included in the analysis by setting their target and/or penalty factors to zero. Marxan will not try to collect them, but the tabular outputs will allow the user to track how much was included. Alternatively, giving a feature a much lower than usual (but non-zero) penalty factor and/or target will allow it to "tip the scales" in situations when two planning units are otherwise calculated as being equal. However, good practice dictates that such fine-tuning only occurs after the more important features and their targets have already been sorted out (see *Section 4.4 - Targets and Trade-Offs*).

4.3.5 Existing protection levels

If a user "locks in" existing spatially protected areas, current protection levels for features within those areas will be accounted for in an analysis.

However, when a particular feature is already protected through non-spatial measures, such as stringent quotas, this cannot be directly accounted for in a Marxan analysis. If such a feature is to be given spatial protection, then the benefit it is already deriving from existing non-spatial protection can mean that a lower spatial target will provide sufficient overall protection. This will depend on the ecological objective, bearing in mind it can be hard to accurately quantify the effectiveness of non-spatial measures and translate them into a spatial equivalent.

4.3.6 Legal framework or mandate

Many countries are signatories to conventions or subject to legislation that require a certain proportion of particular species / habitats to be preserved (e.g., the European Community's Birds and Habitats Directives). This will provide a starting point for setting ecological targets, as well as making them defensible publicly and in a court of law; however, caution is advised, as a legal target may not match what is ecologically required. If there appears to be a discrepancy in this regard, running two sets of scenarios (the "legal" and the "ecological") can help visually demonstrate the differences in the possible solutions to stakeholders and decision-makers. Likewise, some organisations have mission statements that commit them to certain targets. Again, these can be run alongside targets based on project-specific ecological assessments, as well as those created by other stakeholders, government policy, or legal requirements (see Box 4.5).

<u>Box 4.6</u>: The policy side of setting targets

By George F. Wilhere, Washington Department of Fish and Wildlife

Target development should be informed by science, but it should not be freed from economic concerns or removed from political discourse (Wilhere 2008).[7] Those who develop conservation targets within the context of a planning process without acknowledging the nexus with economics and ethics are possibly guilty of "stealth" policy advocacy (Lackey 2007).[8]

To avoid inadvertent stealth policy advocacy, Wilhere (2008) makes the following recommendations: Scientists should understand that (1) conservation targets are ultimately expressions of acceptable risk; i.e., how much of a gamble are you willing to make? (2) attitudes toward anthropogenic extinction risk are based on ethical values, and (3) ethical value judgments are outside the realm of science. Therefore, when scientists base a conservation assessment on a set of subjective targets, they should clearly state that it represents just one policy option from a wider range of potential options. Whenever practical, scientists should do conservation assessments for a range of targets, even including targets that might make conservation biologists uncomfortable. Scientists should refrain from favouring a particular set of *a priori* targets within the published assessment, except for indicating how well these targets would be expected to meet the conservation objectives of the process. When the data are available, conservation biologists should ideally work with economists to estimate the relative costs of different risk levels, including information about absolute and marginal costs. Extinction risk could be framed in terms of cost–benefit trade-offs, while still recognizing the decision as ultimately an ethical dilemma.

4.3.7 Trans-regional planning

Noting the proportional importance or degree of endemism of a species within a study region may assist in setting targets and in edge-matching of conservation plans, particularly if the regions follow administrative rather than ecological boundaries, or in ecological regions where it is not possible to run one single assessment. For example, a species that is rare in a particular region may be at the edge of its geographical range, and well represented (and protected) in an adjacent region: such a species should generally be given a lower target than a globally rare species. Usually it is good practice to preserve species in the core of their geographical range, i.e., their "strongholds;" however in some cases it might be appropriate to consider targets for species at the edge of their geographical range, if it is known that the distribution is shifting in that direction; e.g., due to climate change.

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[7] Wilhere, G.F. 2008. The how-much-is-enough myth. Conservation Biology 22: 514-517.

[8] Lackey, R. T. 2007. Science, scientists, and policy advocacy. Conservation Biology 21: 12–17.

Where the geographical range of feature classes spans multiple planning regions, and it is not possible to run a single assessment for all regions together, setting the same representativity targets for the different feature classes in adjacent regions, irrespective of their relative abundance within each region, will ensure some degree of consistency between the plans covering adjacent areas. Such consistency can be important to stakeholders, whereby all regions are seen to be treated equally, which is interpreted to mean "fairly." Ecologically, however, this is usually not ideal, as it disregards ecological differences between regions and good practice would dictate attempting to take these differences into account, when practicable.

4.4 TARGETS AND TRADE-OFFS

4.4.1 Iterative planning

Achieving broad ecosystem goals, and thus all ecological objectives and Marxan targets that flow from them, should be considered central to any ecosystem-based analysis. However, pragmatic considerations often require trade-offs to be made. In exploring trade-offs, it is a good practice to iteratively explore a range of plausible targets, to document the pros and cons, and the reasoning behind the decisions ultimately made. For example, if experts are unable to agree on a target for a conservation feature, it can be helpful to run different scenarios, exploring these differences. It may be found that they do not make much difference to the reserve design. Or, if they do change the solutions dramatically, then this clearly indicates an area where more research or additional advice is required (see *Section 8.4 - Sensitivity Analysis*).

Likewise, it can be important for stakeholders to understand that changing some targets may not impact outcomes significantly, because targets for other objectives are driving overall outcomes. Since it is often not possible to be certain if a particular target will meet the criteria of adequacy (of conserving viable populations, for example), it is important to communicate other (higher or lower risk) options may exist, so that stakeholders understand the tradeoffs (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*).

4.4.2 Weighting targets through the species penalty factor

Promising Marxan solutions should be evaluated in light of meeting their ecological targets, and initially the two most likely issues will be:

- **Under-representation**: When not all targets were achieved, what was the shortfall? Was it ecologically / statistically significant? Does this indicate that the target was unrealistic? Should the target be lowered, or alternatively, does increasing the species penalty factor[9] correct this shortfall? What impact does making those adjustments have on the new Marxan solutions overall?

- **Over-representation**: Were targets overachieved? This can mean that the solution is not spatially efficient and the associated species penalty factor could be adjusted downwards. What impact does making those adjustments have on the new Marxan solutions overall?

As indicated above, the user can decide how important it is to meet the target for a specific conservation feature through adjustment of the species penalty factor. Initially, it ought to be set the same for all features in an analysis. If some targets are not being met for some conservation features, these may be iteratively given a higher species penalty factor than others, in order for all targets to be met (see *Section 8.3.1 - Iterations*). Some practitioners may hesitate to do this, reasoning that each conservation feature and its ecological objective (hence target) is considered equally important. However, it may be that some conservation features are more costly / difficult to obtain than others, and with a flat penalty factor their targets will not be met. If including these features is a necessary objective, then their species penalty factor will have to be increased (or, their costs decreased; or, the factors for other features decreased). Philosophically, the use of equal penalty factors assumes a "flat" ecological hierarchy, which can be difficult to defend, since it goes against the commonly accepted notions of the heightened ecological importance of keystones species, the intrinsic value in protecting rarity, etc. Regardless of which decision is taken, good practice dictates that the underlying reasoning for such decisions be clearly explained. Further guidance on setting the species penalty factor is given in the Marxan User Manual and in *Chapter 8: Ensuring Robust Analysis*.

4.4.3 Adjusting targets based on pragmatic considerations

A decision may be taken to lower some targets. For example, if targets are set to represent a percentage of each broad habitat within a study area, even if that percentage is low, it may only be possible for Marxan to meet those targets by selecting very large areas - especially if additional constraints are included in the analysis (e.g., locked in areas or fine filter targets for individual species, as discussed above). In such circumstances, the outcome may not be politically or practically achievable, and such targets that drive selection towards large swaths of area may have to be lowered. For the purposes of decision-making, a final product may include a number of reserve scenarios created based on the same conservation features but a variety of different targets for the features (e.g., 10%, 20%, 30%, etc.), reflecting differing levels of protection, differing conservation costs, and differing risks to species viability and ecological integrity.

[9] The species penalty factor (SFP) can be applied to any kind of feature, including species, but also habitats, biomes, etc. To clarify this, some users instead use the term *conservation penalty factor*.

It may be impractical to achieve all ecological objectives. Difficult trade-offs often have to be made by decision makers and planners, which are ultimately borne by the wider stakeholders and public; i.e., society. That is not to say that scientists and conservationists should not continue to argue their case for ecological objectives. Presenting to planners and decision makers a variety of output solutions illustrating trade-offs with other activities or interests is good practice.

Marxan outputs can be compared with solutions from other conservation planning tools, such as C-Plan (see Carwardine et al. 2006) or Zonation (http://www.helsinki.fi/bioscience/consplan/). These can suggest other solutions to difficult trade-offs.

It may be enlightening to compare solutions to random surfaces, in order to measure the ratio of efficiency (e.g., 30 times more efficient than random chance), which can also help build confidence that the tool is working as it should despite the difficult trade-offs.

As always, the rationale behind the Marxan trade-offs and the ultimate decisions taken should be transparent and documented, ideally with the relevant authorities accountable for their decisions.

More detailed guidance on evaluating Marxan outputs is provided in *Chapter 9: Interpreting and Communicating Outputs*.

4.5 CHALLENGES

4.5.1 Gaps in quality and coverage of spatial data

The ecological importance of a feature has to be balanced with the quality of its data. Weak or incomplete data should not be "driving" the analysis.

It may be tempting to include all conservation features for which there is some data, but if particular datasets are very weak, it may be preferable not to include them at all. However, if a feature is rare or otherwise important, then perhaps including incomplete or weak data will be judged as being better than using none at all. In such cases, it is generally good practice to assign the weaker dataset a lower than normal species penalty factor. It's a balancing act. Whatever the case, analysts and planners should record the decision and its rationale.

Sampling bias is a common problem; the algorithm will gravitate towards data-rich areas, so that even those features that are more widely distributed and recorded will be chosen in these data-rich areas, if possible (see *Chapter 7: Assessing and Managing Data*). If there are comprehensive surveys for a particular feature in one part of the region, and not another, and it is decided to include it, then mitigating strategies will have to be employed, such as breaking the study area into sub-regions, and setting targets for conservation features for both the entire study area and each of the regions in which data are found (e.g., Pryce et al. 2006). If significantly different data collection methods have been used in different places, then these might be better treated as separate features. Sometimes, it is easier to run a separate analysis for smaller data-rich regions.

Where data are even but patchy then statistical models can be used to extrapolate distributional data for features evenly across the region (Rondini et al. 2005).

When there are no data for conservation features to inform targets for a particular ecological objective, then a surrogate or modelled surface should be used if possible.

In terms of good practice, it is important to understand the actual effects of using incomplete or varying datasets, make an informed decision, and to communicate the trade-offs clearly, especially if important ecological objectives cannot be addressed.

More advice on data preparation is given in *Chapter 7: Assessing and Managing Data* and *Chapter 8: Ensuring Robust Analysis*.

4.5.2 Gaps in scientific knowledge

Even with good knowledge on the distribution of features, it is often not known what targets are necessary in order to achieve ecological objectives. In some cases, there may be very specific scientific evidence that can be used, e.g., minimum viable population sizes, or the minimum area of a habitat required for foraging for individuals of a particular species. However, such cases are the exception. It is usually hard to come up with definite figures such as a percentage of the total area of a habitat that should be placed under protection in order to ensure its integrity and persistence. No matter what value is chosen, some species inevitably will fare better than others. In such cases, the exploration of plausible ranges of values may be more meaningful, and often can highlight likely compromises. Plotting the cost of the overall network versus the upper and lower range values of the targets can indicate if there are non-linear relationships to be considered, where the network is relatively “cheap” up to a certain point, and then becomes costly.

5 Reserve Design Considerations

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ABSTRACT

In addition to setting ecological targets (see Chapter 4: Addressing Ecological Objectives through the Setting of Targets), there are a number of spatial reserve design considerations that can be addressed using Marxan. These include options to set minimum patch sizes for specific features (to allow for the capture of ecological processes that operate at known spatial scales), and to specify a minimum distance between and number of replications of patches for specific features (to allow the incorporation of an "insurance factor" against local catastrophic events). One of the most complex issues in conservation planning is ecological connectivity; this can be partially addressed by choosing appropriate boundary length modifier (BLM) values and planning unit shapes, as well as modifying the boundary file to bias the algorithm towards selecting specific sets of spatially separated planning units together. The main obstacle to the adequate incorporation of ecological connectivity into the planning process, however, remains the lack of spatially explicit knowledge about connectivity at broad ecological scales. No single tool can consider all ecological aspects, and for those that are not easily delineated spatially, other tools could be used in conjunction with Marxan.

5.1 INTRODUCTION

In addition to the setting of ecological targets (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*), Marxan allows for several other reserve network design considerations to be incorporated. This chapter outlines these considerations and how they relate to Marxan functionalities, which together with well chosen targets, can help to achieve ecological objectives. Readers are also directed to the Marxan User Manual, which discusses the operation of these features.

Within the framework of systematic conservation planning there are at least four general classes of ecological objectives: representation, adequacy, efficiency and design

(Possingham et al. 2006).[10] Representation objectives are about "getting a bit of everything". For example, the specific objective to conserve every habitat type is primarily about representation, with little thought about adequacy and design. Adequacy objectives focus on creating a reserve network that is sufficient to conserve the conservation features in perpetuity. For example, the specific objective of conserving a viable population of mammals emphasises adequacy. Ecological uncertainty in these issues speaks to the need to understand trade-offs (costs versus precaution) when defining such objectives. The threat to particular areas, and allowing that threat to modify decisions, can also be considered as part of adequacy objectives; e.g., to conserve 15% of the distribution of all types of coral reef, using those sites that are least threatened by coral bleaching. Efficiency objectives focus on achieving ecological objectives while still keeping the cost of the whole system small, where cost is often measured in socio-economic terms (see *Chapter 6: Addressing Socioeconomic Objectives*). Finally, reserve design objectives address issues of spatial position, size and shape. For example, we may wish to ensure all reserves are at least 1000 ha, or the whole system is relatively compact (has a low edge to area ratio). Reserve design considerations may also include issues such as replication and connectivity, as discussed below.

5.2 CONNECTIVITY

Connectivity (within the sea/landscape) is defined as "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al. 1993). It is a complicated issue, varying from feature to feature, and cannot be fully incorporated using reserve selection tools currently available, including Marxan. However, some aspects of it can be addressed. Brooks (2003) recognises two components to landscape connectivity: structural and functional connectivity.

Structural connectivity is the spatial structure of a landscape and can be described from map elements (e.g., vegetation units). Ensuring clusters and corridors connecting clusters across the landscape, assists in maintaining structural connectivity. In Marxan changing the "boundary length modifier" (BLM) alters the relative importance of maintaining structural connectivity.

The shape of planning units will also have an effect on structural connectivity. Multi-facetted (edged) planning units (e.g., hexagons) are often more efficient than a square grid in creating reserves with low edge to area ratios. If unevenly sized planning units are chosen, larger units will naturally be internally better connected than smaller ones, but the chances of external connectivity (between planning units) is greater with smaller units because they generally "cost" less to join together than larger units. On land,

[10] There are several variations on this theme. For example, the OSPAR and HELCOM regional seas conventions consider four network criteria: representation, adaquacy, connectivity, and replication (OSPAR 2007). The Convention on Biological Diversity is considering the four OSPAR/HELCOM criteria, plus a fifth: *Ecologically or Biologically Significant Areas* (CBD 2008)

planning units are sometimes chosen to represent watersheds, which are inherently internally connected. In the marine realm, however, such delineations are much less clear, and regularly sized units are most often selected. In the Great Barrier Reef Marine Park rezoning a decision was made that each coral reef would be a single planning unit so, in general, whole reefs are either inside, or outside, the reserve system.

Functional connectivity recognises the response of individuals to landscape features (e.g., certain fish require continuous stretches of river for feeding and spawning). Functional connectivity considers the biology and life history of the features concerned, and the reality is that there may be very limited data available. Furthermore, connectivity distances vary widely between species, and a “sink” for one may be a “source” for another, making it difficult to address connectivity at a landscape or ecosystem scale (as opposed to for individual species or populations).

In the marine environment, ocean currents are often used as a proxy for connectivity, based on the fact that many species have a larval development phase, during which they may disperse “passively” in currents. However, the actual dispersal patterns of marine species can be strongly affected by larval behaviour, often resulting in shorter dispersal distances than expected based on current strengths and direction (e.g., Leis 2002).

In the terrestrial environment, it may be possible to spatially define and map corridors for individual features, such as migration routes along mountain passes. It may also be possible to define probabilistic corridors in the marine environment. Spatial models can be used to assist in predicting corridors; a least-cost path analysis (such as available in several GIS) is one approach. If there are known critical corridors or “bottlenecks” they can be locked into the Marxan reserve system.

If there is reliable evidence of functional connectivity between two spatially separated areas for a given feature, they can be given a common boundary in the boundary input file. It does not matter if planning units do not actually share a boundary – if they share a high boundary value in the input file, Marxan is effectively "tricked" into treating them as neighbours, and it will act to reduce *boundary costs* by selecting them together (see the CLUZ website at www.mosaic-conservation.org/cluz/). New versions of Marxan will make this more explicit by calling the boundary length a “connectivity cost”. In effect, the “connectivity cost” allows for the fact that the whole network is more than the sum of its parts, and that spatial adjacency is just one form of connectivity, amongst others.

5.3 MINIMUM CLUMP OR PATCH SIZE

In Marxan, it is possible to define how large a patch of a particular feature must be in order for it to count towards meeting its target. This can help ensure persistence and integrity of the feature. Species area curves (Figure 4.1), or population viability analyses, can be helpful in calculating minimum clump targets, if such data are available. Minimum clump size targets can also ensure that dynamic ecological processes are captured, which are otherwise difficult to add as features. For example, if we know that most fires burn to around a certain size, the user may wish to make all reserves several times that size so the chance that a whole park burns is very small, and each park maintains a mosaic of successional stages. Similarly we may wish to set a minimum clump size large enough to allow for plant-pollinator interactions to continue.

Within the marine environment, it has been suggested that if clump sizes are too small, most larvae will disperse beyond the protected areas, making populations within the clusters unable to sustain themselves (Halpern and Warner 2003). However, there is evidence for high levels of larval retention mechanisms in many marine environments, such as coral reefs (e.g., Swearer 1999, Cowen et al. 2000, Leis 2002, Cowen et al. 2006). Where there is good data available for the spatial scales of larval dispersal/retention, this can help inform minimum clump size targets, as well as design considerations relating to wider connectivity (see above). In general, however, marine organisms have a wide variety of dispersal distances, and thus it is important in designating patch sizes to consider whether there are neighbouring sites that can supply recruits (Johnson et al. 2008).

It is worth bearing in mind that increasing the BLM setting will increase the clump size throughout the reserve network. This is of course different from specifying the minimum clump size for individual conservation features, but in practice is often sufficient. The effect of the BLM can readily be calculated in a GIS by merging ("dissolving") all of the selected reserve network units and calculating the average patch size and other statistics, which can be compared with the required patch sizes to support viable populations of conservation features. Setting minimum clump targets for individual features increases Marxan processing time considerably, and it may also result in some representation targets not being achieved (one solution may then be to increase the species penalty values for those features not adequately represented). It is important to understand such trade-offs, and how they can affect final solutions, when using minimum clump size targets.

5.4 Replication and Separation

To ensure long-term persistence of some conservation features, a conservation area network may require those features to be protected in multiple separate patches, spaced apart from one another. Replication of features can:

- spread risk against damaging events and long term change affecting individual sites;
- ensure that natural variation in the feature is covered (either at a genetic level within species or within habitat types);
- increase the number of connections between sites and enhance connectivity in the network;
- allow the establishment of replicate scientific reference areas; and,
- allow for uncertainty in the identification of features, such that the greater the uncertainty, the more replication is required to ensure the feature is likely being protected (OSPAR 2007, p27).

To achieve this, the practitioner can set minimum distances between different protected patches containing a particular feature. Additionally, the design can also ask for a given number of replications of features within a reserve network. For example, in Mpumalanga, South Africa, at least three replications of large montane grassland patches (>15 000 hectares each) were required, with a minimum distance of 20 km between these patches, so that they could not be contiguous (Ferrar and Lötter 2007).

Where separation distance and replication are used to provide an insurance against disaster, areas containing the same features should be separated by sufficiently large distances to offset the chance of a catastrophic event affecting more than one site. The distances and number of replications required will vary depending on the nature of the main threat(s), and the vulnerability of the features to those threats. Applying the precautionary principle means increasing the number replicates when there is uncertainty about data, for features that are particularly vulnerable, and in areas / regions that are particularly threatened (e.g., for seabird feeding areas near major shipping routes, where oil spills are more likely than elsewhere).

When using separation distance, it is important to be aware of the distance units being used. If units and boundaries are measured in metres, then distance (separation) needs to be measured in metres. Use of the separation distance option can also considerably increase processing time.

Planners need to weigh the importance of insurance against catastrophic events against considerations that may require distances between patches to be kept small, e.g., facilitating recolonisations in a metapopulation and ecological connectivity in general (see above).

There are possible alternatives to the use of replication settings. In the Colombian Caribbean the names (codes) of single conservation features were altered depending on what part of the planning region they occurred in (e.g., feature1area1, feature1area2 etc.), and then targets were set for each "different" feature. That ensured a spread of the feature across the protected area network, rather than it being represented in a single clump (Alonso et al. 2008). In Cuba, a planning region was split into sub-regions, each of which was included as a conservation feature, assigning it a high penalty factor and setting specific targets for each of the sub-regions. This way reserves were replicated across the entire planning region (Halidina et al. 2004). However, these approaches limit to some degree the algorithm's ability to spatially optimise solutions.

Because of the computational costs of the two Marxan parameters, *clumping* and separation distance, we recommend that the user first try alternative methods such as discussed in the previous paragraph.

5.5 Shape (Edge to Area Ratio)

Although Marxan does not select optimal portfolios according to specific reserve shapes, the shape of the reserve network can be influenced by the boundary length modifier and boundary cost values. The BLM acts to cluster units, so the higher the BLM, the more Marxan tries to cluster them. If the boundary cost values are altered for certain planning units, the algorithm will tend to cluster those sets which share higher cost boundaries. By modifying boundary cost, it is possible to create solutions with different degrees of fragmentation in different parts of a study region (see Box 5.1).

Box 5.1: Accounting for varying degrees of fragmentation in the landscape

In British Columbia, Canada, where there are a variety of open and constrained marine water bodies, Ardron (2003, 2008) used boundary cost to fine-tune the relative clumping of hexagons in the analysis' four Ecological Regions (inlets, passages, shelf, slope). To determine this value the edge to area ratio of each of these regions was calculated to inform an appropriate scalar. The non-dimensional measure used was: $(P^2/A)^{0.5}$, where P = total perimeter of region, and A = total area of the region. Altering the boundary costs per region allowed for more fragmented solutions in areas constrained by geography, such as inlets, but encouraged more clumped solutions in open waters, such as over the continental slope.

In trying to select reserves with low perimeter to area ratios, it may be expedient to first undertake the calculations and select suitable sites that qualify in a GIS, before incorporating them as features within Marxan. For example, within the Mpumalanga Biodiversity Conservation Plan (Ferrar and Lötter 2007), suitable grassland areas were selected by first removing transformed land, then selecting grassland patches with low perimeter to area ratios, and only incorporating these patches as a feature layer within the Marxan assessment. Following from that, minimum clump size, clump distance, and number of clumps were set for that feature.

5.6 COST

Every planning unit in Marxan has a cost. Marxan tries to meet all the biodiversity constraints for minimum total cost (ignoring for now design issues). Hence the cost setting can be used to favour selection of planning units in certain areas, over other areas of equal size, e.g., to favour the selection of planning units in areas of high biological integrity. Usually cost is calculated either as simple reflection of area, or as an economic cost; however there is no reason why the cost of each planning unit cannot reflect an ecological issue where high cost sites are ones we wish to avoid, all else being equal. Here we discuss some possible ecological applications of the cost variable to influence reserve design.

As mentioned in *Section 5.2 - Connectivity*, the cost surface can effectively be used to reflect corridors that connect protected areas with one another, or species with protected areas, by lowering the cost value of the planning units within these identified corridors. Several options exist to create a cost surface, such as least-cost path analysis or friction surfaces (reduced movement through the landscape). One can use a friction surface (cost raster in Idrisi or ArcGIS) directly as a Marxan cost surface where increased friction areas, or areas unsuitable for the movement or migration of species through the landscape, are more expensive and so will be generally avoided during Marxan's selection of planning units.

In order to favour areas with high ecological integrity, planning units in a healthy (less disturbed) state can be given a lower cost (relative to their size) than planning units in unhealthy areas. The Nature Conservancy of Canada developed a cost surface (called the suitability index) by weighting between and within a number of factors using a pairwise comparison and expert evaluation (see Box 5.2) (Pryce et al., 2006). The Nature Conservancy routinely uses external threats to a site as a surrogate of cost. Threat can be a good proxy for economic cost, and if the threat cannot be abated then making threatened sites high costs will mean the chosen reserve system is less likely to be influenced by these external forces. The cost of planning units can be increased in areas that are important for economic activities, such as fishing, relative to areas that are less important for fishing, as was tested in the Irish Sea Pilot project in the UK (Lieberknecht et al. 2004). That way, it is possible to explore ways of meeting ecological targets whilst minimising impacts on ongoing human activities (see *Chapter 6: Addressing Socioeconomic Objectives*).

Marxan can, however, only use one cost surface within each analysis. It is possible to combine different spatial surfaces into one cost layer, but care should be taken not to combine too many different themes into one layer where consideration may need to be given to transformation, scaling, standardisation, weighting, etc. If one needs to merge different layers into one cost surface, it is advisable to use a more rigorous and defensible method of layer integration, such as the use of a multi criteria analysis (MCA) methods or software (see *Chapter 6: Addressing Socioeconomic Objectives*). Good practice suggests keeping the costs as straight-forward and interpretable, as possible. If data depicting the economic cost of implementing conservation measures is available, it is a good practice to use this as the cost layer as it will produce cost-efficient solutions. The use of a new cost layer may require adjusting some species penalty factors (up or down) in order to efficiently achieve ecological targets (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets* and *Chapter 8: Ensuring Robust Analysis*).

5.7 Adaptive Reserve Network Planning

Reserve network design should be adaptive to changing environments and priorities. While Marxan is principally designed to develop a network based on a static "snapshot" of the way features are spatially distributed, options such as those outlined above illustrate that the tool is flexible, and thus it can be used iteratively to adapt to changing situations. Marxan can also incorporate regular data updates, and be used for re-analyses as the environment or priorities change. The F-TRAC Florida Forever program is a land acquisition program that was able to update the plan every 6 months (Oeting et al. 2006). Furthermore, if a reserve system designed with a low conservation target, e.g., 5% of every feature, needs to be expanded, then using a higher target with the original 5% system locked in is reasonably efficient (Stewart et al. 2007).

Box 5.2: Developing a cost surface using multiple factors

The Nature Conservancy of Canada wanted to include a number of ecological suitability factors into its cost surface (Pryce et al. 2006). However, they recognised that factors such as road density and land development did not have equal impacts on suitability for conservation or chance of conservation success. To overcome this limitation they developed a suitability index using a linear combination of factors thought to affect suitability. Each factor was represented by a separate term in the equation, and each term multiplied by a weighting factor. The weighting factors were obtained through a technique known as pair-wise comparisons where expert (local knowledge and subject matter) opinion is solicited for the rank and relative importance of each term in the equation, comparing two terms at a time. The cost (suitability) was defined by the following equation:

$$\text{Terrestrial Suitability} = A * \text{management\_status} + B * \text{land\_use} + C * \text{road\_density} + D * \text{future\_urban\_potential} + E * \text{fire\_condition\_class}$$

Where A, B, C, D and E are weighting factors, calculated from expert input and pairwise comparison, which collectively sum to 100%.

Sub-weights, summing to 100%, were also applied to sub-factors within the management status, land use and fire condition classes. For example:

$$\text{land\_use} = q * \%\ \text{urban} + r * \%\ \text{agriculture} + s * \%\ \text{mine}$$

Values for each factor (or sub-factor) are based on the percent area of that factor in the planning unit. Values for each factor are standardised prior to applying the weights according to the following equation:

$$\text{Standardised score} = (\text{score for that PU} / \text{highest score for all PU})*100$$

This standardisation has the advantage of creating equal score ranges, which are easily comparable. As a drawback, it does not account for varying data variability, and will tend to over-emphasise factors that come with little variability. Thus, it is best applied in situations where factors have similar variabilities, or where these variabilities have also been standardised.

Although the simple index used in this assessment cannot account for the many complex local situations which influence successful conservation, the study concluded that some reasonable generalities such as this were useful for assessing conservation opportunities across an entire study area.

5.8 OTHER CHALLENGES

5.8.1 Difficult ecological issues

Many context-specific design considerations arise when striving to meet ecological objectives. It is impossible to cover all eventualities, but here are three common examples:

- There is sometimes strong political pressure to account for the effects of climate change, even though it is often very difficult to do so. Simple proxies can start to address some climate change considerations, though. For example, if it is expected that taxa may migrate to specific areas, such as the cooler slopes of a mountain in an area where they cannot migrate higher up the slopes, then it is possible to include the cool slopes as a conservation feature and set a target for them, or to bias the algorithm towards selection of these areas by lowering the relative cost of planning units within them. Features on the periphery of their range may become more important under a climate change scenario. Some areas may become more prone to extreme weather events and thus could have higher associated costs applied to them. In all cases, though, the use of such proxies assumes a level of scientific certainty. Good practice would suggest that these proxies be applied or emphasised (e.g., though the Species Penalty Factory) commensurate with their certainty.

- Not all configurations of planning units are suited to all types of ecological objectives. For example, dividing up a planning region into regular hexagons might not be suitable to freshwater conservation plans, which could accrue greater benefit using (modelled) sub-catchments. Some features, such as wetlands or reefs, are ideally treated as whole, functional, planning units. If they are sub-divided by smaller planning units, however, then strategies will have to be employed to keep them together (e.g., high internal boundary costs). Be aware that units grouped together to best represent one feature will preclude grouping them together for other features. In cases where the correct choice of planning units is not clear, a sensitivity analysis on the effects of different planning unit choices is good practice, and can help eliminate options that appear to be heavily skew results as compared to other choices. Starting with a basic grid is a good way to get a sense of what baseline solutions might look like; then, other more sophisticated planning unit shapes can be explored. In addition to above (see *Section 5.2 - Connectivity*), planning units are also discussed in *Chapter 7: Assessing and Managing Data)*.

- Integrating planning realms, such as freshwater and marine, or terrestrial and aquatic, is an ongoing area of research. The Mpumalanga Biodiversity Conservation Plan (Ferrar and Lötter 2007) combined the output from a freshwater Marxan analysis as input files (cost surface) for a finer-scale terrestrial Marxan analysis. This was an attempt to combine both freshwater and terrestrial conservation planning into one holistic plan.

5.8.2 Limitations of Marxan in addressing ecological objectives

Marxan is primarily designed to consider objectives that translate into static spatial targets. For example, Marxan is very good at achieving targets related to objectives such as representativity, or incorporating specific sites important to certain life history stages of a feature. However, persistence of a habitat or species is often influenced by ecological processes that are hard to represent spatially and are difficult to incorporate into a spatial "snapshot" analysis. Thus, spatial tools like Marxan are just one tool in the toolbox.

Likewise, spatial planning is just one toolbox, and other approaches (such as economic tools) will likely be necessary to ensure overall sustainable resource use and conservation.

With Marxan it is difficult to consider:

- objectives for which there are no or few spatial data;
- ecological objectives that are not persistent in space and/or time;
- resilience;
- connectivity (other than straight-line distances, and using boundary costs as described above); and
- ecological functions that are not spatially defined or persistent.

In summary, no single analysis tool can address all aspects of ecology, or incorporate all kinds of ecological objectives. Using different tools (spatial and non-spatial) as a suite can be more powerful than one at a time, where the output from one tool may help to inform the input to another (see Box 2.1). For example, habitat suitability models can produce input into Marxan when complete data coverage is not available. Likewise Marxan outputs can be used to as input options for non-spatial analyses. For example, the size and relative protections of species in a given site can be fed into a trophic model to indicate the possible effects on the food web of a site. Or, a model of larval dispersal can shed light on network level objectives, such as connectivity and gene flow, amongst various Marxan scenarios under consideration.

6 Addressing Socioeconomic Objectives

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ABSTRACT

It is good practice to include explicit socioeconomic considerations into conservation planning. These should be defined clearly and transparently so that all participants understand what information will be included in the analysis. It is possible to develop cost surrogates to represent the cost of conservation when spatially explicit data are not available or are not available at an appropriate resolution. Socioeconomic goals are usually represented as costs (a factor to be minimised) but may also be represented as features (a factor to be targeted). It is also possible to use other Marxan parameters, such as the BLM to achieve socioeconomic objectives. Marxan only considers one cost at a time. Therefore, if multiple socioeconomic costs are present, they must either be treated individually or combined into a single overall cost index. If socioeconomic costs are all measured in the same units and have the same value to stakeholders, they can be combined additively. Often, however, costs are represented in different units, and thus it is not straightforward to combine them. Marxan results are influenced by socioeconomic objectives and their incorporation may be critical in achieving stakeholder support for a network of protected areas.

6.1 INTRODUCTION

The establishment of conservation areas is often a conflict between biodiversity conservation and other socioeconomic objectives. In this chapter, we suggest several ways to address multiple objectives in reserve network design using Marxan. First, we recommend that the costs of conservation (e.g., opportunity cost, management cost, acquisition cost) be minimised given certain biodiversity conservation objectives. Second, we suggest ways that areas of social and cultural importance can be targeted for inclusion in a network of conservation areas. Finally, we provide advice on how to use the boundary length modifier (BLM) to achieve certain socio-economic objective. We believe that careful consideration of socioeconomic objectives is good practice.

Socioeconomic objectives are often not included in reserve network design for a variety of reasons:

- It is difficult to translate qualitative socioeconomic goals and objectives into quantitative, spatial data that can be used in Marxan.
- It can be challenging for stakeholders to communicate their needs to planners and for planners to account for the needs of different stakeholders.
- Incorporating socioeconomic goals requires transparency, and knowledge of the broad goals for the project from the outset.
- Planners who are trained as ecologists or spatial scientists may lack the expertise to process socioeconomic data.

However, we believe the benefits of using socioeconomic data outweigh the challenges:

- Consideration of socioeconomic goals can reduce the overall cost and impact of conservation areas.
- Including socioeconomic goals can increase stakeholder trust and acceptance.

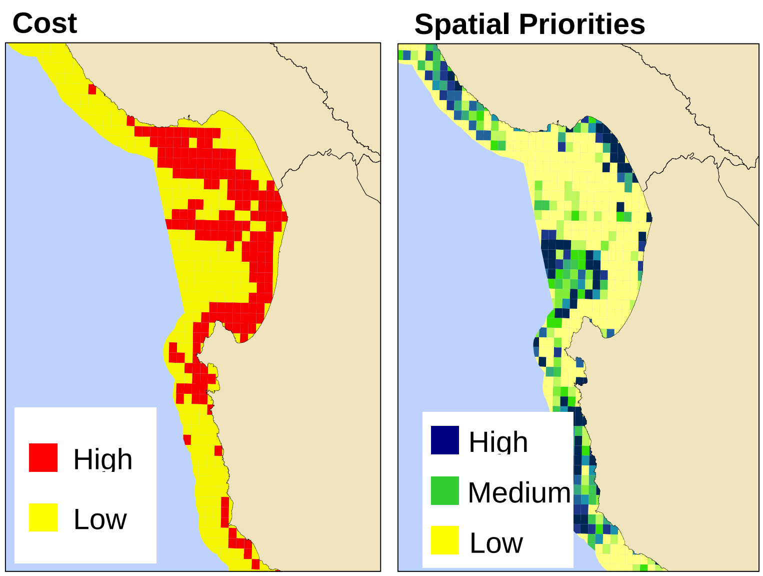
In an effective plan, both planners and stakeholders will work together to translate aspirational socioeconomic goals into quantitative measures that can be included into Marxan. This is often an iterative process. Although development of socioeconomic data and objectives can be time consuming, inclusion of this information at the outset results in solutions that are more efficient and more acceptable to stakeholders, than solutions considering socioeconomic cost post-hoc.

6.2 DEFINING SOCIOECONOMIC OBJECTIVES

It is critical to define socioeconomic objectives clearly so that all participants understand what information will be included in the analysis. Early education about what Marxan does and how it uses data may be appropriate so stakeholders know what type of data can be included. Socioeconomic objectives will largely reflect the project's mandate and/or the aspirations of the stakeholders. Therefore, it is important for planners to have a clear idea of the goals of a conservation planning exercise and who the relevant stakeholders are. Again, defining these objectives may be an iterative process. Objectives may change as project goals evolve or as stakeholders are added. While initial stakeholder goals may be aspirational, it is important to emphasise that these objectives must be translated into spatial, quantitative data to be used in Marxan. Socioeconomic objectives that do not meet these requirements are still important, but cannot be included in a Marxan analysis.

Box 6.1: Incorporating socioeconomic information into Marxan

Any socioeconomic goal that can be represented quantitatively and spatially can be included in Marxan. Socioeconomic information can be captured in Marxan through the cost, target, and BLM parameters. Typically, socioeconomic information is factored in through a cost (see Box 6.4). Marxan aims to minimise the cost of a system of planning units, subject to the constraint that biodiversity targets are achieved (see below). If the values of a user group (e.g., fishermen) can be quantified across a planning region, then Marxan can produce solutions that minimise negative socioeconomic impact.



Marxan aims to minimize the cost of a reserve system, subject to the constraint that biodiversity targets are achieved. Here, we show how several high priority areas (i.e. selected frequently in 100 solutions) were identified in areas of low opportunity cost around Monterey Bay, California (USA). Thirty percent of each biodiversity feature was represented in each solution.

6.3 Data Issues

One of the largest obstacles to using socioeconomic data is the real or perceived difficulty of obtaining it. As mentioned before, data must be spatial and quantitative to be used in Marxan. Data quality is always an issue to consider. Ascertaining data quality can be difficult with socioeconomic data because of constraints on data collection, i.e., to protect confidentiality. OceanMap, developed by Ecotrust (http://www.ecotrust.org/mlpa/index.html), is being used to collate socioeconomic data for the California Marine Life Protection Act and is a good example of a tool to collect, manage, and analyse sensitive data transparently while maintaining stakeholder confidentiality.

Credible spatially explicit data across a study region may not be available at all or at an appropriate resolution. Just as biodiversity surrogates are used to represent biodiversity, it is possible to develop cost surrogates to represent the cost of conservation. For example, the distance from fishing ports or accessibility points (Clark 2007) could be a surrogate for fishing effort in some marine regions. In terrestrial systems, topographic slope may indicate areas that are not suitable for logging, even if no timber volume data are available (Cameron et al. 2008). The applicability of using surrogates is dependent upon the predictability of activities within the study region, required scale / detail, the quality of the surrogate data, and the sophistication of the surrogate model. Richardson (2005) showed that the incorporation of fine-resolution commercial fishing information in marine-reserve design substantially reduces the economic losses incurred by fisherman, compared with reserves designed based on coarse-resolution data. It is also possible to combine surrogates to improve coverage. As with any scientific study, it is advised to have explicit collection and analysis protocols agreed on by all participants.

Box 6.2: Recommendations for incorporating socioeconomic information into Marxan

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Recommended practices for socioeconomic data incorporation include:

- Collecting or collating human use data is highly recommended and can help start to build bridges to user communities.
- Using human use data in zoning options (Marxan with Zones) was more desirable than using these data to create a single cost layer for use in Marxan, especially if there is more than one human use.
- Designing scenarios with more than one human use zone, which can sort out conflicting uses, is theoretically preferable to a single zone, but these advantages of spatial efficiency have to be weighed against the additional effort, and possible confusion arising when communicating the outputs to users.
- In many cases, for reasons of communication and creating familiarity with Marxan/Marxan with Zones, starting with a simpler zoning scheme may be preferable to a more complicated one, even if the latter is ultimately more realistic.
- Communicating outputs, soliciting feedback, and further building relationships with users is as important in the planning process as the Marxan outputs themselves.

6.4 Linking with Marxan Parameters

6.4.1 Incorporating socioeconomic objectives into the objective function

If socioeconomic goals cannot be translated into spatial, qualitative data they cannot be used in Marxan. However, these data are still important, and should be considered for inclusion at a different place in the planning process. Generally, socioeconomic goals in Marxan are set using the "cost" function. Socioeconomic goals are typically stated as costs to be minimised. For example, the cost function could be used to minimise the cost of land, fishing effort, cost of stewardship agreements, cost of enforcement, or cost of management. There are other ways to include socioeconomic goals in Marxan. Ecosystem services, recreation values and other "positive" socioeconomic objectives can be included as "Features" in Marxan. Necessarily there is a trade off between the budget and time available for a conservation planning project and money and the number of socioeconomic goals that can be included. Also, as the number of socioeconomic goals increase, balancing them becomes more difficult and the problem itself becomes harder to solve.

It is also possible to incorporate some types of socioeconomic information by targeting areas of social importance. For example, it may be important to include all or a fraction of the cultural sites in a system of protected areas. To do this, the cultural sites would be considered an additional conservation feature and each would have a target amount to be included in each solution. If these socially important areas are essential it is possible to lock them in a priori. For example, sacred sites ("taboo areas") in New Guinea were included as must-have areas and were used to initialise Marxan (Cameron et al. 2008).

The boundary length modifier can be used to incorporate other types of socioeconomic information. One aim of the stakeholders involved in marine protected area design along the central coast of California was to identify marine protected areas that were adjacent to terrestrial land parks and other "eyes on the water" to facilitate enforcement and monitoring of the marine protected areas (Klein et al. 2008). One way of doing this is to implement a zero boundary length between planning units adjacent to terrestrial land parks and run Marxan with the BLM function. In doing this, Marxan will preferentially identify marine protected areas that are adjacent to the land parks, to reduce the boundary length cost. In conclusion, if credible spatially explicit socioeconomic data are available across a study region, there are multiple ways that it can be incorporated into designing a system of protected areas with Marxan (see Box 6.4).

6.4.2 Addressing multiple socioeconomic goals

Marxan only considers one cost at a time. Therefore, if multiple socioeconomic costs are present, they must either be treated individually or combined into a single overall cost index. If socioeconomic costs are all measured in the same units and have the same value to stakeholders, they can be combined additively. Often, however, costs are represented in different units, and thus it is not straightforward to combine them. In that case, it is often necessary to assign weights to each cost before adding them (Sarkar et al. 2006). This process often requires extensive stakeholder engagement (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*) to assign weights in order to combine them. If costs are not in the same units (e.g., timber volume, agricultural potential, and distance to roads) they must first be standardised into the same units before weights can be appropriately applied. Implications of combining multiple costs should be carefully considered before aggregating them. The weighting process provides a way for stakeholders to participate in explicit goal setting and to visualise tradeoffs. Marxan results may be particularly sensitive to cost weightings, so a thorough sensitivity analysis of this process is recommended. Ideally decision-makers are presented with a variety of Marxan selection frequency maps derived using weightings that emphasise different costs.

Employing a scoring system (i.e., 1-10 for all costs) to combine costs is a quick, but not always very effective or transparent process (Bedward et al. 1991). See *Chapter 5: Reserve Design Considerations* for an example of combining costs with a cost index. Combining multiple costs requires transparency and iterative stakeholder engagement, to avoid the process being seen as a "black box". If in doubt, it is best to use each cost individually in a series of Marxan analyses and to then present maps of individual results for each cost. Presenting individual results is often a useful step for stakeholders to visualise how the datasets and goals affect the solution.

6.5 EVALUATING RESULTS / INDICATORS OF PERFORMANCE

Marxan results are dependent upon subjective choices about socioeconomic objectives. Which costs are included and what weightings are used strongly affect the outcome. We recommend thorough documentation of the rationale behind all decisions regarding the socioeconomic analysis, for review by all participants. This ensures that the analysis is transparent and repeatable. Many of the evaluation steps recommended in *Chapter 9: Interpreting and Communicating Outputs* are relevant for socioeconomic data to ensure a rigorous, defensible analysis.

Box 6.3: Defining conservation "costs" in Marxan

Conservation costs are often considered secondary to biological factors in the designs of protected areas (Scholz et al. 2004), and tend to be analysed post hoc for areas selected based only on biophysical data (Stewart and Possingham 2005). Implicit in Marxan is a cost minimisation objective (see *Chapter 1: Introduction*) that allows users to consider costs a priori. We review three different definitions of "cost" that have been implemented in Marxan to identify a system of priority areas.

Cost equals area

Many conservation planning assessments define the cost as the area of the planning to identify areas that represent biodiversity targets within the smallest possible area of land or sea. In this case, the spatial variation in the cost of different conservation actions is ignored and may not lead to the identification of the most cost-effective areas for investment (Stewart and Possingham 2005, Carwardine et al. 2006, Klein et al. 2008).

Cost equals foregone fishing effort

The establishment of marine protected areas is often viewed as a conflict between conservation and fishing. In order to minimise this conflict, Marxan can be utilised to identify protected areas that minimise the impact of marine protected areas on fishermen, while achieving biodiversity conservation goals. For example, Stewart and Possingham (2005) used effort data for the commercial rock lobster fishery to reduce foregone fishing effort in a system of marine reserves in South Australia. Similarly, Klein et al. (2008) compiled effort data on 24 commercial and recreational fisheries to minimise the impact of marine protected areas on fishermen in central California.

Cost equals cost of conservation action (e.g., acquisition and stewardship)

In Australia, there are two conservation actions, acquisition and stewardship, under consideration by the national government to protect biodiversity. Carwardine et al. (2006) prioritised areas to meet biodiversity targets whilst minimising the costs of two alternative conservation actions: land acquisition and stewardship. Unimproved land value data was used to represent acquisition costs and agricultural profitability data was used to estimate the opportunity costs of landowners entering into stewardship agreements. This study found remarkable gains in financial efficiency when employing spatially variable data that reflects the cost of the planned conservation action.

A key element for successful achievement of socioeconomic objectives is to approach it as an iterative process. It may be necessary to present results to stakeholders multiple times for refinement of objectives and weights (see *Chapter 9: Interpreting and Communicating Outputs* and *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*). Stakeholders like to know where their input data are reflected in the outcome and how the solution affects them in terms of costs and benefits. Presenting solutions for different scenarios will help stakeholders visualise and understand the Marxan process.

It is possible to summarise results generated with and without costs included to evaluate tradeoffs and performance (i.e., difference in total cost, targets achieved, total area, total boundary length).

It is important to realise that, despite the complexities of including socioeconomic costs in a Marxan analysis, ignoring costs is generally unwise. The Great Barrier Reef Marine Park Authority spent more than a year running analyses with cost equal to area and found that Marxan was particularly indecisive – providing selection frequency maps that gave little advice to decision-makers. It was only after socioeconomic costs were included that Marxan started to produce useful results. The temptation to create cost-free "pure" ecological results should be avoided in practical applications. Assuming cost equals area is seldom valid, and otherwise can be misleading.

6.6 Research and Development Priorities

To date, there are relatively few studies that incorporate socioeconomic data in the literature. Building this literature will aid planners in selecting appropriate measures to include in their analyses. Developing links between Marxan and existing socioeconomic tools (i.e., multi-criteria decision analysis, MCDA) will likely increase use of socioeconomic data in conservation planning. Resnet, a decision support tool with similar objectives to Marxan, incorporates MCDA into its analysis (Sarkar et al. 2004).

A second area of research and development involves dynamic consideration of time and space. Socioeconomic objectives and priorities change over time and it is possible, though not trivial, to include these types of data into Marxan (Wilson et al. 2006). Further research is needed to link socioeconomic objectives with future growth scenarios and other future projections. Consideration of uncertainty in socioeconomic data is another area for research.

Marxan with zones was introduced recently and allows the user to specify multiple zonings. Thus, some socio-economic uses, for example fishing or logging, could be incorporated as zones each with specified targets. This would allow for the full power of the simulated annealing algorithm to find efficient spatial solutions subject to various competing uses. To do so, however, will require spatial data of comparable resolution to the environmental, species, and habitat layers. Shifting costs to zones could relieve a lot of the difficulty in balancing various costs in the single Marxan cost function. Nonetheless, some socioeconomic costs, such as acquisition costs, management costs and so forth, will remain and would still be a part of the cost function.

7 Assessing and Managing Data

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ABSTRACT

This chapter examines a number of issues related to using and assessing data for use with planning tools such as Marxan. The data required for any analysis are determined by a broader set of objectives for which that analysis is to support. Data have limitations and these need to be understood, documented and corrected where possible. Having a fuller understanding of the limitations of the data allows one to minimise the propagation of error and correctly assess the validity of the results from the analysis. A checklist of items to help practitioners assess data quality, completeness and sample bias and other limitations of datasets is provided. Spatial, temporal and representational consistency should be considered when compiling datasets from various sources. A number of considerations relating to the use of surrogates and or proxies are also highlighted. Understanding the type of temporal variability that a feature exhibits is important to elucidate as it will help determine how the data should be represented in an analysis. When compiling and managing data for analysis and applications using Marxan, it is important to pay attention to data management practices. Some considerations and general guidance to keep in mind when selecting a planning unit size and shape are noted. Limitations and considerations inherent in datasets, as discussed in this chapter, are summarised in Table 7.3.

7.1 INTRODUCTION

From the outset of an analysis, it is important to clarify several points that relate to the use of data.

a. The data to be used within any analysis to support a planning process or project should be determined to a large extent by the broader set of goals and objectives of the planning exercise/project. Those broad goals and objectives may have been articulated in terms of biodiversity conservation, sustainable fisheries, socio-economic benefits, or other purposes (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets* and *Chapter 6: Addressing Socioeconomic Objectives*).

b. For any quantitative and data-intensive analysis it is critical for the practitioner to understand the many limitations of the data that are to be compiled and assess if they are of sufficient quality to use in the analysis. Decision Support Tools like Marxan generate outputs regardless of the quality of data they are fed with. To ascertain the validity of an analysis, one must have a good understanding of all the limitations inherent in the data being used.

c. The limitations of data are generally related to the quality and/or quantity of data. Having complete and consistent datasets is desirable but not always possible. Some of the limitations in data and data gaps can be addressed and it is important to have an appreciation of what limitations can be addressed versus not.

d. The data that are used for within an analysis to support decision-making are often derived from multiple sources. It is important to have traceable and repeatable analysis and follow professional practice with regards to data management, which includes proper documentation and metadata standards.

This chapter proceeds along the themes laid out above and fits into the analytical process as illustrated in *Section 1.1.2 - Eight stages of systematic conservation planning*.

7.2 What Data are You Seeking?

There is a tendency in some analyses to include all available data without more thoroughly checking on how appropriate these data are for the goals and objectives of the analysis. Data that are to be used in any Marxan analysis must reliably reflect the objectives and related criteria that have been set for site selection if the results are to be meaningful. The setting of meaningful objectives is discussed in *Chapter 5: Reserve Design Considerations* and the issue of translating objectives to data requirements is touched on there.

When compiling required data for an analysis, rarely will "perfect" or even high quality datasets be available. That said, it is worthwhile to have a sense of what the ideal dataset would look like, and then work from that point to determine what may be acceptable or not. For instance, with an objective to protect spawning aggregations of a fish species, it is desirable to know where the spawning sites have been identified and verified. When these data aren't available, a proxy dataset may need to be substituted. Suitable proxies may be data that represent the distribution or abundance of gravid female fish of those species. The distribution of juvenile fishes or adult female fish though useful in other contexts would not the appropriate dataset to represent what this particular objective demands. Hence, for each dataset that is under consideration for inclusion in the analysis it is appropriate to ask what that dataset and the associated metric represents and if it meets the specific objectives and site selection criteria for the analysis.

7.2.1 A note on sourcing data

This is not an extensive review of where to obtain data. There are numerous sources ranging from individual researchers, peer reviewed publications, holdings of data centres, research institutes, research programs, government agencies, statistical bureaus etc., with which many practitioners are familiar. When sourcing data there are some good practices to keep in mind:

- Know the thematic experts for each dataset, they often have the most insight on the status of a dataset, its quality and usability for different purposes – use that knowledge.
- Seek out datasets with high-quality metadata and be cautious when considering datasets without metadata. Ask questions and seek answers (Table 7.1)

7.3 Assessing Data Quality, Completeness and Sample Bias

In addition to identifying the appropriate data and metrics for use in the analysis, it is also necessary to assess each dataset individually to get a handle on its characteristics and limitations. The checklist in Table 7.1 suggests some of the main things to consider when evaluating a dataset. This checklist is helpful for reporting on limitations and caveats that should be given upfront in any report that describes a subsequent analysis. The items in this checklist are also often part of the metadata about any dataset. As well as indicated earlier, it is advisable to consult with data owners, thematic experts and others such as statisticians on any of these items.

Table 7.1: Suggested checklist for assessing datasets being sourced/used

ITEMS TO CHECK	THINGS TO LOOK OUT FOR	IMPLICATIONS
Data Origin Source Compilation	Are the data from a first hand source (raw data), or are they a secondary compilation or value-added product, from several other sources? If they came from different sources were the sampling methods comparable and have the data been standardised?	Inconsistencies mean data may not be comparable, may require standardisation, or error correction
Reason for Data Collection Sampling Strategy Spatial and Temporal Coverage	Understand the reason and purpose data were collected for, and the method of data collection. What was the sampling protocol? Was there adequate and consistent sampling across space and time? Has data collection been biased toward one area, time period or by the collector? How comprehensive are the data relative to the project area? Are they representative, e.g., a random sample? If there was differential sampling effort then the data should be corrected for effort and should be reported per unit of effort.	Data collected for different purposes might not be appropriate for your specific analysis There may be Spatial or Temporal biases in the data such as survey effort and sampling protocol
Data Representation Data Classification Data Generalisation	How are the data reported and spatially represented? Are they in the form of continuous data or have they been generalised or grouped into classes or categories. What is the variability in the data reported (are there error bars associated with them)? How were the classes derived, and what is the classification accuracy? Is the way the data are represented appropriate for the purpose you require?	Data may require reclassification, normalisation or other treatment
Spatial Resolution Spatial Scale and Accuracy	How are the data represented spatially? Are they vector or raster features? At what scale (resolution and extent) were the features observed or compiled? What is the spatial resolution and accuracy for the features being represented? Are they comparable with the scale for the analysis?	Data may or may not be at a coarser or finer scale than that of the analysis
Data Currency	How current are the data? If they are dated by several years are they expected to offer an adequate representation of reality at current time? Is the feature being represented change rapidly or it is relatively stable? Are long-term means provided and with a metric of variability, e.g., standard variation, min-max?	Dated data for specific times and seasons may or may not be appropriate for present distributions.

7.4 Data Compilation and Preparation – Things to Keep in Mind

More often than not, the practitioner will have to compile data from several sources and assemble a single thematic dataset (or sets) that cover the geographic area of the analysis. The checklist in Table 7.1 should be a guide to evaluating each of the several datasets that have to be compiled into a thematic dataset for a Marxan analysis. In addition, the key consideration when compiling a dataset from several sources is consistency, e.g., in regards to coverage of the study area, collection protocol, units and digital format. The practitioner should strive to ensure a level of spatial, temporal and representational consistency such that the data adequately reflect reality and do not introduce unintended biases into the analysis. Finally, be certain to carefully document each step during data preparation (in metadata this is referred to as "lineage"), as this documentation is critical for repeatability and transparency in the planning process.

Spatial consistency relates to ensuring that the entire study area is sufficiently represented by the data that is being compiled.

- A spatial boundary must be delineated for the study area. Strive for adequate, proportional and representative data. This should be corrected for observation effort in order to provide an unbiased picture. (IMPORTANT NOTE: If some datasets only cover part of a study area, their usage will require setting up within the analysis sub-areas and associated targets / penalties for the features in those sub-areas).

- It is important to distinguish between presence/absence data and presence only data (these are data that usually consist of opportunistic presence records, and which lack "confirmed absence"). A feature is considered absent in a particular area because it was sampled for and not found, and <u>not</u> because no sampling occurred there. These are crucial distinctions. One should emphasise here that any of the data above are virtually a function of search effort. Ideally, such data should be corrected for equal search effort in space and time.

- At times implicit assumptions are made about the distribution of a feature or phenomena. For instance, a spatial distribution may be obtained by interpolating sample data across a geographic area (e.g., depth sounding point data interpolated into a bathymetric surface). Not all data are appropriate to interpolate (e.g., some sediment grab sample point data of the seafloor interpolated regionally into a substrate surface), so one should be aware of the assumptions used when creating such a dataset.

- For ocean data, depth strata (vertical resolution) can play a major role. Although satellite imagery is widely available for the sea surface, marine applications often require the inclusion of deeper water columns and the seafloor. Keep in mind that data quality often degrades by depth, reflecting its greater inaccessibility.

Temporal consistency in data relates to the time period over which the data were collected, particularly with features that are known to be dynamic and that may have seasonality associated with them.

- A feature may change with seasons and it is important to identify which season(s) best reflect or represent the distribution of the feature that is appropriate for the analysis where possible. It is suggested here to let the data drive these temporal stratifications, rather than using a classification scheme that normalises the data into annual integers.

- Compiling data without regard to temporal variation may misrepresent the distribution of the features of interest, and can allow for key seasonal areas to be overlooked.
- Other considerations with regard to temporal variability of data are dealt with in *Section 7.7 - Data management and maintenance*).

Representational consistency relates to how data are reported and/or how a feature or phenomena of interest is represented geographically. Within your data the same feature may be classified in various ways and be represented spatially in the form of a point, line, area (polygon) or a pixel depending on the scale it was observed.

- Data being compiled from various sources that will make up a comprehensive dataset covering the project area can be reported into a common classification system where appropriate (e.g., classifying the seafloor based on primary factors such as bathymetry, geomorphology, and substrate). Relying on a known, standard classification system offers structure to the data being developed, can bring out patterns not seen in individual data layers, and may be more robust during peer review.
- However, we caution the use of pre-conceived classification schemes that do not necessarily represent observable conditions. Often it is advisable to use the underlying data to naturally classify the information. (NOTE: The number of classes and the method of aggregation are important decisions in terms of the amount of information going into a decision support tool and the how defensible the ecological characterisation will be. Whether using natural breaks or more standardised classifications to compile the information it is important to clearly document your decisions as they should be based on the objectives of the project).
- Data transformation or normalisation may be required to make data comparable or consistent in the way they are represented. However, such data processing should be well documented, as it can create/overcome skews and change of units.

Over large planning/analysis areas it is often difficult to attain a high level of consistency with regards to the above elements, simply because there is a very uneven sampling across the area. In such cases the planning area will need to be sub-divided to account for data biases. Often smaller sub-areas are constructed based on political or ecological divisions within the larger study area (eco-regions or sections, watersheds or watershed councils, international jurisdictions) within which some level of data consistency can be obtained. Care is required, however, as that such spatial stratification sometimes can suffer from a lack of understanding actual differences between sub-areas (e.g., physical parameters such as surface current patterns) and may therefore misrepresent biological dispersal patterns.

7.5 SURROGATES AND ECOLOGICAL CLASSIFICATION SYSTEMS

Surrogate or proxy or index data are utilised when data on the desired feature are not available. Often, biological datasets are difficult to collect and information on them may be patchy. Generally if there are gaps in data coverage for a particular species, habitat or ecosystem predictive modeling (or other approaches with a known accuracy) is a good alternative to fill those gaps. In some cases, geophysical or non-biological features may be a good proxy or surrogate for biological data at certain scales (Ramey and Snelgrove 2003, Roff et al. 2003, Post et al. 2007). The distribution of a particular species can be modeled on the basis of environmental conditions or physical features that the species depends on; and indeed many species-habitat models are based on this premise, but see Anderson et al. (2003) cautioning on the use of such data. One should check whether the input data of such a dataset, or its proxy, are sufficiently reliable to allow for sound analysis, and ultimately whether the proxy is defensible; i.e., that it is comparable what it is supposed to substitute.

In conservation planning, a common approach has been to map the range of environmental conditions (geology, climate, hydrology, oceanography etc.) and classify them in an ecologically useful manner that reflects the different and diverse environment types of a region. Many of these classifications make assumptions on and/or establish relationships between the environment types and the resultant expression of biodiversity (community types, higher levels of biological organisation etc.). A number of practitioners do maintain that there is value in characterizing these environment types at some scale even without fully clarifying what limits the expression of biodiversity. Not knowing a priori how the different physical conditions interact to affect the distribution of species and habitats precludes a reliable classification of communities on the basis of physical features. Thus, it requires thorough testing, calibration and verification with biological information where possible. This can be data and time intensive, since alternative datasets are needed that cover the classes in the study area. A robust ecological classification system is validated and clearly identifies what aspects of biodiversity it represents. If a classification system has not been validated, as is usually the case, this should be noted.

Box 7.1: Correcting Data for Observation Effort

Data biases are often created where one area is more observed and sampled than another. Datasets that show abundances of species may be misleading if they do not account for the time or effort spent observing the data. If used in an analysis the results may be skewed and will raise questions on the reliability of the analysis.

Consider a simple example of two sites that are each sampled a number of times each season. One of the sites (site A) is more accessible (e.g., near a road and in flat terrain) is more frequented by researchers than the other site (site B). Each time a site is visited a standard observation protocol (a 30 min transect walk) is employed and the number of birds per species observed are recorded. The observations for one species of bird, let's say the yellow rumped warbler (YWRA), is summarised in the table below, with and without correction for sampling effort.

Observations corrected for sampling effort

	Number of times site visited/sampled	Number of YRWA observed	Average number of YRWA/visit
SITE A	10	45	4.5
SITE B	5	35	7

Although site A has a greater number of YRWA observations recorded, when both are considered with a correction for sampling effort then site B shows up a having a greater density of YRWA. These results are not only found for the abundance but also for the spatial patterns of occurrences. One can for instance find a very rare bird at a given site after 10 hours of intense searching by 20 observers, whereas another site is only searched for 10 minutes by one observer and if a bird is not found be (wrongly) labelled "absence".

Although a simple example, interpreting the data without a correction of effort would have been misleading and led to site selection biases in Marxan. Many spatial datasets suffer from a lack information on the underlying search effort and if this detail is not provided in the metadata, enquiries should be made.

If it is decided to use surrogates, their appropriateness for the study should be assessed. The following are some considerations:

- Be clear as to what the surrogate, index, modeled parameter or classification system represents and how it relates to the feature for which it is serving as a proxy. Is it appropriate for the conservation objectives of your study or planning exercise? Is it biologically meaningful?

- Ensure that the surrogate, index, modeled parameter or classification system has been tested or verified and validated to at least some degree with regard to what it represents across the study area. This will help in assessing the level of confidence in using it. Biological data that the surrogate information is attempting to represent may exist for a portion of the study area, in which case the validity of the surrogate can be (partially) tested. Is there alignment between the biological and surrogate data? For instance, has modeled rocky habitat been predicted where adult rocky reef fish distributions are known to exist? Is such information available as a quantitative metric? These tests should inform the reporting on the confidence and certainty of the surrogate data.
- Ensure that the spatial scale of the data that are being used to derive the modeled parameter/surrogate is appropriate for representing the conservation feature of interest.
- If the modeled parameter or classification system has been derived from combining multiple datasets, it is advisable to have an indication of the source data and their level of accuracy. Errors in source datasets can propagate through the resultant products. Metadata, or the published citation, should report on accuracy (though often this is not the case).
- If using or creating a classification system, ensure the breaks in the classification system reflect ecologically meaningful breaks and are not data processing artefacts (as can be the case in unsupervised learning and clustering algorithms). Do the classes make ecological sense or reflect what may be known about distributions of biodiversity? Literature reviews can help establish such breaks and good practice suggests that the science should drive such breaks.
- Does the classification account for the dynamics, seasonality and temporal variability of features it represents? If not, can the classification be sub-divided in order to take these into account?

Box 7.2: An example of detectability errors

A species can easily be missed on a survey or transect. Data that were not corrected for such errors (referred to as index of relative abundance/occurrence) represent underestimates are usually biased and carry a high variance. Methods exist that allow correcting for the fraction of animals missed to obtain "true" estimates (referred to absolute abundance, density). It is not unusual that the fraction of animals missed ranges between 10 to 80%.

As a natural law, detectability declines by observer distance; in other words, animals nearby and in open habitat are more easily detected than those further away and in enclosed habitats. The correction factors are not static and cannot be generalised. They vary by time of day, observer skill and motivation, habitat, survey platform, survey speed and various other factors. One should also emphasise here that often the confidence bounds are more relevant than the actual estimate as such. Producing high-quality survey data is the goal for any application, and in general data with a coefficient of variation (CV) below 15% are desirable.

Several methods exist to overcome the notion of detectability, and they are freely available online and well known among surveyors and in the literature. For transect and plot methods, DISTANCE Sampling is widely applied (www.ruwpa.st-and.ac.uk/distance/). For presence/absence data *occupancy* models are used. Other methods deal with a mark-capture-recapture, double-counting and sighting-resighting approach to obtain these crucial estimates. Employing such methods represents good professional practice. It is important to document such concepts and methods in the metadata.

7.6 HANDLING DATA WITH TEMPORAL INFLUENCES

Many biological features (and some physical ones) are not static and have a dynamic nature with shifting patterns of distribution. How does one deal with this and ensure that the data that are meant to represent these features accurately reflect these temporal variations?

- Features can exhibit seasonality on an annual basis (summer, winter, etc.) and/or over the course of many years (other long-term variations/decadal cycles, etc.). It is important to know the type of temporal variability that exists for the feature of interest. This will determine what part of the data you make use of and how.
- For a feature that predominantly shows seasonality over an annual basis (e.g., many mobile species), it can be appropriate to aggregate multiple years of data for the season/s of interest and identify areas of persistence.
- For a feature that does not have much annual seasonality associated with its distribution (e.g., species with low mobility) but that shows shifts over many years, it may be appropriate to use data over several years in a non-aggregative manner

(i.e., as separate layers) so as to account for the full range of historical and present distributions.

- For biological features it is also important to ascertain and understand the life cycle and life history stages associated with the feature of interest. Is it the entire feature that is of interest in your analysis or particular (and vulnerable) life stages? A life stage may be associated with a particular season or time period. Keep in mind that life stages are not stand-alone features and need to be placed in the context of the overall ecology of the area and the application context.
- Are old data useful? The distribution of the features may have changed significantly such that present day distributions do not resemble historical distributions. It depends on the objectives of your study and on the causes and nature of change (natural dynamics or human induced). An historic perspective can be very helpful for setting conservation goals and identifying consistent distribution patterns through time.
- With the advancement of climate change, many features and phenomena are either expected to change in their distributions, or have already changed drastically. It may be desirable in certain instances to examine future probabilistic distributions and use those in your analyses (e.g., Pyke et al. 2005, Pyke and Fischer 2005).

7.7 Data management and maintenance

In order to ensure repeatable and transparent analytical process, careful management of datasets is essential. Practitioners each have their own data management preferences, but common formats and descriptions are either required by institutions, or are emerging and should be followed. Generally, careful consideration should be given to naming conventions, documentation/metadata, data storage locations, data backup and data processing (see Box 7.1).

Most GIS systems provide the functionality for basic data management. Marxan and other Decision Support Tools do not directly interface with GIS systems or GIS formatted datasets. Thus, data often have to be pre-processed and formatted to specifications of the tools. We suggest that these steps should be well documented, with metadata and directly associated with the relational and/or spatial database.

Inputs for Marxan where the spatial data need to be summarised into planning units (see guidance in next section) can be created using a variety of methods either within a GIS or a database / spreadsheet that allows for further processing. Other third party software such as CLUZ and PANDA (see *Appendix A2-3 Some Online Resources*) are examples of tools specifically designed to interface GIS with Marxan and among other things to help format GIS data for use in Marxan.

Box 7.3: File management

Marxan can be used to test a number of scenarios. When conducting scenarios using differing conservation features or targets, changing Marxan settings or conducting sensitivity analysis, the number of Marxan output files will rapidly multiply and a file management protocol should be established.

It is recommended that scenarios be identified with a unique name (both in the input parameter file and the name of the upper level directory) and that the input and output directories, as well as the input parameter file, be stored in their own file directories. For new scenarios or alterations to existing scenarios, input (and output) directories and the input parameter file should be copied to a new, unique file directory. Although this will increase the total number of files, the Marxan input and output files are relatively small and this will allow users to monitor and review changes. This is particularly important if analysis is conducted over a period of time or by several Marxan technicians. It may be desirable to maintain a spreadsheet containing all changes made to each scenario and the new scenario name.

In addition to tracking source data, careful documentation of each step in assembling and manipulating the input data is required. One recommended practice that helps document data preparation is to perform the various preparatory steps with code rather than using point and click methods. Some practitioners use AML scripts, others code in C or Python, others use ArcGIS macros or VBA and SQL in MS-Access. Any of these coding environments provide the essential function of having each step in data preparation documented. Such code should be inserted in Metadata for the dataset being created. These steps can then easily be examined for errors, and can reliably be replicated through the inevitable multiple iterations of the planning process (e.g., as new data become available or new goals are identified). We emphasise that such methods are part of good professional practices and contribute to the validity of any analysis. It is possible to create similarly detailed documentation for manually (point-and-click) processing source data into Marxan files, but be sure to note all the details for each step (including environment variables, etc.).

7.7.1 Data sharing protocols and re-use of value-added data

Once a Marxan analysis is run and completed a set of value added data inputs and outputs is created. The compilation of these data usually presents the best available information for a given area or topic. Since the data have been “vetted” and can be considered “clean”, there will be a high demand for the products and inputs of the analysis. The project executors will have to deal with this well past the completion of the project. It is advisable that data sharing and exchange policies for the project should be worked out beforehand, as this will inform data providers how their data may be used or redistributed.

Most governments have committed to data sharing and providing access to data through commitments like the Rio Convention and initiatives such as OBIS and IPY (Huettmann 2005, 2007a, b) and may have specific initiatives to help with archiving and facilitating access to data (e.g., Geo-connections in Canada). The same applies to data generated by research projects that involve NSF (National Science Foundation, U.S.), NIH (National Institute of Health, U.S.) and NSERC (National Science, Engineering and Research Council, Canada).

It is in line with the spirit of using the best available science for decision-making that sharing data from the Marxan analysis and projects is encouraged. Projects that integrate a variety of datasets and applications of Marxan help define data gaps and insufficiencies. This can trigger the release or update and improvement of datasets demanding a re-run of Marxan and fine-tuning of the findings. Experience shows that being pro-active and transparent regarding data sharing increases the acceptance, public buy-in and reputation of the analysis and decision support tools such Marxan.

Although we believe it is critical to share Marxan outputs, it is also critical to provide upfront documentation about what they represent and how they should be interpreted (see *Chapter 9: Interpreting and Communicating Outputs*).

7.8 DETERMINING THE APPROPRIATE SIZE AND SHAPE OF THE PLANNING UNIT

There are many considerations that should go into determining the appropriate size and shape of planning units. There isn't a one-size fits all solution, and the appropriate size and shape will depend on the circumstances of each individual planning exercise. In general, planning unit size and shape is informed by a combination of: the scale of planning (i.e., global, regional, national or local); the resolution of datasets being used; the objective of planning exercise and the intended use of the outputs (e.g., general area prioritisation or specific plans for implementation such as a comprehensive zoning scheme).

- Planning units should be no finer than the supporting data (generally the average patch size of the conservation features being mapped) and no coarser than what is required for management i.e., the scale for which the outputs are to be used.
- Planning units should generally be of a consistent range of sizes to avoid variable unit problem biases (see Box 7.4). However, some planning processes require the use of natural units of analysis that may of variable size. If using watersheds, for example, be sure to adjust your parameters (i.e., normalise for area and/or perimeter) to compensate for size biases.
- If using the boundary length modifier (BLM) to produce clustered solutions, planning units should also have a relatively consistent perimeter to area ratio (i.e., avoid mixing very long skinny planning units with more circular planning units).
- Using more, smaller planning units to partition the study area will, up to a point, produce more efficient solutions (i.e., solutions with lower costs to achieve the same

stated targets (see *Section 7.9 - Number of Planning Units*). However, using fewer, larger planning units will generally allow Marxan to produce solutions more quickly.

- We advise to be opportunistic when considering planning units. Where possible match the analysis with the management scheme or objective be planned. While it is sensible to consider size and shape from a modeling standpoint, perhaps conducting sensitivity analyses between natural and abstract, uniform units, we also suggest exploring the use of already-delineated units that may be being used in current management schemes.

A review of various studies and the reasons provided for the choices of planning unit size and shape is provided in Table 7.2. Many the studies outlined do not provide a reason for choosing the size and/or shape of the planning unit. This is likely due to the lack of strong theoretical basis for using a specific selection unit (Stoms 1994, Pressey and Logan 1998).

Box 7.4: A precautionary tale of two different sized planning units in one analysis

By Karin Bodtker, BCMCA

The BCMCA decided to use two different sized planning units (i.e., 2 km x 2 km square planning units on-shelf and 4 km x 4 km square planning units off-shelf) for an analysis spanning the entire Canadian Pacific EEZ. The decision was made despite solicited Marxan expert advise warning that using two different sizes of planning units could create complicated issues in regards to cost layers and balance'. However, the issues or problems are not well documented and the decision was made to try the analysis with two sizes of planning units for a variety of reasons, including:

- Quite large marine study area overall with a natural break in the physical environment at the base of the slope.
- Resolution of available data was finer for the nearshore and continental shelf regions, and courser for the larger off-shore deep sea region.
- The original grid was also designed to align with the 4 km x 4 km grid in which some of the fisheries catch and effort data were provided.
- The BCMCA wanted to keep the total number of planning units less than 65 000 for ease of use in Excel spreadsheets.
- Past experience with slow processing speeds when using Marxan with more than 65 000 planning units.
- Many of the ecological features were to be targeted by broad *ecosections*, of which there are twelve in the study area, and it was reasoned that this would effectively spread solutions over the study area and reduce bias problems related to the different size planning units.

- The work to populate existing planning units with roughly half of the ecological features had already been completed when the advice was received.

When the time came for Marxan calibration, BCMCA tested for an inherent bias in the selection of the two sizes of planning units and did discover a consistent bias. To test this, they created a single feature that occupied each planning unit fully (i.e., the quantity was equal to the area of the planning unit) and targeted that feature using a simple proportional target. The BLM was set to zero and a random distribution of selected planning units was expected. BCMCA expected the summed solutions file to approximate a normal distribution, with the mean equal to the targeted proportion. However, they found that the small planning units were chosen at nearly twice the rate as big planning units, and the distribution of the values in the summed solution file was clearly bimodal with a mean higher than the targeted proportion. They found the same result whether the scenario ran for 1 million iterations or 500 million iterations.

It may be possible to correct the bias by increasing the boundary cost of the large planning units, but then the correction factor also interacts with the BLM parameter, number of iterations, and number and spatial distribution of real features. BCMCA did not proceed with an analysis using two different sized planning units and, in hindsight, we would recommend using single sized planning units.

7.9 Number of Planning Units

Many people ask: What is the maximum number of planning units that Marxan can process? Technically, there was an upper limit of around 20 000 to 30 000 on the number of planning units that early versions of Marxan could handle (version 1.8.10 and earlier), though the optimised version (version 2.0+) has less restrictions and has been successful at processing much larger numbers, over 100 000, or even 150 000 planning units on newer computers with ample RAM memory. However, computer horsepower aside, there are mathematical reasons why Marxan, with its algorithms that try to do a reasonable job with optimality, will struggle to successfully process large numbers of PUs and features into an efficient, and hence meaningful, solution.

The number of possible network solutions is 2 to the power of the number of PUs. Thus, 100 000 PUs is more than 10 to the power 10 000 possible solutions which is greater than number of atoms in universe! That said, there are some cases where the decision space is so constrained by the arrangement of its features that even with huge numbers of PUs, near-optimal results are still tractable. However, these situations are the exception, and in general, when there are lots of possible network configurations, optimal solutions will be hard to find when using over 50 000 PUs.

Considering issues of scale and precision, blocking fine-scale raster data into sub-catchments and hexagons really does not cause you to lose any data and it should not be seen as a problem. Ultimately, it is all about the spatial scale of decision-making. If decision-making in a large study area is still on the scale of individual hectares then the problem has to be divided into sub-regional analyses. However, usually this is not the case. If required, sequential or greedy algorithms can work on such huge numbers of PUs but it is very unlikely that the solutions produced would be anywhere near optimal. Thus, good practice would dictate either aggregating data into larger PUs or sub-dividing the study area. If you do decide to use a large number of PUs, you will need to do extensive testing to find the number of iterations required whereby the good solutions begin to converge. Even with the latest desktop computers, getting meaningful near-optimal solutions could increase processing time dramatically, perhaps 24 hours or longer per Marxan scenario.

Table 7.2: Summary of planning unit choices in various studies.

AUTHOR/ TITLE	SHAPE	SIZE	REASON PROVIDED
Leslie et al. 2003.	Square	1-km^2 and 100-km^2	No – preferred 1 km^2 to 100 km^2 because solution area decreased.
Airame et al. 2003.	Square	1 x 1 min	Socioeconomic information collected at this scale because they are the CA Department of Fish and Game planning units.
Beck and Odaya 2001.	Bays/ Eco-region	Vary	Goal of project was to identify priority sites (i.e., eco-regions) for conservation.
Ardron et al. 2002.	Hexagon	250 ha	No
Lewis, et al. 2003.	Hexagon	30 km^2 and 10 km^2, reefs	Used different planning units to reflect the spatial scale of management and administrative and physical boundaries. No reason for choosing hexagon.
Chan et al. 2006.	Square	1 x 1 min	Socioeconomic information collected at this scale because they are the CA Department of Fish and Game planning units.
Richardson et al.	Square	2 x 2 min	No
Stewart and Possingham 2003.	Square	5 x 5 km	No
Geselbracht et al. 2005.	Hexagon	1500 ha	Hexagons provide more natural appearing clumps as sites have six sides shared among individual units. The size of the PU was selected to provide fine enough detail for state-wide analysis while not overwhelming processing capabilities with excessive units that may add little to analytical resolutions.
CLF and WWF 2006.	Square	5 x 5 min	Size consistent with regional planning for which outputs were intended and scale and constraints of available data.
Tallis, H, Ferdana, Z, Gray, E 2008.	Hexagon	500 Ha Hexagons, & Hexagons split at the shoreline to account for terrestrial and coastal features	Hexagons integrated terrestrial and near shore area selection. Reasons for size: (1) consideration of scales of input data for ecological features; (2) promoting ecological accuracy between terrestrial and coastal realms by splitting units at the shoreline thereby accounting for a natural shared boundary

AUTHOR/ TITLE	SHAPE	SIZE	REASON PROVIDED
Ferdana 2005	Hexagon, and shoreline unit	750 Ha Hexagons, & Hexagons and Variable length shorelines	Hexagons integrated terrestrial and near shore area selection. No reason for size Shoreline was a more natural unit with ecological boundaries
Ferrar and Lötter 2007	DEM modeled sub-catchments	5820 ha	Freshwater assessment needed to protect intact wetlands and rivers, within healthy sub-catchments
Pence (2008)	Segmented satellite image or landcover image (eCognition)	23 ha (range 0.25-550 ha)	Land-cover based planning units; ensuring homogenous contents of planning units (also ensure features not artificially dissected by planning unit boundaries); improves translation of product into management plan/guidelines
Klein et al. (2008)	Sub-catchments	Average of 50 km^2 and 800 km^2 in the intensive and extensive land-use zones, respectively	To facilitate the protection of the integrity and function of ecosystem processes occurring on a sub-catchment scale

7.10 SUMMARY

Table 7.3: Some common data limitations and ways of dealing with them.

LIMITATION	WAYS TO ADDRESS LIMITATIONS
Data exist are not reported in a consistent form across the region	Standardise datasets between areas and correct for observation effort and detectability problems Create sub-regions or sub-areas where data are more or less of consistent Use site-scale data to verify and calibrate a standardised or regional dataset
Data do not exist for the feature of interest	Use an alternative/feature data that may serve as a surrogate or proxy
There are only limited data for a particular feature	Use existing data for environmental variables and model occurrence of feature. Use the limited area for which data exists to test and validate your model.
There are no data for part of the region or study area	If feasible, create and use “no data” classes in the analysis
Data are not from the same temporal time period	If the feature does not have much temporal variability over seasons or years this may be ok If not, the data may be usable only for limited time periods, perhaps aggregated over many years

8 Ensuring Robust Analysis

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Abstract

Marxan is a useful tool, but to get robust results requires a significant investment in setting up the problem, calibrating the algorithm, and running sensitivity tests on the results. This chapter provides guidance in some of the necessary steps in that process. For a given solution, check that it is feasible (meets all targets). Each time a change is made to the problem being solved, Marxan's other parameters may need re-adjustment. Evaluate the quality of solutions generated in terms of the costs, objective function, and levels of protection provided. Test how sensitive the results are to changes in Marxan parameters, input data (especially uncertain data) and conservation targets. Following these steps will develop a much better understanding of the problem, how the various parameters and features affect it, and the robustness of the solutions generated.

8.1 Introduction

The objective of the optimiser in Marxan is to "select some of everything, for the lowest cost" (see Box 1.1). Calibrating and fine-tuning Marxan to achieve this stated goal of "lowest cost" while generating a range of solutions is the subject of this chapter. Other chapters have covered some of the issues surrounding the process of translating broad policy goals into a mathematical problem statement, and hence parameters, that Marxan can work on. This chapter will address the various user settings, calibration procedures, and sensitivity testing necessary to ensure Marxan is producing a range of near-optimal, "lowest cost" solutions to each variant of the specified problem.

Once the initial data are assembled, the recommended solution process iterates through multiple steps (Figure 8.1). The first step is to prepare initial input files for calibration (setting planning unit costs, the amount of each conservation feature in each planning unit, and a target for each conservation feature). The decisions made in setting up the planning unit costs, etc. (see *Section 8.2.2 - Planning unit cost*) can strongly influence results, so good practice includes sensitivity testing for effects of these decisions (see *Section 8.4 - Sensitivity Analysis*).

The next step is to calibrate the main parameters for running the Marxan simulated annealing (SA) heuristic (see *Section 8.3 - Calibration – adjusting the parameters of Marxan*). This step may involve extensive calibration the first time through a given problem but once set, it may only occasionally require further adjustments on subsequent runs.

During each step in the calibration and sensitivity testing cycle, it is important to test a range of variables for each parameter and carefully examine the results both for achievement of conservation feature protection targets and for spatial characteristics (e.g., clustering, regional bias, etc.).

Following that examination, the practitioner may choose to iterate through the process a number of times to test effects of boundary length modifier (BLM) on clustering/reserve network compactness and to test how sensitive results are to decisions made in assembling input data. The decisions made in calibration can strongly influence results so good practice includes documenting and sensitivity testing of these decisions (see *Section 8.4 - Sensitivity Analysis*).

As parameters (i.e., BLM, conservation targets, costs, etc.) are varied between Marxan scenarios, it is useful to analyse the results quantitatively and qualitatively. A quantitative analysis is useful to determine if/how the scenarios differ. A qualitative analysis is useful in explaining the different configurations of the results (i.e., what factors led the heuristic to select certain areas) and verifying meaningfulness of results. An overview of various qualitative and quantitative analytical methods is presented in this chapter.

8.2 Good Practices in the use of Key Marxan Input Parameters

The Marxan User Manual and *Chapter 4: Addressing Ecological Objectives through the Setting of Targets* and *Chapter 7: Assessing and Managing Data* provide extensive advice on assessing and assembling datasets for use in a Marxan problem. Remaining issues regarding feeding these data into Marxan are discussed below.

8.2.1 Planning unit status (influence of locking areas out or in)

Locking existing reserves into a solution influences the results outside of the fixed reserves. Unlocking current reserves will better illustrate how much of a role they play in achieving conservation targets efficiently. It is not uncommon that current protected areas are inefficient, when considered in terms of meeting broader network objectives; therefore, fixing them generates an overall network solution that can be significantly bigger than a reserve network with all planning units unlocked. Fixed planning units as reserves can affect every characteristic of the network, from spatial congruence to target achievement. In many applications, it is therefore good practice to try both, locked and unlocked, to get a better idea of how existing reserves are affecting the overall network solutions.

Anytime that planning units are locked in or locked out, the mathematical structure of the problem changes. After changing a PU's status, good Marxan practice calls for checking the calibration (SPF, restarts, BLM). If a planning unit will always be locked in or locked out, in some cases it can be excluded from the analysis by changing the question from "select some of everything at the lowest possible cost" to "select some more of everything at the lowest possible increase in cost." This approach can reduce the size of the problem that Marxan has to solve, however it may limit the applicability of some spatial metrics, and will affect the solutions differently. In particular, the effect of the BLM is such that when units are locked in, reserves tend to grow around them, whereas when they are locked out, they create a "donut" and the surrounding units tend to be shunned. If existing protected areas are locked out, then the user needs to take into account separately the features within those units when calculating any spatial statistics.

8.2.2 Planning unit cost

Practitioners use a variety of methods to assign costs to planning units. Some users (particularly those using regular grids) set costs for all planning units to 1. Others (particularly those using irregular polygons) set costs equal to planning unit area. Others set costs to include one or more measures of socioeconomic cost for each planning unit (see *Chapter 7:Assessing and Managing Data* and *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*). Still others use the cost variable to reflect other undesirable aspects of a site (e.g., its level of degradation - see *Chapter 6: Addressing Socioeconomic Objectives*). For example, one might develop different cost indices based on preferences for each of several stakeholder groups (e.g., preferences of fishermen vs. preferences of environmental advocates). These can be examined in separate runs to explore tradeoffs, or combined to produce compromise solutions. When combined, i.e., using more than one measure of cost for each planning unit, it is important to consider the relative weights given to the competing measures of cost. The method outlined below for efficiently selecting values for BLM (see *Section 8.3 - Calibration – adjusting the parameters of Marxan*) can also be used to strike a balance between two competing measures of cost. One just needs to be able to take a given Marxan solution and calculate a cost for it on each different cost index being used. Multidimensional tradeoffs can be efficiently explored in a similar fashion (Solanki et al. 1993).

8.2.3 Boundary cost

Boundary costs are used to encourage clustering and reserve network compactness in the solutions generated. In Marxan, shared boundaries can be interpreted as a measure of connectivity between adjacent planning units. When selecting planning units, the total perimeter (modified by the BLM and boundary cost) is added to the objective function, and any shared boundaries with other selected PUs are subtracted away. This way, a planning unit that fills a donut hole actually reduces the total boundary of a solution, since all of its boundaries are shared. It makes sense to express boundary costs in units scaled so that boundary lengths are similar in magnitude to PU costs, conservation targets, etc. If expressing boundaries in meters doesn't work, try kilometres, or hectometres, or another unit that scales well. If using PUs that are based on variable units of length like degrees of latitude and longitude, it is good practice to convert these boundaries to units of fixed length, like nautical miles or kilometres.

Some users have observed a selection bias against PUs on the edge of the study area when using boundary costs to promote clustering (see Box 8.1). This is primarily an issue with relatively high values of BLM. One solution that has been used is to not count the study area edge as part of the boundary of PUs on the edge. This solution can create an opposite bias, preferentially selecting PUs on the edge because a large fraction of their boundaries are set to 0 boundary cost. If either bias appears to be an issue in sensitivity testing, then boundaries along the study area edge can instead be set to any fraction (between 0 and 1) of their actual length.

Box 8.1: How to test for potential bias related to the external boundary cost

By Karin Bodtker, BCMCA

When using CLUZ to create the bound.dat file, the user has the option to include or exclude records in the file related to the external boundary. When they are included, a record for each planning unit on the external boundary of the study area is entered as if it had a boundary with itself equal to the length of the external boundary within that planning unit. If the external boundaries are included at the same cost as other boundaries, solutions will avoid the boundary planning units, and if excluded, solutions will be drawn to include a boundary edge. This issue was especially problematic for the BCMCA because its study area included convoluted coastline with many narrow fjords lined with boundary planning units. They wanted to be sure that solutions were neither biased toward or away from choosing these units. They created a single feature, populated all the planning units equally with it, and set a proportional target overall. To see the bias, a non-zero value for the BLM was used, and the scenario results for each of the two boundary files compared. BCMCA reduced the boundary cost of the external edges in the boundary file to 50%, 25%, 12.5%, and finally 6.25% until the distribution of the summed solution file overall matched the distribution of the summed solution file for the boundary planning units alone. Visual examination of the summed solution results of 100 runs can help to determine if a bias exists, as the boundary planning units will have a slightly different colour than the rest of the study area. Visual examination of the best solution or any random solution is also recommended to assess whether clumps are either tending to avoid or include the boundary edges. The effect will change as the number of iterations and the BLM values change so it is best to test using a BLM close to that being used in final scenarios. (However, if you do use two different sized planning units, be aware that there are issues when using the CLUZ interface to create the boundary file, and that it would be probably easier to create it using another tool.)

8.2.4 Conservation feature abundances

A certain amount of each conservation feature exists in each planning unit. However the total abundance and spatial distribution of conservation features can vary substantially. Some features may be present at very low levels but be found in most planning units, while others may be present at very high levels but only in a few planning units. Some may be quite rare in the study area, while others may be quite common throughout the study area (but are rare enough elsewhere to still be a conservation priority). When there are large differences in the distribution of conservation features, a few conservation features can begin to dominate the solutions generated by Marxan. In those cases it can be helpful to normalise conservation feature abundances in each planning unit as a percentage of that conservation feature's total abundance in the study area. In that way, the protection of every conservation feature receives equal weight in the solver. (Alternatively, if a feature is dominating solutions and this is not desired, then its SPF could also be reduced. See *Chapter 4: Addressing Ecological Objectives through the Setting of Targets.*) Again this step is only indicated where there are large differences in feature abundance, or if the user decides, against the advice of this chapter, to consider solutions where not all protection targets are met.

8.2.5 Conservation targets

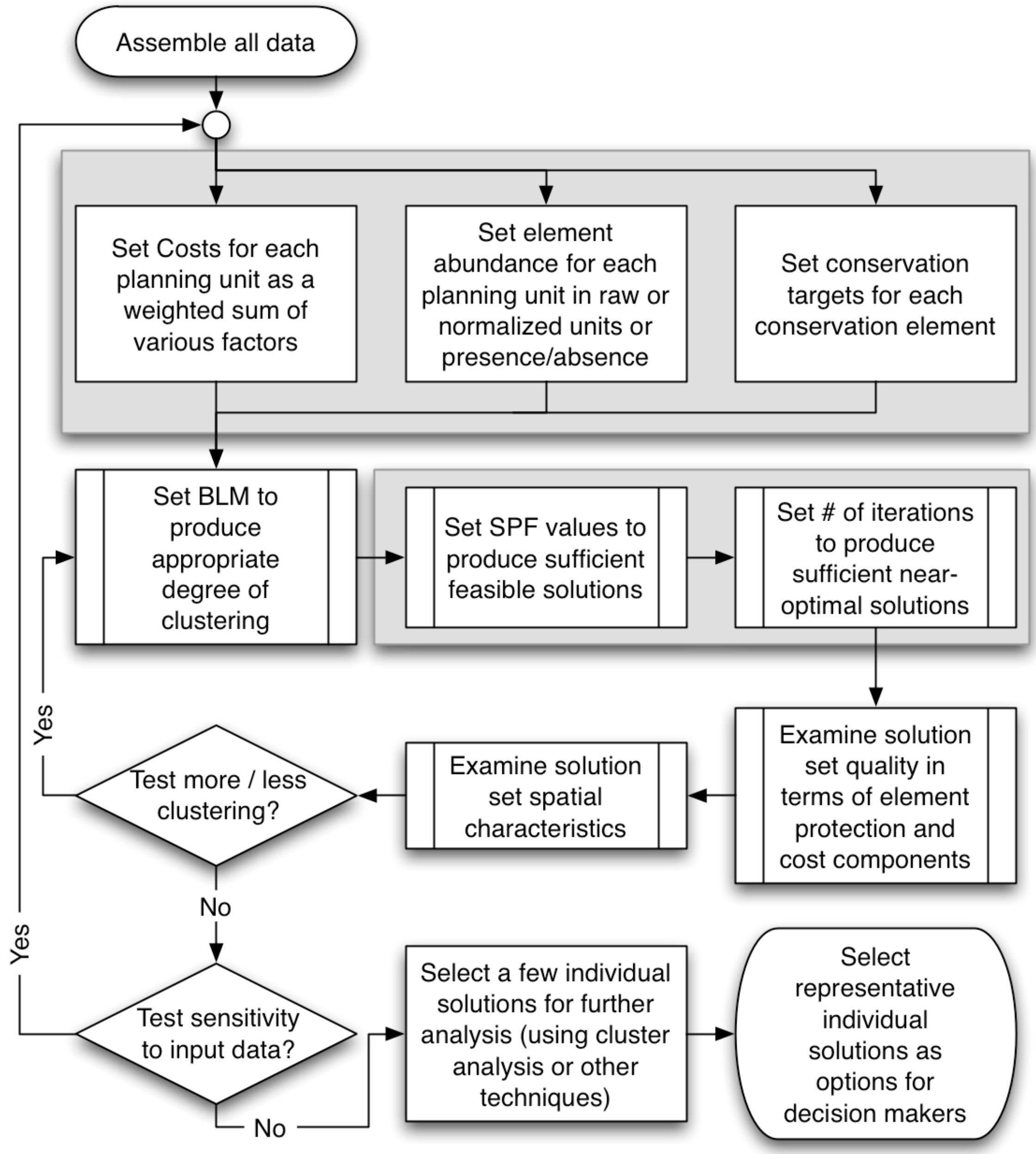
There are many different methods for setting conservation targets (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*). Conservation targets are most often set in a broader discussion based on the objectives of the project or planning exercise and the conservation requirements for an area. Most often a range of targets will be explored. The most important points when setting up Marxan are (a) to ensure that the numerical targets accurately represent the planning objectives, (b) to check and make sure the targets are achievable and (c) to do at least some sensitivity testing to see the effects of changing individual targets. Some practitioners gain insight into their datasets with an exploratory technique. They initially set targets very high and use cost thresholds to explore the range of targets that may be achievable at different cost thresholds. This exploratory technique then guides them in selecting appropriate, achievable targets for further Marxan runs. Practitioners tend to have different targets for more widely occurring features vs. those that are rare or threatened (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*). Ensure that translating your conservation objectives to conservation features and corresponding targets preserves the intent for your planning. Think carefully about what problem Marxan is actually solving and how the target of each feature will affect the overall solution.

8.2.6 Cost threshold

Cost thresholds can be useful in the initial planning stages to help explore the ranges of conservation targets that may be practical given known cost constraints. One approach would be to set targets for each conservation feature to 100% of available habitat and set a cost threshold (based on guesses of what might be politically feasible, or perhaps some percentage of what it would cost to select every planning unit). The resulting solutions will likely provide very different levels of protection for each conservation feature. These differences can be reduced by increasing the SPF for underrepresented conservation features and/or reducing the SPF for overrepresented conservation features. Though this does not reflect ecological considerations (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*), once gross disparities have been eliminated, these trial solutions can help with understanding what target levels are actually achievable. This process can be repeated for a few different cost thresholds as desired, although the amount of new information rapidly diminishes.

After the initial exploratory planning stages, it is better practice to explicitly set meaningful protection targets and focus on minimizing cost rather than trading off the protection of one conservation feature against another.

Figure 8.1: Flowchart for running Marxan with calibration and sensitivity testing.



8.3 CALIBRATION – ADJUSTING THE PARAMETERS OF MARXAN

Solutions generated by Marxan can be classed as either "feasible" solutions, those that meet all conservation targets, or "infeasible" solutions, those that fail to meet one or more conservation targets. (This mathematical definition of "feasible" is obviously only a starting point for determining which solutions might actually be considered practical.) The first step in analyzing any solution set is to determine how many solutions, and which solutions, are feasible. Feasible solutions are listed in the <problem_name>_sum.dat file as having a shortfall and penalty of zero. The next step with the infeasible solutions is to determine which conservation targets are being missed and why. Infeasible solutions result either from (a) having targets that are higher than the total amount of a conservation feature available or (b) having the penalty for missing targets (SPF) set too low. In the latter case, the cost for adding another useful planning unit is greater than the penalty for missing a target (shortfall * SPF) in the arbitrary units of the objective function.

If Marxan is not generating feasible solutions, it generally makes more sense to explicitly and consciously vary your conservation targets or SPFs rather than to allow Marxan to simply fail to meet certain targets. Allowing Marxan to miss targets means that Marxan is arbitrarily changing protection levels for certain conservation features based on generally invalid tradeoffs. Entering the world of trading-off cost vs. meeting targets is dangerous and results generated are far from transparent to modellers or stakeholders. The next step with the feasible solutions is to examine how consistently Marxan was able to produce "lowest cost" solutions.

The objective of calibration is to ensure that the set of solutions Marxan produces are close to the "lowest cost" or optimum. The simulated annealing optimiser in Marxan is powerful, flexible and highly automated — it requires only a few user settings. Those user settings, however, can have a large impact on solution efficiency (Fischer and Church, 2005).

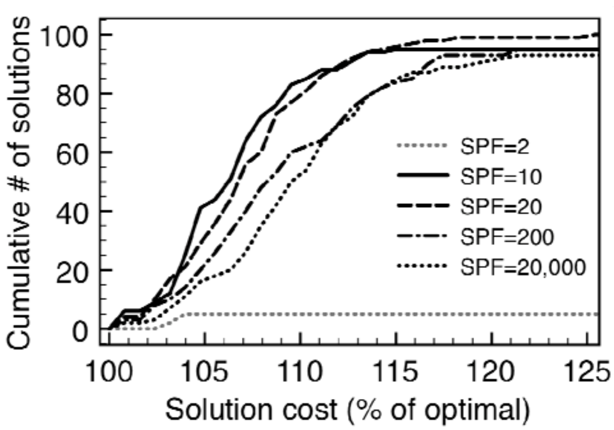
The basic calibration procedure is to iteratively set and check SPF values and the number of iterations necessary to achieve consistent results and ensure all targets are met. This basic calibration should be performed after each significant change to the problem being solved (for instance, after a significant change in some planning unit costs or boundary length modifier).

8.3.1 Conservation / species penalty factor (SPF)

Once all the datasets have been assembled and are ready to run, the user must decide on SPF values for each conservation target (see Box 8.2). The SPF parameter is crucial to getting good results. Too high a weight restricts Marxan's performance. Too low a weight means targets may not be achieved as often. SPF values are incorporated into the objective function that Marxan tries to minimise. If the SPF values are very small (relative to the BLM, units used to measure boundary length, and planning unit costs), then the "lowest cost" solution could miss achieving several targets, because the costs of selecting additional planning units is greater than the small penalties for missing protection targets. If the SPF values are very large, then the simulated annealing algorithm will not be able to explore as many options in the solution process. As a result Marxan will tend to produce fewer different solutions with higher average costs. The key point here is that SPF values must be chosen so that penalties for missing conservation targets are scaled appropriately and *relative to each other*. Each problem instance will have a different appropriate set of values for SPF depending on the BLM and associated planning unit costs, and hence experimentation is required.

The importance of calibrating SPF values is illustrated with results from a sample problem in Figure 8.2. Results are from a problem with 99 planning units and 24 conservation features. SPF values were set the same for all conservation features. At SPF = 200 several solutions out of 100 were infeasible (not all conservation targets were met). Increasing SPF values to 20 000 actually increased the number of infeasible solutions, and the set of solutions was more expensive as a whole (shifting to the right). Decreasing SPF values to 20 resulted in a less expensive set of solutions and slightly decreased the number of infeasible solutions. Decreasing SPF values to 2 resulted in only five feasible solutions. Setting SPF values to 10 produced only a few infeasible solutions and provided a more consistently low-cost set of solutions than the higher values examined.

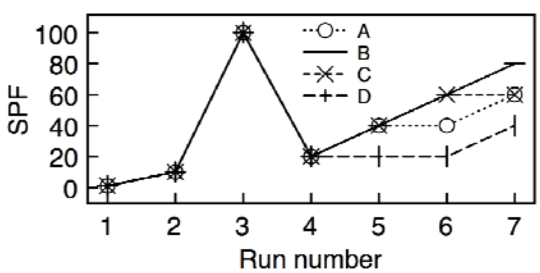
Figure 8.2: Cumulative distribution function of solution set cost for a test problem using five different levels for SPF values. For this problem, SPF of 2 failed to produce many feasible solutions. SPF of 20 000 produced mostly feasible solutions, but almost half of them cost more than 110% of optimal cost. Using the calibrated SPF of 10, 90% of the solutions produced were both feasible and cost less than 110% of optimal cost. Had the units used to measure cost been different, calibrated SPF values would have differed as well. The lowest-cost solution consisted of 15 planning units with a total cost of 252 cost units.



One approach to calibrating SPF values is to set SPFs for all conservation features the same and iteratively adjust them until 70%-90% of restarts meet all conservation targets. The process is to select an arbitrary value for SPFs, perform a 100 restarts or so, and examine the distribution of solution quality among those restarts. If not all protection targets are being met in most/all solutions, try increasing SPF values (perhaps by a factor in the range of two to ten times greater initially). If all protection targets are being met, try decreasing SPF values iteratively until targets are no longer being met — then increase SPF values slightly. If conservation targets cannot be met, it is appropriate to revaluate the targets. This approach can be successful if all conservation features are generally similar in targets, abundance and spatial distribution. When feature abundances or distributions differ substantially, good practice includes at least some individual adjustment of SPF values.

One method for individually adjusting SPF values is illustrated in Figure 8.3 (based on Chen, pers. comm.). This method consists of finding uniform SPF values for which all targets are met and a lower value for which most are not. The difference between those SPF values is the range explored for each feature. All SPFs are set to the low value, and then for those features missing their targets, the SPF is increased. This process is repeated until all targets are met.

Figure 8.3: Iteratively calibrating individual SPF values for a sample four-feature problem. Run 1 used a uniform SPF for all four conservation features A-D. Targets were not met. Run 2 used uniform SPF of 10 and targets still were not met. Run 3 used uniform SPF of 100 and all targets were met. From this point we explore SPF values between 10 (no targets met) and 100 (all targets met). For Run 4, SPF was lowered again, to 20. Targets were met for feature D only, so SPFs were raised (from 20 to 40) for features A-C that missed their targets. In Run 5, A and D met targets, B and C did not. SPFs for B and C were raised (from 40 to 60). In Run 6, C met targets for the first time, but none of the others did, so their SPFs were increased by 20. In Run 7 all targets were met.



A further important check at this stage is to examine the infeasible solutions to see which conservation targets are not being met. In some cases, it may be only one or two targets that are consistently being missed. In these cases it may be reasonable to set the SPF values for those conservation targets higher, while lowering the other SPF values still further. This level of detail would only be indicated when having difficulty getting consistently low-cost, feasible solutions from Marxan.

Box 8.2: Penalty factor optimisation

By George F. Wilhere, Washington Department of Fish and Wildlife

In Marxan, the conservation/species penalty factors (SPF) impose constraints on optimisation, however, they are soft constraints in that the constraint can be violated. The larger the SPF, the firmer the constraint. Hard constraints can be established by setting an arbitrarily large SPF, or through "locking in" planning units. However, very large penalty factors can create ill-conditioned objective functions exhibiting sharp peaks or valleys, both of which make optimisation more difficult (Gottfried and Weisman, 1973, pp. 253–254).[11]

Wilhere et al. (2008)[12] ran a simple iterative search to find SPF values for all features. All SPF values were initially set to 2. A Marxan run (consisting of 4 million iterations) was executed, and then the amount captured for each feature was compared to the feature's target. If a feature did not meet its target, then its SPF value was incremented by 1. This process was repeated until all features met their targets in at least 38 consecutive Marxan runs (38 was 1.5 times the number of Marxan runs they used in their final analysis). The resulting SPF values ranged from 2 to 6 but at least 97% of the values equalled the default value of 2. In retrospect, given that we only raised SPFs and did not lower them, the initial values for SPF could have been set to 1 instead of 2.

8.3.2 Iterations

The simulated annealing solver in Marxan relies on large numbers of iterations to come up with good solutions. How many iterations should one use? The calibration of this parameter is similar to calibration for SPF. Try a few test runs with different numbers of iterations and compare the cumulative distribution of solution efficiency for feasible solutions (as in Figure 8.2, but using "Score" from *_sum.dat). Generally, as the number of iterations increases, Marxan will succeed more consistently in locating a global optimum, or at least better local optima. For a moderately large problem, it might be appropriate to start with 100 restarts with 10^6 iterations and then compare that solution set to 100 restarts with 10^7 iterations in a plot similar to Figure 8.2. If there's a noticeable improvement with 10^7 iterations (i.e., a leftward shift of the cumulative distribution function), then try 10^8 (or $2*10^7$) and so on. Solution time increases linearly with the number of iterations, so there are practical limits on the number of iterations that can be considered reasonable. At some point it becomes far more useful to have an adequate number of restarts than to try to ensure the efficiency of an entire solution set. After all, one can always simply discard the least efficient solutions in a solution set in the same way that one discards infeasible solutions. That said, if the "selection frequency" option

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[11] Gottfried, B.S., and J. Weisman. 1973. Introduction to Optimization Theory. Prentice-Hall, Englewood Cliffs, NJ.

[12] Wilhere, G.F., M. Goering, and H. Wang. 2008. Average optimacity: an index to guide site prioritization for biodiversity conservation. Biological Conservation 141: 770-781.

of Marxan is being used, then it is good practice to try to produce mainly feasible solutions, and thus keep the iterations on the high side.

There is one caveat for picking the number of iterations. For some small problems Marxan can reliably find the global optimum with a small number of iterations. In fact, the problem graphed in Figure 8.2 was solved using only 4000 iterations. With as few as 10 000 iterations, Marxan found the same global optimum in nearly every restart. In this case, the number of iterations actually had to be lowered in order to generate a diverse set of solutions. For most realistically sized conservation problems this is unlikely to be a concern.

8.3.3 Number of restarts

For any reasonably complex Marxan problem there are more possible solutions than there are stars in the universe (Possingham, pers. comm.). There is no need to identify them all. The goal is to set the number of restarts high enough that the set of solutions generated is a representative sample of the solutions available. To answer questions of how much the lowest-cost solution will likely cost, a relatively few restarts may suffice (100-500). If the feasible solutions generated are all within a few percent of each other in the objective function then the best solution is likely to be close to optimal. To identify spatial patterns may require significantly more restarts. One guideline is to run sufficient restarts that the map of selection frequency ceases to change appreciably with additional restarts. Run Marxan in batches of 100 restarts. Look at the selection frequency patterns (using equal interval classification) for X restarts and 2X restarts. If the spatial pattern of selection frequency values is not changing a lot with the addition of more restarts, it is likely that we have sampled the solution space adequately. One caveat with this approach is that the spatial pattern may differ significantly between the top 10% of lowest-cost solutions and the rest of the solutions (Chen, pers. comm.), and the spatial pattern is likely to be different between feasible and infeasible solutions (Fischer and Church, 2005). This again underlines the good practice of setting up Marxan to generally achieve feasible solutions.

8.3.4 Annealing parameters

Proper set up of annealing parameters is covered in the Marxan User Manual.

8.3.5 Boundary length modifier (BLM)

The BLM is used to improve the clustering and compactness of individual solutions (McDonnell et al. 2002, Fischer and Church, 2003). For initial testing, leave it set to zero. After initial calibration is successful there are several methods for setting the BLM. Even relatively small changes in BLM can significantly alter the mathematical structure of the problem, and good practice requires a calibration check following changes to BLM.

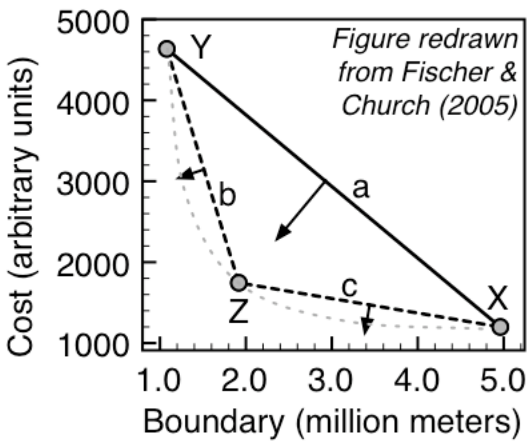
The BLM controls the clustering of reserves in individual solutions. Perhaps the most intuitive way to set BLM is to start at zero and iteratively increase it by arbitrary numbers (e.g., factors of ten) until visual inspection of the results shows the desired degree of clustering, preferably without large increases in cost. The disadvantage of this method is that it may take many runs of Marxan to discover a range of BLM values that even affect the degree of clustering, much less provide results with the desired degrees of clustering. In any case, it is helpful to construct a plot of cost versus boundary length in order to track the effects of changes in BLM (as in Figure 8.4). This plot can also help explain the results to others (see *Chapter 9*: *Interpreting and Communicating Outputs*).

Another way to pick a starting value for the BLM is to set it so that boundary lengths scale to a similar magnitude as the other term in the objective function. If PU costs range from 10 to 50 units, and boundary lengths range from 30 000 m to 60 000 m, there will be huge difference in the penalties associated with minimizing cost and minimizing boundary length. A BLM of 0.001 in this case would get boundaries and costs to a similar order of magnitude (30–60 and 10–50, respectively). Subsequent runs can then be used to explore the sensitivity of solution sets to different values of BLM.

A third way to pick values for BLM is to use a weighting method developed to explore multi-objective tradeoffs in optimisation. This systematic method for varying BLM allows the user to quickly discover the range of BLM values that will make the largest differences in spatial patterns of solutions without having to guess at appropriate values (Cohon et al. 1979, Solanki et al. 1993, Fischer and Church 2005). First, set BLM to 0 and optimise cost to find the lowest cost solution possible. Calculate the cost and boundary length for that solution and plot it as point X, the minimum cost solution (Figure 8.4). Then set all costs to zero and BLM to 1 to find point Y (the minimum possible boundary solution). Calculate the slope of line "a" connecting those two solutions in objective space: (Cost(X) – Cost(Y))/(Boundary(X)-Boundary(Y)). This is the estimated trade-off curve with two points. Use the absolute value of the slope of line "a" as the BLM and reset all costs back to their original values. In this example, the BLM would be 0.00088525. This value represents a "sweet spot" on the trade-off curve between minimizing cost and minimizing boundary length. Small changes in BLM around this "sweet spot" value are likely to make the largest changes in spatial patterns of selected reserve networks. BLM values of 10, 1, and even 0.1 are all so much higher than this "sweet spot" on the curve that they all yield similar reserve networks—clustering reserves to the maximum possible extent. (This example illustrates the potential time-consuming drawbacks of simply starting with a BLM of 0 or 1 and trying to gradually adjust it until the clustering looks "right." That said, other considerations such as management are not considered at this stage.) Run Marxan again to locate point Z. With three solutions, the trade-off curve is estimated as dashed lines "b" and "c." If the solutions represented by point Z are more clustered than desired, the process can be repeated with line "c" in order to find a new value for BLM. If the solutions represented by point Z are not as clustered as desired, the process can be repeated with line "b." (Figure redrawn from Fischer and Church 2005).

This method can be used to find tradeoffs between different measures of cost as follows. Start by setting PU costs equal to a weighted a sum of two or more alternate cost measures (i.e., PU cost = Cost1 + $\text{Weight}_{\text{Cost2}}$ * Cost2). Then follow the directions above, substituting Cost1 for Cost, $Weight_{Cost2}$ for BLM and Cost2 for Boundary.

Figure 8.4: Available trade-off between minimizing cost and minimizing boundary length. Dotted gray line represents possible solutions on the trade-off curve. Solution X is the lowest cost solution available. Solution Z achieves large reductions in boundary length for a small increase in cost (compared to X). See text for calculations.



8.3.6 Importance of calibration

Good practice dictates that the steps above be followed for every change in the problem being solved. Small changes in BLM or PU costs might not make any difference in the percentage of feasible solutions or the number of spatial patterns available—but they might. In some cases small adjustments in relative costs of planning units can lead to very different solutions (Fischer and Church 2003). When first exploring the solution space of a new project, it is recommended that practitioners check for a need to change iterations, SPF, and number of restarts after any change to the problem. In most cases there will not be any need for serious recalibration, but sometimes there will be. This relates to sensitivity analysis, discussed below.

8.4 SENSITIVITY ANALYSIS

8.4.1 A basic framework

The goal of a sensitivity analysis is to determine how sensitive the modeling results are to differences in input data or parameters. Sensitivity analysis provides information on which input data and which parameters make large differences in the solutions generated and which ones do not. Further analysis can then be focused on those data and parameters that matter most. Input data usually have a certain amount of uncertainty associated with them. Perhaps the abundance of a given conservation feature has been estimated to within 50% of its actual abundance. Or perhaps a practitioner has gotten an apparently reasonable degree of clustering with a BLM of X but has no strong reason to use X rather than 0.5 X or 2 X. Sensitivity analysis is the process of checking whether the results obtained with different parameters (e.g., different values of X for BLM) or with different input data (e.g., feature abundance values at the high or low end of the expected range) produce substantially similar or substantially different results.

The first two steps in sensitivity analysis are to decide what data/parameters to test and to decide by what measures to compare the results. Solutions have many characteristics such as total cost, boundary length, number of targets exceeded, spatial distribution, spatial congruence, specific planning units in the solution etc. Therefore, sensitivity analysis requires a clear definition of factors and scale of measurement of the solutions.

The first part of sensitivity analysis is determining what to test. Some items that might commonly be tested:

- effects of lower quality feature abundance data (see *Chapter 7: Assessing and Managing Data*);
- the extent to which the selection process is being driven by rare features, or features with very high conservation targets;
- effects of individual conservation features requiring very high SPF values;
- groups of features included or not in targets;
- different target levels (on individual features or groups);
- different cost surfaces;
- effect of BLM on clustering and cost; and
- planning unit size and shape.

The second part of sensitivity analysis is determining the scales by which the solutions will be measured. Some measures for individual solutions include:

- Is the solution feasible (are all targets met)?
- Which planning units are selected compared with other solutions?
- How does the objective function (cost plus boundary plus penalties, etc.) compare with the best known solution?
- What is the cost of the solution versus the cost of the entire system being conserved
- What is the boundary length of the solution (a measure of clustering/compactness)?
- How many individual planning units / planning unit clusters are selected?
- How many conservation features exceed their targets and by how much?

Some measures for sets of solutions include:

- Are these solutions feasible (are all targets met)?

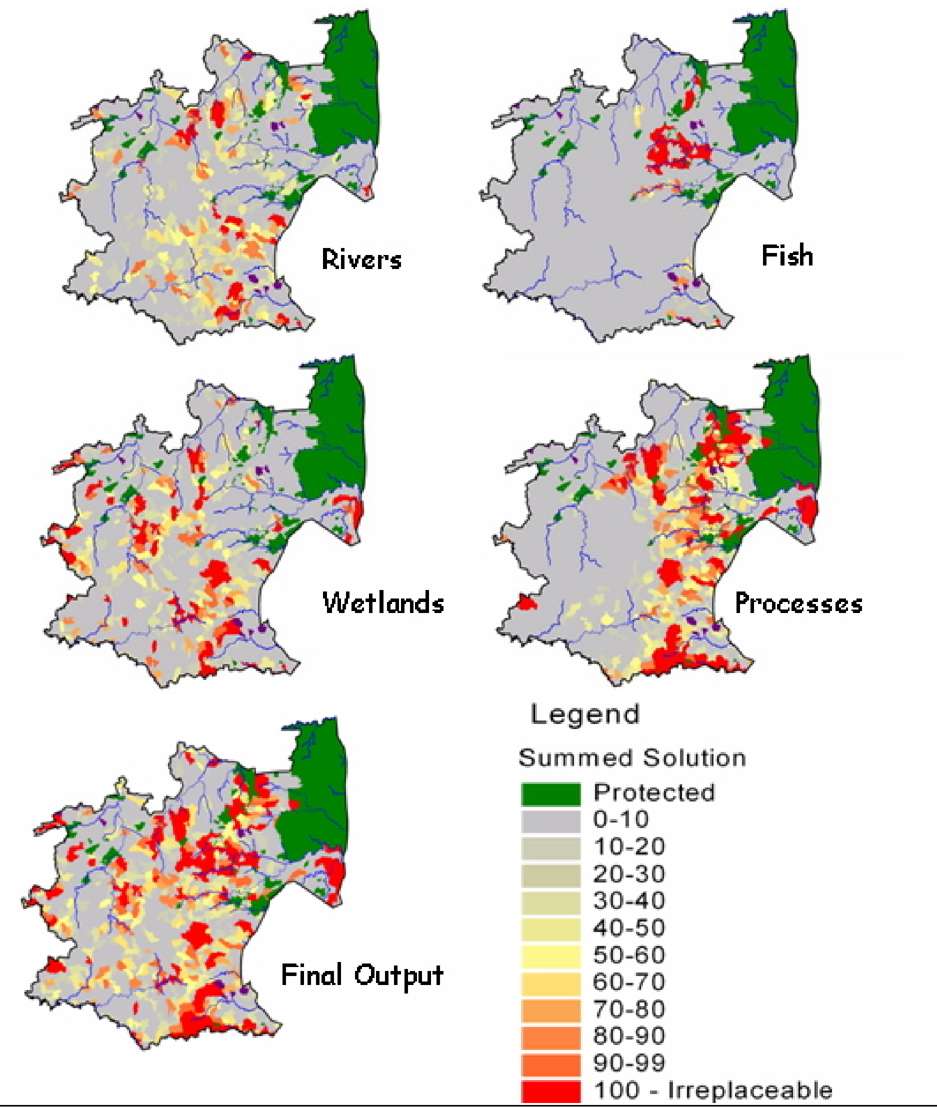
- Does this solution set include substantially the same planning units as other solution sets?
- Which planning units are being selected compared with other sets of solutions? Which planning units are in common? Which are added / subtracted?
- How variable are the solutions within the set in terms of cost(s), objective function, spatial patterning, etc.?
- How does the spatial congruence of the solution set compare with others (using same congruence metric like Jaccard, Kappa, etc.)?
- How do the cost(s), objective function, boundary length, etc. compare within this solution set versus other solution sets?
- Within this solution set are the numbers and identity of conservation features exceeding their targets similar to other solution sets?
- Does a cluster analysis on this solution set reveal any solution or clusters of solutions that are substantially different from solutions produced in other solution sets? (Automated clustering of solutions is planned to be a feature of a future version of Marxan.)

The first pass through a sensitivity analysis can be done most simply by asking whether essentially the same planning units are being selected in one solution (or in one set of solutions) as in another. If that is the case, one need go no further. If the set of planning units differs, however, it is likely that at least some measures of the performance of the solution (solution set) will be different. The determination of whether a set of solutions is similar can be approached qualitatively by visual inspection or quantitatively (see *Section 8.4.2 - Examples of quantitative sensitivity analysis*).

Box 8.3: Sensitivity analysis on a summed solution (selection frequency) spatial output

By Mervyn Lötter, Mpumalanga Tourism & Parks Agency

Sensitivity can be considered by dividing the features into groups (e.g., river types, wetlands, fish, processes), or individual datasets, then setting the targets to zero for all groups except for the group of interest, and looking at the impact that group has on the final spatial output. The figure below provides an example of how sensitivity analysis results were displayed spatially in the freshwater assessment of the Mpumalanga Biodiversity Conservation Plan (Ferrar and Lötter 2007). By comparing summed solution from each group run to the final combined summed solution, it can be determined whether any feature groups (and their settings) are driving the final output of the assessment.



8.4.2 Examples of quantitative sensitivity analysis

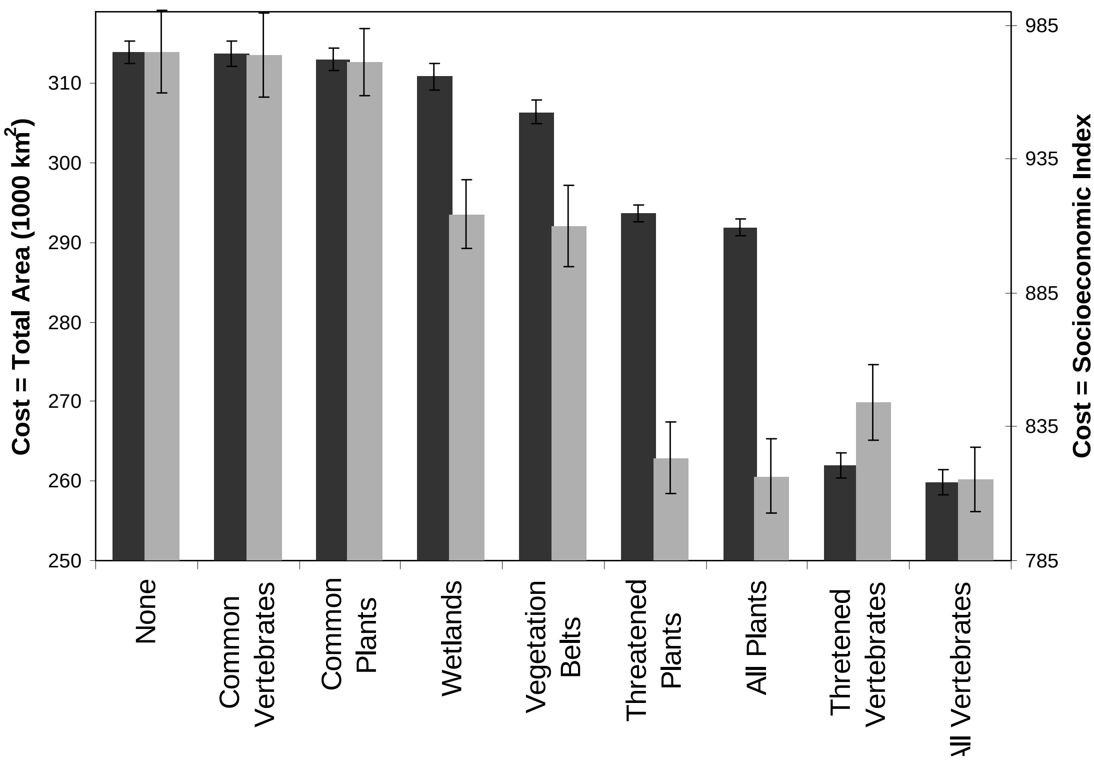
8.4.2.1 Disproportionate effect of some targets in total cost

In some cases particular targets may have little impact on solutions while other features are largely driving the solutions (Church and Gerrard 2003). In other words, if those latter targets are set to 0, then the total cost of the solution will decrease considerably. In these cases good practice includes looking particularly closely at the targets, abundance data, and spatial distribution of those latter conservation features. In some cases those individual features that are driving the solutions may have numerically or spatially uncertain data or have arbitrary targets that can be reasonably changed. In any case determining which conservation features and associated targets are driving the cost of the solution should motivate a further assessment about the confidence in spatial distribution of those features and a re-evaluation of their targets.

In cases where the cost of a planning unit is a combination of several cost measures (e.g., total area combined with some cost based on socioeconomic data), cost measurement choice may result in differences in the relative importance of conservation features in the total cost of the solution. In those cases, it is important to check for features that may be driving the solutions under each different combination of costs.

Figure 8.5 shows the results of a sensitivity analysis from a reserve selection problem in the terrestrial realm. Marxan was run several times, each time excluding the targets for a different set of conservation features. The targets for some conservation features generate small differences in total cost. For example, excluding common vertebrates or common plants has no impact on cost. On the other hand, excluding threatened vertebrates makes the solution significantly less costly whether Marxan minimises total area or socioeconomic cost. Finally, some groups of conservation features, like threatened plants, make a much greater decrease in cost when minimizing socioeconomic cost than when minimizing total area. Figure 8.5 suggests that the confidence in the solution will increase if confidence is increased in spatial distribution of threatened plants and vertebrates.

Figure 8.5: **Effect of excluding groups of conservation features. Figure shows the average area (dark bars) and socioeconomic cost index (light bars) for sets of solutions that exclude a particular group of conservation features. "None" is the reference case, including all features. Vertical bars indicate 2 Standard Errors. Excluding common vertebrates and common plants had no effect on solution cost. On the other hand, excluding threatened vertebrates significantly reduces the total area and socioeconomic cost of solutions (Figure from Ramirez 2007).**



8.4.2.2 Geometry of network

One relatively quick way to quantify results is to explore how the area and perimeter change as one parameter is varied (Airame 2005). Table 8.1 is an example of how the area and perimeter change when the conservation features, conservation targets, and BLM were independently varied. Here, the average and standard deviation are displayed across 100 restarts. Checking if two scenarios' mean areas or perimeters are significantly different will quickly flag if changing parameters (i.e., conservation targets, conservation features, costs, etc.) change the output and is good supplement to the qualitative analysis. If the mean area and perimeter do not change, one can still check differences between the solution sets by making separate scatter plots of area vs. perimeter for the two (or more) solution sets and comparing the graphs. Other options are to look at the summed solution or to use more extensive spatial statistics, as outlined below.

<u>Table 8.1</u>: Area and perimeter of Marxan solutions for three conservation targets. Solutions generated at two different BLMs with conservation targets of 10%, 30%, and 50%. Area and perimeter are expressed as mean ± standard deviation across 100 repeat restarts.

BLM	Conservation Target	Area (km^2)	Perimeter (km)
0	10%	293.6 ± 1.8	893.4 ± 19.6
	30%	881.2 ± 2.2	1977.7 ± 28.2
	50%	1471.4 ± 1.1	2414.7 ± 37.7
0.0001	10%	295.7 ± 1.3	264.1 ± 20.5
	30%	886.4 ± 1.6	494.4 ± 26.9
	50%	1476.9 ±1.5	712.3 ± 27.5

8.4.2.3 Spatial configuration of network – measures of similarity

To understand the roles that different areas in a study area play in overall network solutions, examining the selection frequency of individual PUs is a good place to begin. However, to get a better idea of the possible alternatives to a given area, a cluster analysis of solutions can be more meaningful than just looking at selection frequency (Airame 2005). Currently this requires external statistics packages. A future version of Marxan is under development that will integrate clustering statistics. In this section, comparing one solution to another and their spatial similarities is considered.

Determining how similar the spatial configuration of one solution is to another solution (i.e., how similar the planning units of one network are to the planning units of another network) can be done by conducting a pairwise comparison of the solutions using the *Kappa statistic*, which provides a measure of the similarity of two networks after removing overlap due to chance (Richardson et al. 2006). To do this, the presence/absence of planning unit data from the individual solution's output file should be used as the sample data. Kappa statistics indicate the degree of overlap between two solutions. (Note: the Kappa statistic is not robust when comparing two solutions that vary greatly in total area, and therefore should only be used across solutions of similar or identical targets.)

A similar comparison can be made using the selection frequencies output to compare how similar the selection frequency of one scenario is to another scenario. To compare the selection frequencies output, multivariate correlation analysis should be conducted. This analysis produces a correlation table (see Table 8.2), which is a matrix of correlation coefficients that summarise the strength of the relationships between each pair of responses.

For both the Kappa and multivariate correlation analysis, a statistic of 1 indicates perfect overlap, 0 indicates overlap due to chance, and negative one indicates no overlap. In other words, the closer the statistic is to 1, the more the spatial configurations of the solutions are similar to each other due to the data and not due to chance. Table 8.2 shows the results of a multivariate correlation analysis done using the selection frequencies of three scenarios.

Table 8.2: Multivariate correlation analysis for three selection frequency outputs. The scenarios a, b, and c correspond to the output shown in Figure 2.

Scenario	**a**	**b**	**c**
A	1	0.96	-0.04
B	0.96	1	-0.02
C	-0.04	-0.02	1

Another way to compare the spatial configuration of networks is using a cluster analysis (Clark and Warwick 2001, Airame 2005). The sample data can either be the presence of planning unit data from the output file or the selection frequency output data of each scenario. The result of this analysis is a dendrogram that defines the similarity level of all the networks.

Each of these methods of measuring similarity is useful to compare several outputs with one another simultaneously within scenarios and between scenarios. For example, within a particular scenario, two different restarts can be compared. In addition, one restart from the first scenario can be compared with another restart from a different scenario. Knowing this information is useful to determine how changing a parameter (i.e., conservation target, conservation feature, BLM, cost, etc.) affects the output. For example, if two scenarios are identical with the exception of one parameter, and the scenarios produce very similar results, then the parameter did not change the results

8.4.2.4 Flexibility of scenario

The number of different network options varies between scenarios and can be quantified using the selection frequency output. There is less variability between networks as the proportion of very frequently selected planning units increases (i.e., those selected in more than 80% of restarts) (Richardson 2006). For example, one solution set might have 20% of the PUs being very frequently selected. During sensitivity testing, a subsequent solution set might have 40% of PUs being very frequently selected. This implies that there are fewer options for network design that meet the conservation targets in the subsequent scenario than in the first. In that case the flexibility of the reserve network is sensitive to whatever parameters were changed in sensitivity testing and confidence in those parameters should be examined.

8.5 EXPLORING DIFFERENT SCENARIOS

In addition to sensitivity testing outlined above, it can be useful to explore substantially different scenarios (e.g., based on entirely independent sets of planning unit costs, or with substantially higher or lower targets, etc.). Particularly if using a cost index that combines multiple costs (e.g., economic costs, stakeholder opinions, etc.) it is useful to change the weights on the different costs to see how different the spatial arrangements become. Also check to see which conservation features exceed their targets, and by how much.

In order to ensure that you are measuring meaningful change between two different scenarios it essential that you both calibrate the Marxan algorithm (to ensure that it is solving the objective function efficiently—truly optimizing) and that you perform sensitivity analyses.

9 Interpreting and Communicating Outputs

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ABSTRACT

This chapter describes good practices relating to interpreting and communicating Marxan outputs. Throughout this chapter we assume that Marxan is being used as recommended in the Marxan User Manual, version 1.8.10 (2008). Good practices related to the three categories of Marxan outputs (screen, tabular and spatial) are described. Although the intended audience of this chapter is the scientists / analysts conducting Marxan analysis, a brief discussion on how Marxan practitioners can present results to both internal and external reviewers is also provided. Because setting targets in Marxan is as much an art as a science, Marxan outputs should always be reviewed and interpreted internally by the project team prior to presenting the results to external stakeholders or even to the project sponsor. The outcome of this review should be agreement on the interpretation of the outputs and on how well the objectives have been achieved. The project team should consider the best way to display the Marxan outputs, which will depend in part on the technical capability and local knowledge of the intended audience. Through interactively interpreting, refining and communicating Marxan outputs as the analysis is conducted, the project is likely to achieve the greatest clarity.

9.1 MARXAN OUTPUTS

Chapter 5 of the Marxan User Manual describes Marxan outputs as screen output and tabular file output. These are controlled by the selected settings in the input parameter file (see Marxan User Manual section 3.2.1.5). Tabular outputs are readily converted to spatial outputs (see Marxan User Manual Appendix C). Below we describe some considerations and good practices for reviewing, interpreting and communicating the screen, tabular and spatial Marxan outputs, which can contribute to conducting robust analysis (see *Chapter 8: Ensuring Robust Analysis*) as well as engaging external stakeholders (see *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*).

9.1.1 Screen output

For analyses using a large number of planning units, iterations, runs, or conservation features, a scenario may take many hours or days to complete. The screen output (verbose mode 3) is useful for quickly ensuring the Marxan runs are continuing to proceed in a predictable fashion. Using the verbose mode users can identify if annealing slows down and halts prior to finishing the iterations; if it does not, there may not be enough iterations, or a sufficiently low end temperature, for example. This mode can also be used to demonstrate how Marxan works to those unfamiliar with simulated annealing. The details found on screen can be saved in the text output files. Section 5.2.2 of the Marxan User Manual provides other reasons for using the screen output when running Marxan.

9.1.2 Tabular outputs

Marxan can produce a number of tabular outputs, shown in Table 9.1. Each of these files can be viewed using a text editor; most can be manipulated in a spreadsheet or database or linked to the spatial planning units to create spatial output.

Table 9.1: Summary of output files.

Output File Type	File Name[13]
Solutions for each run	*scenario*_r001.dat
Missing value information for each run	*scenario*_mv001.dat
Best solution from all runs	*scenario*_best.dat
Missing value information for the best run	*scenario*_mvbest.dat
Summed solution (Selection frequency)	*scenariio*_ssoln.dat
Summary information	*scenario*_sum.dat
Screen log file	*scenario*_log.dat
Scenario details	*scenario*_sen.dat
Snapshot files	*scenario*_snap_r00001t01000.dat

9.1.2.1 Solution and missing values for each run

Each scenario will have multiple runs, or solutions (the total number of runs is defined in the *input parameter file*). Each run has an output file identifying the solution (r001.dat,

[13] The file prefix 'scenario' will take on whatever name is specified by the user in the Input Parameter File. Where a number is included in the file name (e.g., scenario_r001.dat), it references the run number that generated that particular output. Tabular outputs have a .dat extension. For tabular outputs that can be viewed spatially, the ArcView option is selected and the tabular output will have a .txt extension.

r002.dat…r00n.dat), and the "missing values" (mv001.dat, mv002.dat… mv00n.dat). The solution consists of the planning units included in the set of reserves identified by Marxan within the run. The "missing values" table lists the conservation features for which targets were set, how much of each of those features is represented in the solution, and whether the target has been met for each feature.

By importing the *solution* tables into a database or spreadsheet, users can conduct a number of different analyses, including testing the sensitivity of a variety of parameters (see *Section 8.4 - Sensitivity Analysis*). For instance Munro (2006) found that Marxan met or exceeded 99% of targets, but of those targets that were not met, conservation features with high feature penalties were better represented than those with medium penalties, which in turn were better represented than those with low penalties. Marxan settings can be adjusted so as to achieve different outcomes like: reducing the cost of reserve boundary, decreasing the number of missing targets, or decreasing the costs of the planning units. Through use of a spreadsheet, the results of different runs, or scenarios, can be graphed and compared to evaluate the performance of the reserve networks derived in each scenario. The solution file can be imported to a GIS, to help visualise the Marxan output (see *Section 9.1 - Marxan outputs*), although it is more common to only turn the best and summed solution (selection frequency) into spatial layers.

The *missing values* table provides a measure of conservation comprehensiveness or representation, and includes the feature name, target, amount of feature held in a reserve and whether the target was met. In a spreadsheet, the missing values tables can be sorted to identify which features met 100% of their targets, which features were under-represented, and the proportion of target met, showing for example, where *conservation feature penalty* might need to be adjusted.

Best solution from all runs (best.dat)

Arguably the most widely recognised and commonly used Marxan outputs are the "best solution" and the "selection frequency" (discussed below). Both provide different information to the user and can inform the group in charge of designing the reserve network.

The "best" solution is portrayed by the solution file (best.dat), and a corresponding "missing values" table (mvbest.dat). The same analyses described above, for solutions for each run, can also be conducted on the "best" solution.

The terminology of "best run" may be a bit misleading. The "best" solution is the solution with the lowest objective function value (i.e., the most efficient solution) (see Marxan User Manual Section 1.5). Hence the user should have a firm understanding of how the objective function is calculated – there may be factors not included in the objective function which make the feasibility of implementing the "best" Marxan solution difficult or prohibitive.

Note that the "best" solution may not always produce the same results each time an identical scenario is conducted. The algorithm is unable to guarantee finding the very best solution, especially for big problems, so the "best solution" is better thought of as a very good solution, not the best possible. The ability to produce several very good options is one of Marxan's greatest strengths.

Users should not limit themselves to looking only at the "best solution" for a given scenario. There may be several other runs with very similar objective function costs that are virtually as good, and more easily implemented. The "best" solution may not be practical. Similarly, the "best" solution should never be communicated to stakeholders or decision-makes as such, but rather as a very good solution within a continuum of options. Practitioners should consider presenting more than one spatial output of areas required to meet targets. This will allow stakeholders/experts to use the flexibility of the Marxan analysis to compare and contrast several conservation options that may address their inherent concerns while meeting ecological objectives.

Summed solution (ssoln.dat)

The "summed solution", also referred to as "selection frequency" or previously as "irreplaceability", represents the number of times a planning unit was selected as part of a good solution from all runs in a scenario. Practitioners can use this solution to consider how useful a planning unit is for creating an efficient reserve system. This in turn may contribute towards prioritisation. In essence, if we lose a planning unit that has a selection frequency of 60% then we are roughly losing 60% of the good reserve network options.

The summed solution does not equal "irreplaceability" in the strictest sense. It is literally a measure of a unit's frequency of selection under a certain set of constraints. If a planning unit is selected in nearly every solution, it does not necessarily mean that it is irreplaceable; rather, the planning unit could be located geographically so that it is required to provide efficient solutions, even though the features it contains may be found in other planning units. The summed solution can therefore also be described as a "utility score", because it describes the utility of a planning unit in building efficient solutions within a given scenario. When interpreting and communicating summed solutions, it is very important to be clear that the summed solution output is not a reserve network fulfilling the criteria of a given scenario. To clarify the difference, the summed solution should be presented in conjunction with one or more of the better individual solutions.

Fischer and Church (2005) caution about interpretations based on the summed solution file because they correctly point out that all solutions contribute equally to the file. Highly efficient solutions in which all targets are met contribute just as much as inefficient solutions in which not all targets have been met. In short, frequently selected sites are not necessarily part of the most efficient solutions. Fischer and Church (2003) found numerous "popular" sites (selected in more than 50% of the solutions) that were not part of an optimal solution, and numerous "unpopular" sites (selected in fewer than 20% of the solutions) that were. In such cases, when Marxan is often not finding near-optimal solutions, parameters should be re-adjusted (see *Chapter 8: Ensuring Robust*

Analysis). A higher SPF value for under-represented features limits the algorithm's flexibility, but ensures a greater number of feasible solutions from which to choose. Increasing the number of iterations also helps limit unfeasible options. In any case, the selection frequency output is much more meaningful if unfeasible or poor solutions have been removed.

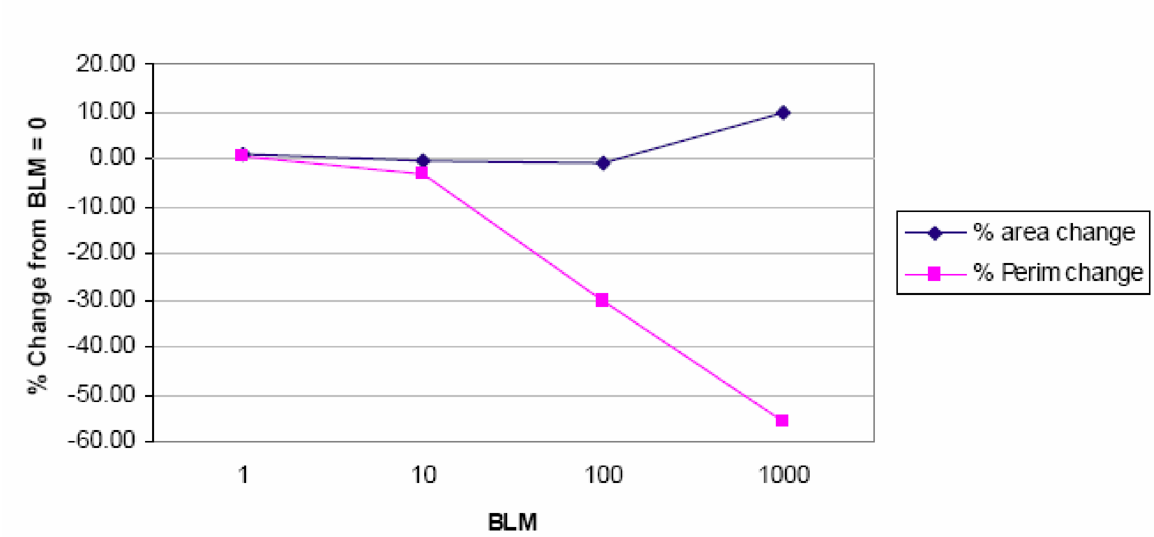
Summary information (sum.dat)

The sum.dat file provides summary information from Marxan regarding the performance for each run in the scenario, allowing for a comparison of the different runs. The file contains: the total score for the reserve, cost of planning units (PU Cost), number of planning units (#PU), cost of reserve boundary, penalty for missing targets, combined shortfall for missing conservation features, and the number of features missing targets. These can be reviewed using a spreadsheet to compare between runs, or between scenarios. Most users consider "cost", "penalty" and "number of planning units" the most important criteria when evaluating solutions. The "shortfall" is not particularly useful because it is a summed field and does not provide insight into which features are underrepresented.

A useful method to check Marxan performance is to create a histogram of the scores for each run. Looking at the shape of the histogram, there should be a low range of scores; a high range of scores may suggest that the algorithm is not annealing enough. Consider natural break points. Carwardine et al. (2006) used frequency histograms of the selection frequency values for each scenario to provide an indication of the similarity of the distributions of selection frequency values across the study area. However, a limitation of looking at just histogram comparisons is that they give no insight into the spatial differences and similarities. To address this limitation Carwardine et al. (2006) turned to spatial comparisons, measuring the proportional overlap in areas with selection frequency values of 1.0 between each pair of methods (see *Chapter 8: Ensuring Robust Analysis*).

Marxan outputs can be plotted against the scenario variables. This is useful information for justifying selections, and particularly important when communicating solutions to project sponsors or stakeholders. Examples of graphs include various boundary length modifier (BLM) scenarios against solution surface area required, perimeter or penalty or graphs displaying how well targets were achieved for various taxa. Figure 9.1 below shows the impact of altering the BLM on a reserve perimeter and area, which can be useful in justifying the selection of a BLM to others (and also in setting up the parameters, see *Section 8.3.5 - Boundary length modifier (BLM)*).

<u>Figure 9.1</u>: Percent change in area and perimeter of a best solution compared to BLM (Loos 2006).



Summed solution results of a Marxan analysis can be distilled a number of ways. Pryce et al. (2006) prepared a scatter plot showing collections of planning units rating conservation value (mean number of times a collection of planning units was selected in the summed solution) to the vulnerability (mean threat cost to the integrity of the collection of planning units). This in turn was used to prioritise conservation action. The results of the analysis can also be displayed spatially, as shown in *Section 9.1.4 - Spatial outputs*).

When comparing results of Marxan runs for interpretation and communication, four factors should be considered (described in more detail in *Chapter 8: Ensuring Robust Analysis*):

1. Size/efficiency (between runs): The total surface area of selected sites relative to all available planning units. This is particularly important when irregularly sized planning units are used.
2. Shape/clumping: The perimeter to area ratio of contiguous sites (both mean and median size of contiguous sites). This analysis can be conducted spatially using a GIS to dissolve adjacent planning units. Is the shape and size of the solution suitable to achieving ecological / project objectives?
3. Completeness: The number of conservation features not included in reserve. How close were features that did not achieve their targets (e.g., 1% missing or 50% missing –presumably in solutions under serious consideration, all targets should be met or nearly met).
4. Overrepresentation: Conservation features which are over-represented in the solution.

9.1.3 Other tabular output files (screen log, scenario details, and snapshot)

The screen log file (*log.dat*) captures the information that is presented on-screen when Marxan is running using verbose output, and is useful for debugging scenarios (see Section 5.2.2 of the Marxan User Manual). The *sen.dat* file contains a record of parameter settings that made up a given scenario. It should be retained, particularly if conducting multiple scenarios, and can be used to assist in interpreting the differing output from different scenarios. *Snapshot.dat* is an optional variable, and we have made a recommendation regarding converting this tabular output to spatial in *Section 9.1.4 - Spatial outputs*.

9.1.4 Spatial outputs

Although Marxan is not integrated with GIS software, the tabular output is readily imported into a GIS through linking output tables to the spatial planning units if the ArcView format is selected in the input parameter file (see Marxan User Manual Appendix C). Reviewing the tabular output spatially will provide further clarity to the results of the analysis and may ease communication to internal and external users. Converting tabular output to spatial format is most commonly undertaken with the best and summed solutions. *It is a good practice is to use both the "best" solution(s) and summed solutions when interpreting, refining and communicating Marxan outputs spatially.*

User-friendly GIS interface freeware that exists for the easy importing and analysis of data using Marxan includes:

CLUZ for ArcView 3.x users (http://www.mosaic-conservation.org/cluz/).

PANDA for ArcGIS users (http://www.mappamondogis.it/panda_en.htm).

TNC ArcGIS 9.x extension (http://conserveonline.org/workspaces/macr.gis/Protected_Area_Gap_DSS_Nov06.zip/view).[14]

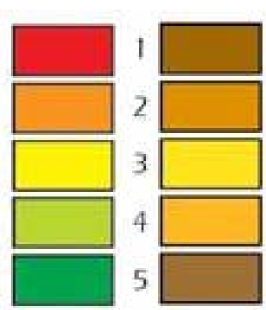
The best and selection frequency maps can be displayed and classified in a variety of ways. Some points to consider when displaying mapped output are listed below:

- Include information on the Marxan analysis settings. Maps dissociated from sufficient information relevant to the generation of the data displayed can be misleading. Useful information includes BLM values, % area required, number of features, locality, etc.
- Use colour gradients to display output. Some authors use colour gradients and change in colour at natural breaks.

[14] Terminology used by The Nature Conservancy (TNC) differs from that used in the Marxan User Manual and in this handbook; e.g., *conservation feature* = TNC's target, and *target* = TNC's goal.

- Follow basic cartographic rules for colouring concepts and consider when choosing gradients that some end users may be colour blind, of may only have grey-scale printers. Figure 9.2 shows how colours are perceived by a colour blind individual.
- Maps should be designed to be intuitive, so that people can look at them and interpret them correctly without having to refer to a legend. Having said this though, a legend must always be provided.
- There are many statistical methods for the classification of data. In cartography, the four most common are: equal steps, quantiles, standard deviation, and natural breaks. The best choice for data display depends upon the underlying distribution of the data. Plotting a scattergram or histogram that employs basic descriptive statistics (such as mean, mode, median, range, or standard deviation) will reveal the shape of the distribution. This shape will aid in the selection of the most appropriate classification method. However, in the case of Marxan outputs, a natural break is often the appropriate choice. More information on this topic is found with The Atlas of Canada: (http://atlas.gc.ca/sitefrancais/english/learningresources/carto_corner/map_content_carto_symbology.html).
- The output can be classified into categories that assist with interpretation and refining the output for end users. For example, the Mpumalanga terrestrial biodiversity assessment was classified into meaningful categories to be used in a land-use decision support tool (Ferrar and Lötter 2007).

Figure 9.2: Actual legend (left) and how these colours are perceived by a colour-blind individual (right). Note the similarity between colours 1 and 5. For best readability by colour blind individuals, use a colour gradient, and avoid the use of pure colours (use mixes). Print out the map in grey-scale to ensure it makes sense to colour-blind individuals and when printed out on a non-colour printer.



Some further data exploration methods for looking at multiple scenarios are summarised below:

- Combine the summed solution results from different runs/scenarios into one output as a measure of site importance across several scenarios (for example, different BLM scenarios). Areas that keep recurring under different scenarios may be a good starting point for a reserve if there is a lack of confidence in the data and/or assumptions.

- Sum only some of the runs (e.g., top natural breaks, or selection frequency for different steps in the natural break, or sum of the most efficient runs).
- Compare the best or summed runs to a run conducted without a BLM setting. This may highlight smaller fragmented areas with important biodiversity values. These differences can be communicated as part of the "single large or several small" (SLOSS) trade-offs in network design.

9.1.5 Snapshot files

The snapshot files (see Marxan User Manual Section 5.3.9) can be used to create a video (mpeg), providing a visual appreciation of how Marxan works as it moves through multiple iterations of a run. Each snapshot file comes in the same format as the final run and can be linked to the planning units to create a spatial output. A jpeg image of the spatial output is then created. Jpegs of all the snapshot files would then be combined in sequential order in movie editing software to create a "video" displaying how Marxan works towards a solution. Practitioners can review this output to ensure Marxan operates in a predictable pattern, with unpredictable results warranting further exploration. Such an output would also be useful in explaining how Marxan works to external audiences (Munro 2006).

9.2 Interpreting the Solution

Marxan is a decision support tool, designed to help guide the selection of efficient reserve systems; its output should never be interpreted as "The Answer". Whilst each set of Marxan runs will produce a mathematically "best" solution, there is no single best solution to most of the conservation planning problems that Marxan is used to address, and likely many good solutions contingent upon factors not necessarily in the analysis (e.g., human use preferences, etc.) (see *Chapter 1: Introduction*).

Working with Marxan is as much an art as a science, particularly as many of the input parameters are best determined through trial and error (see *Chapter 8: Ensuring Robust Analysis*). Understanding its performance requires practitioners to have an in-depth understanding of both the nature of the spatial data used to depict the conservation features, and of how Marxan works. The key point in assessing Marxan solutions is to determine if it has succeeded in meeting the problem's ecological targets, objectives and goals (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*).

It is recommended that practitioners conduct two levels of review: Internal and External. Each will have a different focus and both should include reviewing tabular and spatial outputs. The internal review should be conducted by those responsible for the Marxan analysis prior to taking the results to external review. This review should focus on Marxan performance and ensuring Marxan is running correctly, producing efficient, repeatable results. The external review should focus on the solutions themselves, including the solution's ecological merits and if a reserve design is practical from a management or implementation perspective. This job is made easier if earlier stages of interpretation and refinement are well documented and justified.

9.2.1 Internal review

The internal review should focus on determining how Marxan is performing, and how it responds to different suites of input parameters and datasets. As a Marxan analysis is best conducted iteratively, there will be many internal reviews prior to taking the outputs to an external audience. The exact nature of the issues considered in the internal review will vary amongst different processes. Three important aspects that have been discussed in this handbook, mostly in *Chapter 4 -Addressing Ecological Objectives through the Setting of Targets, Chapter 5 -Reserve Design Considerations*, and *Chapter 8 -Ensuring Robust Analysis*, are:

- **achievement of targets**: how well the project's objectives have been met through the achievement of targets;
- **efficiency**: consideration of how well solutions that meet targets do so for minimal cost / area, as well as how the clumping of sites suits the planning purposes;
- **sensitivity analyses**: measuring how much influence each parameter has on the solutions, and also evaluating the potential effects of poor parameter estimates or weak assumptions (Caswell 1989).

Some other points to consider in the internal review, such that it is ready for external review, include:

- The degree of technical involvement of the project supervisor / project sponsor / project team members in the process, their technical knowledge, and how to best communicate the results to them.
- How the targets and objectives were formulated and that these are defensible and are supported by the project team.
- That the outcomes of the analysis are understandable and "make sense." If there are unexpected results, these should be discussed.
- That the messages are clear. Carefully consider which outputs to show both internally and externally. This will depend on the process and objectives of the project: you may show a single result, or the full range of outcomes for a number of different scenarios. Be aware that information overload can paralyse decision-making, but that not showing enough information can trap the discussion in false trade-offs.
- Take note of the strengths and weaknesses of your analysis and results, as well as the assumptions inherent in your analysis.

- Anticipate potential conflicts, and highlight them (e.g., overlaps between areas selected for reserves, and socio-economic uses of those areas). Consider also the possibility of economic impacts beyond the scope of the analysis, e.g., might the chosen plan affect land values?
- Be aware of and note how much the plan changes the status quo.

It is important to have on hand a detailed technical document that explains what data went into the analysis, and what targets, constraints and parameters were set, so as to allow for a full explanation of details, sufficient to replicate it if necessary.

Before moving to a formal external review, it can be helpful to practise presenting results to friendly experts and locals. They can provide invaluable feedback as to whether the results make intuitive sense. If the results do not make sense to friendly reviewers, further examination (either correcting the analysis, or uncovering the legitimate reasons that explain these results) should undertaken before moving to external review, where the comments will undoubtedly be more critical.

9.2.2 External review

Depending on the process and its goals, external review may mean involving experts, decision makers, implementers, and wider stakeholders (see *Chapter 6: Addressing Socioeconomic Objectives* and *Chapter 10: Using Marxan in Multi-Stakeholder Planning Processes*).

One of the key purposes of an external review process is as a "reality check". Is the solution one which could be realistically implemented? How does the average clump size compare with the average size of the protected areas in an existing reserve network? Is the distribution realistic? Do the results make "sense?" Box 9.1 and Figure 9.3 describe an interpretation of a Marxan analysis that may help facilitate external review.

Experts often have knowledge about particular areas that are not represented in available datasets, and can therefore make valuable contributions to reviewing the quality of Marxan outputs. However, experts may also have their own subjective opinions about sites: If an expert recommends a site which Marxan did not select for inclusion in a reserve network, try to distil whether the recommendation is a result of a personal preference or bias, a data deficiency, or a factor not considered in the Marxan analysis.

Experts often have quantifiable and unquantifiable knowledge (i.e., "gut feelings," "hunches," intuitions) regarding a particular species or taxon, which usually can improve its protection. However, the implications of their recommendations vis-à-vis the preservation of other important taxa should be considered. An "ideal" configuration for the preservation of a wide-ranging animal species might look very different from that for the preservation of a vegetation community, for example.

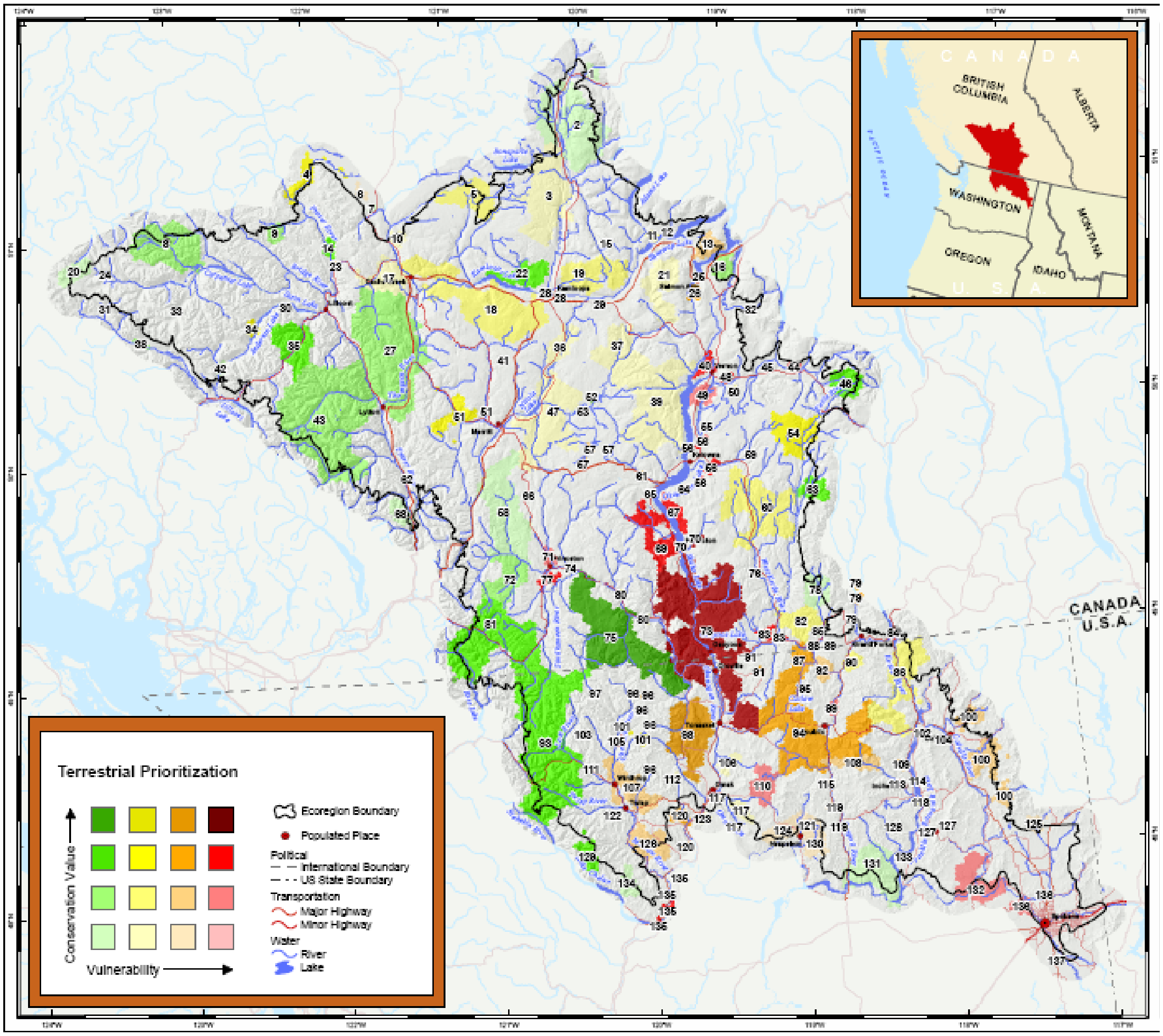
In the external review, it is important to not just show a single best solution, but also present summed solutions (selection frequency) for each Marxan scenario. A single solution provides no indication of the degree of variability between solutions. In addition to the summed solution, it can be a good idea to show a selection of single good solutions, to communicate the overall extent of area necessary to represent the targets in a given scenario. When different scenarios are shown, communicate the ecological objectives that are being addressed, and explain how they are being addressed by Marxan. It is also important to spend time explaining how Marxan works, to avoid the perception that it is a "black box" solution generator.

One must be prepared to defend the targets selected, and the trade-offs implemented to achieve the Marxan output (see *Chapter 4: Addressing Ecological Objectives through the Setting of Targets*). One of the best ways to achieve this is through conducting a robust analysis (see *Chapter 8: Ensuring Robust Analysis*) and internal review, as well as following the good practice of documenting the datasets and input parameter settings used in each scenario, along with the rationale behind them. Approaches that have been used elsewhere should be referenced. If possible, it is a good idea to have novel aspects of the analysis peer reviewed. This, in combination with peer-review of the results, will greatly increase the likelihood that the analysis is sound and acceptable to those involved in the broader conservation planning process.

Box 9.1: Interpreting results and prioritisation

The plot described in *Section 9.1.4 - Spatial outputs* can be used to spatially prioritise the Marxan Solution, as was done for the Okanagan Ecoregional Assessment (Pryce et al. 2006) (Figure 9.3). For this exercise planning units (hexagons) were grouped together based on the conservation action to be implemented or similar conservation features. Groups of planning units were then assigned a conservation value and a vulnerability value, based respectively on the mean summed solution and mean cost. Using a scatter plot sites were assigned a place on the matrix shown in Figure 9.3. This was translated to a colour value which can be displayed spatially.

Figure 9.3: Prioritisation of the results of Okanagan Ecoregional Assessment Marxan analysis using measures of conservation value and vulnerability (Pryce et al. 2006).



10 Using Marxan in Multi-Stakeholder Planning Processes

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ABSTRACT

This chapter presents good practices for successful stakeholder engagement in a reserve network planning process with Marxan. Section 10.2 discusses principles of multi-stakeholder planning process including defining stakeholders, and how and when to involve them. Section 10.3 discusses integration of stakeholders and Marxan. A summary and conclusions are presented in Section 10.4.

10.1 INTRODUCTION

It is now well accepted that involvement of stakeholders and communities in reserve network planning is crucial for a successful outcome. Increased stakeholder participation and more informed use of socio-economic data, rather than increased scientific knowledge of marine ecosystems, can be the key to successful reserve network design and implementation (Morin 2001). Meaningful stakeholder involvement engenders community pride and "ownership" of the reserve network and thus increased relevance, support and compliance (Wells and White 1995, Kessler 2004). In contrast, ineffective or lack of stakeholder involvement in which stakeholder interests are perceived to be threatened or not being met can give rise to agenda driving by a vocal stakeholder group, disenfranchisement and opposition which can undermine, derail or even halt a process (Wells and White 1995, Lien 1999, Helvey 2004b, Kessler 2004). Marginalised fishermen, for example, can lead to increased resource depletion (Brown et al. 2001). The first attempt in 1999 at implementing the California Marine Life Protection Act was halted because stakeholders criticised and protested against a proposal for a state-wide network of reserves that had been developed without significant stakeholder input (California Department of Fish and Game 2005). Experience in the Channel Islands also illustrates the consequences of ineffective involvement of stakeholders.

10.2 Involving Stakeholders in the Planning Process

This section discusses the following four good practices:

1. Strive for broad representation of **stakeholders**;
2. Prepare a stakeholder engagement plan at the **onset**;
3. Use a range of multiple stakeholder engagement **methods**; and
4. Engage crucial stakeholders at the outset once overall process objectives have been **defined**.

10.2.1 Strive for broad representation of stakeholders

Stakeholders are any persons who have an interest in the resources or areas under consideration in a planning exercise, or who may be affected by the establishment of a reserve network. A stakeholder's interest may be economic, societal, cultural, spiritual or any combination of these interests. For example, commercial fishers may have an economic interest in the resources they harvest, but their involvement in the fishery may also have a cultural component that defines their community. Some examples of stakeholder groups in any resource planning effort include:

- government resource managers and regulators;
- consumptive user groups (e.g., recreational and commercial fishing, oil and gas extraction, aggregate extraction, aquaculture);
- non-consumptive user groups (e.g., bird-watchers, photographers, divers, tourists, boaters);
- potentially impacted industries (e.g., processors, wholesalers, distributors, hospitality operators);
- residents in or near the area under consideration;
- conservation interests; and
- landowners and lease holders in the area under consideration.

It is up to the project planning body to decide which stakeholders to engage. In the case of government-mandated processes, we recommend that all potential stakeholders be invited to participate in the planning process. Otherwise, there is a risk later in the process that uninvited stakeholders will hold up or delay plan progress by claiming that they were excluded and time will be lost getting them up to speed and engaged. In the case of non-government lead processes, they may chose to invite only stakeholders with similar interests to participate in their effort and only pursue wider stakeholder involvement as necessary to further their goals. In part, which stakeholders are involved will reflect cultural expectations / norms and can vary from place to place. Participation can also depend on the body leading the process and its relevant competencies.

10.2.2 Prepare a stakeholder engagement plan at the onset

How stakeholders are involved in a planning process is a crucial step and should be carefully considered at the outset of the planning process. We advise that project leads prepare a stakeholder engagement plan describing the expected role of stakeholders in the planning process and how they will be engaged. Stakeholders need to be clearly informed of how their input and involvement will contribute to the planning process. The stakeholder engagement plan should be well integrated with the larger articulated plan process, which describes: the objective of the planning effort; who will set the objectives of the planning effort; and, how objectives will be set. This larger plan process as well as the stakeholder engagement process and expectations should be transparent and thoroughly communicated. Project leads would be wise to consider multiple communication strategies and opportunities to ensure that all messages are well understood. There is no one recipe for formulating successful stakeholder engagement. Each project will have its own nuances. Transparency, commitment, inclusivity, communication, and a thorough understanding of the process and expectations by stakeholders will increase the likelihood that they will productively engage in the planning process, and thus increase the probability of project success.

Levels of participation. For participatory processes in general, decision making occurs along a continuum of participation (Arnstein 1969). Planners and stakeholders should both be clear and in agreement at what level of involvement stakeholders will be involved. Four levels of participatory decision making have been characterised as follows by NOAA (NOAA Coastal Services Center 2000):

- **Level I** – This level of participatory decision-making is made solely by the management authority/agency, and stakeholders are only informed about the decision after it has been made. This level includes information-giving activities such as newsletters, presentations at meetings, briefing media through press releases, advertising through posters, and radio announcements.
- **Level II** – This level of participatory decision-making is made by the management authority/agency after input is obtained from stakeholders. This level includes consultative activities such as public meetings, workshops, or task groups. Often these consultative activities will be used in conjunction with information-giving activities described above.
- **Level III –** This level of participatory decision-making involves stakeholder discussions and decisions on a course of action. However, at this level, the stakeholders are unable to act until they receive approval from the management agency. At this level, information-giving activities are used to start the process, followed by collaborative activities such as advisory committees or joint planning teams.
- **Level IV –** This level of participatory decision-making applies to situations in which the stakeholders have been given the authority to make decisions and implement action plans without having to seek final approval from a management agency.

10.2.3 Use a range of multiple stakeholder engagement methods

Depending on the degree of involvement, ingredients for stakeholder engagement include newsletters, websites, questionnaire surveys, open houses, focus groups, mapping workshops, meetings with all stakeholders, meetings with individual stakeholders, sector meetings, field trips, membership on advisory committees, or participation directly at the planning table. One or any combination of these can be undertaken to solicit information on the planning process, objectives, desired outcomes, scenario iterations, etc. It is recommended that multiple stakeholder engagement methods be used throughout the process to ensure a broad audience is reached. That said, too much public consultation without visible progress can lead to stakeholder burnout and frustration.

10.2.4 Engage crucial stakeholders at the outset once overall process objectives have been defined

When to involve stakeholders in a process will in part depend on the level of expected participation, as outlined in *Section 10.2.2 - Prepare a stakeholder engagement plan at the onset*, above; fuller engagement will likely require earlier engagement. Successful handling of this consideration may be more an art than a science. Involving stakeholders too early in the process, before project leads are well versed in what they are setting out to accomplish, can be an inefficient way to spend time, confusing to stakeholders and frustrating for project leads. Involving stakeholders too late in the process or not at all may lead stakeholders to conclude that all the important decisions have already been made and that their involvement is inconsequential and a waste of time. In the California Marine Life Protection Act, following one to two years of planning by scientists, meetings were scheduled in various communities with one week notice. Until the announcement of the meetings, stakeholders were not aware of the planning process, nor of the need for a planning process. A huge uproar ensued and the process had to be cancelled. It took six years to rebuild credibility in the community.

In another example, The Nature Conservancy undertook a regional conservation planning assessment in the Pacific Northwest. For this assessment, Washington state coastal tribes were critical stakeholders. Although several of the coastal tribes took part in the review of draft Marxan scenarios, they felt like they had come in late to the planning process. Engaging key groups like the tribes as early as possible is very important in building trust and being transparent about what information is compiled into assessment units used in Marxan. Successful planning processes have involved key stakeholders during the building of a database that characterises the ecological and human use elements of a region. In the spirit of being transparent, critical junctures include what biological and ecological features make up the ecosystem, building the cost of suitability index and presenting draft Marxan scenarios to share and discuss. Each planning situation will be unique and careful consideration should be given to the stakeholders to be involved. Stakeholders may even be consulted to evaluate when the appropriate time for engagement is.

On the other hand, some prior projects had successfully used media campaigns in advance of stakeholder engagement as an effective tool for setting the tone of the stakeholder meetings.

Box 10.1: Engaging stakeholders in a Marxan analysis

Despite the effectiveness of Marxan in designing optimal reserve networks, the software should not take the place of stakeholder-driven planning processes. A stakeholder-driven process is important in defining biodiversity conservation and socioeconomic objectives, addressing any objectives that are not incorporated in the software, and supporting the final outcome. Once the objectives are clear, Marxan can be applied to support stakeholders in designing marine reserves. We describe two case studies that demonstrate ways to include both stakeholders and a Marxan analysis in marine reserve network planning. In addition, we describe a software program that is being developed to facilitate the interaction of stakeholders in protected area design process that uses Marxan.

Channel Islands National Marine Sanctuary

A network of ten fully protected marine reserves and two marine conservation areas that allow limited fishing were established around California's northern Channel Islands in April 2003. The network of marine protected areas was a result of an intensive planning process involving state and Federal agencies, scientists, and stakeholders. An early version of the planning tool Marxan was used by the science advisory panel to identify a suite of potential locations for marine protected areas. The stakeholders used a combination of ecological guidelines developed by the science advisory panel for design of marine protected areas, options generated through the Marxan analysis, and their own knowledge, to craft a suite of alternative networks of marine protected areas. The stakeholders used a computer planning tool, known as the Channel Islands Spatial Support and Analysis Tool (or CI-SSAT), to view data and evaluate potential marine protected areas.

Conservation features were defined on the basis of the goals for marine protected areas, which were developed by the stakeholder working group. The goals included protection of marine habitats and species, use of marine protected areas to contribute to sustainable fisheries, and maximum long-term benefits while limiting short-term impacts to users. The stakeholders and science advisory team identified over 100 species of interest.

The cost of each planning unit was considered to be equivalent to its area. Although planners gathered data on commercial and recreational fisheries and other activities in the planning region, use of data was restricted because of their proprietary nature. In addition, the stakeholders preferred to review the output from Marxan without the added complexity of economic costs. Stakeholders in the process intended to evaluate the solutions based on ecological guidelines separately from the considerations of potential socioeconomic costs.

By producing a suite of solutions, Marxan provided the flexibility needed to address policy concerns within the framework of an analytical process that was repeatable and rigorous. Given the range of solutions, the stakeholders were able to identify alternatives to establishing protected areas in locations of high use. The selection frequency map was particularly useful for advancing discussions about where to establish marine protected areas.

Ultimately, the stakeholders were unable to come to consensus on a single preferred alternative so the state and Federal agency staffs were required to develop a compromise between the two alternative networks of marine protected areas favoured by stakeholders.

Local conservation groups in the southern Strait of Georgia

In preparation for a consultation process surrounding a proposed National Marine Conservation Areas (NMCA) in the southern Strait of Georgia, British Columbia, local conservation groups are interested in developing a conservation-based zoning vision using Marxan, a tool which is also being used by Parks Canada as part of a systematic conservation planning process. Working with researchers at the Department of Geography, University of Victoria, Canada, conservation stakeholders gathered over a series of workshops to identify their goals, define their objectives with targets, costs and penalties, and explore various zoning scenarios. While specifications were made by the stakeholders the analysis was undertaken by the researchers. Data and results were then projected onto a screen at the workshops allowing users to direct the operator to navigate through the results.

Zoning was undertaken in a stepwise fashion starting with the highest protection zone deemed as being the highest priority. After describing the intent of the zone, stakeholders then selected the relevant GIS layers. Browsing through the layers stakeholders evaluated reliability of the data. The stakeholders then collectively identified targets for each layer and planning unit costs associated with desirable features (e.g., adjacency to upland parks) or undesirable (e.g, adjacency to industrial areas). Stakeholders learned that given the distribution of the data, their ideal targets selected about 90% of the study area as the highest protection zone. This was not a realistic scenario. Target levels and costs were explored and revised to generate different scenarios.

The use of Marxan in a collaborative setting enabled the stakeholders to again a detailed understanding to the analysis which Parks Canada is undertaking and thus they can be more effective contributors to the consultation process. In particular they learned of the implications of the spatial distribution of data with respect to setting targets and the limitations of data quality. In addition, by exploring potential scenarios with Marxan stakeholders also have a better understanding of the scope of possibilities and the implications of their goals on other users.

10.3 Involving Stakeholders with Marxan

Introduce Marxan according to the level of involvement

Translate stakeholder goals and values into Marxan objectives and parameters

Systematically generate alternative scenarios

Incorporate communication into initial planning

Target the outputs and interpretation for each stakeholder audience

Understand the difference between "best" solution and selection frequency

Explain the meaning behind the maps

Ensure that cartographic styles do not mislead the reader

Select communicators who understand the technical aspect as well as the perspective of the target audience

Stakeholders can be consulted as members of the general public in providing general input and feedback to Marxan analysis. In this case, scientists and spatial analysts use Marxan to generate and explore scenarios based on stakeholder input, scientific information and policy direction[15]. This is the traditional approach in which Marxan has primarily resided in the domain of scientists and technical analysts, and stakeholders are more indirectly involved with Marxan. However, when stakeholders are more involved or hope to be more involved in a planning process, such as representative members of a working or advisory group, they often express their discomfort if the process of mapping reserve networks is relegated to a group of scientists, agency staff or a decision support tool. Instead, they want to have more direct involvement in designing reserve networks and using tools. For example, a network of conservation groups in southern British Columbia has taken a proactive role in using Marxan to provide a vision of a reserve network to be able to provide more robust input into the planning process.

10.3.1 Introduce Marxan according to the level of involvement

The level of involvement by stakeholders (see *Section 10.2.2 - Prepare a stakeholder engagement plan at the onset*) with Marxan determines when and to what extent stakeholders are introduced to Marxan. While Marxan, as any other decision support tool, may be a key tool in the planning approach, it should not drive the planning process, but facilitate it when relevant. Therefore, it is often good practice to not introduce Marxan in initial stakeholder meetings, which instead should focus on fundamental goals of the reserve network design. From these discussions it may emerge that Marxan is an appropriate tool with which to answer questions and generate ideas to

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[15] For examples of translating policy into MPA spatial analysis see Bruce & Eliot 2006 and Chan et al. 2006.

meet the goals. Alternatively, other tools may be more appropriate for the task at hand or may be used in conjunction with Marxan.

In some cases when stakeholders are indirectly involved with Marxan, it may not be necessary to mention Marxan or describe specific aspects of the tool. In other cases, particularly when stakeholders are more directly involved in Marxan analysis or in evaluating outputs, they must clearly understand to some extent how Marxan works. A transparent and easily understood analysis is particularly important to build acceptance and trust from stakeholders. Approaches to introduce Marxan can include:

- explaining the fundamental principles and calculations of Marxan[16]; for example many stakeholders are encouraged when they discover one of the key objectives may be to minimise the impact of the network on economic pursuits;
- clarifying Marxan vocabulary which may mean different things to different stakeholders;
- demonstrating examples in which Marxan has been used;
- inviting stakeholders involved in another reserve network planning process to provide a stakeholder perspective; and
- using Marxan to provide some initial answers to some basic "what if" questions posed by the stakeholder group.

For example Marxan was used to explore a conservation–based vision for the Southern Strait of Georgia, British Columbia (see Box 10.1). Participants were given an overview of Marxan with examples where it has been used elsewhere and the kinds of outputs Marxan can generate. This was followed by more detailed Marxan orientation sessions in smaller groups covering targets, costs and data requirements.

The aim of introducing and explaining Marxan to stakeholders is not to oversell or undersell the tool, but to acknowledge its advantages and disadvantages, i.e., what it can do and what it cannot do. When stakeholders are directly involved in a planning process, Marxan can be introduced in steps with increasing level of detail as the process proceeds. For example, in introducing Marxan to a network of marine conservation groups in British Columbia, a short general presentation introducing Marxan was made. This was followed up by a more detailed presentation to individual conservation groups highlighting fundamental concepts such as planning units, targets and costs, with several illustrations of how Marxan was used in other projects. Individuals participating directly in the planning process had felt sufficiently comfortable to start the planning process. As it proceeded, increased complexity and explanation was presented informally through discussions and scenario exploration. After several scenarios were generated and discussed, the group took a step back, and addressed the questions: What

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[16] Introductory materials can be found in the early chapters of this handbook, the Marxan User Manual, the Marxan web site, and the CLUZ web site.

are the Marxan scenarios telling us? What other questions do we have that Marxan cannot easily answer?

The rest of this section provides good practices for involving stakeholders, both directly and indirectly, in three stages of using Marxan for reserve network design:

1. defining Marxan objectives;
2. generating and exploring scenarios; and
3. evaluating and providing feedback on Marxan outputs.

10.3.2 Translate stakeholder goals and values into Marxan objectives and parameters

Prior to embarking on any analysis, it is important to have a clear vision of the goals of the process and the goals of the reserve network and objectives to meet those goals that are expressed as a Marxan objective.

The Marxan algorithm is based on a minimizing cost algorithm defined by various parameters such as targets and costs associated with feature layers. Current practice has dictated that scientists and experts have typically defined the parameters of the Marxan objectives. In a recent survey of 77 Marxan users worldwide in 97% of the projects objectives were set by scientists/experts. However, stakeholders were involved in setting the objectives in 39% of the projects (see *Appendix 1: Results of Marxan User Survey*) and this percentage can increase as stakeholders become more directly involved in the planning process. Some parameters of the algorithm such as boundary length modifier (BLM), planning unit shape and planning unity size are best left to analysts. Others such as relevant feature layers, targets and other location parameters which can influence cost values and penalty factors can be defined by stakeholders.

Expressing their interests and value in an algorithm can be challenging for stakeholders. First of all they must clearly articulate their overall goals for the reserve network and then these must be articulated mathematically into an algorithm (Leslie et al. 2003). The time necessary to clearly articulate goals whether they are conservation goals, socio-economic goals or regulatory goals cannot be understated as they are foundation of the analysis. Launching straight into the details of Marxan before preparation can lead to misdirected paths down dead ends. In the Channel Islands, the multi-stakeholder working group spent one year considering the state of the marine ecosystem and goals for marine reserves before exploring SPEXAN results from the scientific advisory panel (see Box 10.1) (Airame 2005). Similarly, in the Southern Strait of Georgia, conservation groups spent most of the first two workshops discussing their overall goals for the region in general and zones in particular. Examining policy (Bruce and Eliot 2006, Chan et al. 2006), stakeholders interests and scientific knowledge can all combine to specify goals.

Questions to stakeholders must be phrased in familiar language such as:

- What would you like a reserve network to look in 20 years time?

- What conservation features are important to you?
- What habitats and features are most important to protect?
- What socio-economic activities are important to the community?
- How should existing marine protected areas be incorporated into the new design?
- What upland and foreshore factors are important in siting marine reserves?

10.3.3 Systematically generate alternative scenarios

In running Marxan, there is a danger in people thinking that Marxan will generate the definitive solution. This may produce a narrow view of possible outcomes and a confrontational response from stakeholders. Presenting and evaluating several alternative solutions not as an endpoint but as a starting point to explore the decision space will offer a means of engagement, stimulate more creative and constructive discussion and encourage an understanding that there will likely be more than one solution which meets a set of goals (Airame 2005). Alternative scenarios help stakeholders understand tradeoffs and the full range of possibilities. The flexibility of generating multiple solutions was by far the most commonly noted strength of Marxan (62% of users surveyed – see *Appendix 1: Results of Marxan User Survey*).

Exploring the use of SPEXAN (a precursor to Marxan) to identify a network of marine reserves in the Florida Keys National Marine Sanctuary demonstrated the value of generating alternative scenarios. It was concluded that generating scenarios with different conservation goals could provide stakeholders with a visual sense of how their goals translate into a spatial network design, how different goals affect the potential network design and also which areas behaved consistently and therefore were particularly important in contributing to an ecologically and socially sustainable system of marine reserves (Leslie et al. 2003). In designing a network of reserves in the Channel Islands National Marine Sanctuary, a working group of stakeholders worked with scientists using SPEXAN to develop and explore over 40 different network designs during the planning process (Airame 2005). Through each alternative, stakeholders were able to evaluate the sensitivity of the outputs to different types of data, classification schemes and goals. The range of solutions generated was credited with facilitating the identification of constructive alternatives in areas of high conflict among stakeholders. In planning for the Great Barrier Reef Marine Park, Marxan was used to generate a starting "solution". The public was then invited to comment.

One of the limitations in using Marxan in multi-stakeholder planning processes is the time it takes to generate scenarios dependent on the number of data layers, planning units etc. In the new optimised version of Marxan, users are now able to generate solutions in real time/interactively. A higher degree of interactivity and exploration of the decision space and possible solutions can also be achieved by having the data and GIS for visualising and querying the data so that stakeholders can see various layers, add data, remove data, explore and query solutions generated by Marxan. In both the Channel Islands and the Southern Strait of Georgia examples (see Box 10.1), the GIS was available and projected on to a screen so that stakeholders could directly explore the data and ask questions of the Marxan scenarios generated. Another option is to have the data available on a public web link such as www.marinemap.org/mlpa. A *user interface* would be required, however, to allow user to draw a reserve network and evaluate biophysical and socio-economic impacts.

While generating alternative solutions is valuable, generating solutions that are considerably different, and not well explained, can lose credibility among stakeholders who may perceive the solutions generated by chance or without perceived patterns leading to more confident solutions. A wide range of solutions can indeed suggest that the algorithm has not been given sufficient constraints, and in such cases the addition of more detailed costs can be helpful (see *Chapter 6: Addressing Socioeconomic Objectives*).

10.3.4 Incorporate communication into initial planning

An important element in generating scenarios is understanding the output and interpreting the results to provide feedback to guide the generation of different scenarios. This requires a clear communication strategy among analysts, decision makers and stakeholders as explained in this section.

A recent survey of 77 Marxan users worldwide revealed that in 57% of the projects results were communicated to stakeholders and 28% were communicated to the general public (see *Appendix 1: Results of Marxan User Survey*). As discussed in the Introduction to this chapter, success or failure of a reserve network design process often relies on the support and trust of stakeholders. Understanding the process including analysis upon which decisions are based is key to establishing that trust and buy-in. If decisions are perceived to be subjective, ad hoc or within a black box, then trust can be compromised. Stakeholders also need to understand their own stake or vested interest and the impact, positive and negative, which a proposed reserve network will have on that interest, especially for those who might lose the right to harvest or access an area.

This section provides good practices for taking out the mystery of Marxan, and particularly the outputs, through effective communication so that stakeholders are comfortable with their understanding and can make informed contributions to the process. In so doing, it is important not to lose sight of the fact that Marxan is only one component, and possibly a minor one, of the overall process.

Communication is often left as an afterthought to the planning process and might involve presentation of a map with lines drawn with scant explanation. Stakeholders may then be taken by surprise. Communication needs to be part of initial planning and a component of the overall stakeholder engagement plan for the process. Good communication of Marxan is no different than other good communication practices and can be found in the broad literature on this topic. Ideally, a communications specialist should be involved.

10.3.5 Target the outputs and interpretation for each stakeholder audience

While all stakeholders need to have a common understanding of Marxan outputs, fundamentally, stakeholders will be particularly attuned to the outputs in relation to their own interests. Thus, communication should be audience driven. The outputs should be tied to the stakeholders' own values and costs. Therefore, it is first of all important to understand stakeholders' values, how they will measure the costs and benefits of a reserve network and how they will use the information communicated to them. For example, fishermen need to know if fishing access is being restricted in particular areas and what this might mean to employment and the cultural definition of fishing communities. Used creatively, Marxan can assist in determining compensation for loss of fishing access. Fishermen will also need to know of anticipated long-term benefits of marine reserves on stock recovery and potential spill-over effects. They may want to know where marine reserves are in relation to nursery grounds. Outputs and interpretation of those outputs should be presented and explained in language that is meaningful to the audience, rather than make the audience translate and add another layer of interpretation and possibly misinterpretation. Finally, it is important to also listen to user feedback that may indicate inadequacies or errors in the data used, and warrant revision.

10.3.6 Understand the difference between "best" solution and selection frequency

The survey of Marxan users revealed that the selection frequency and the overall best solution were the outputs most commonly used (83% and 77% respectively) (*Appendix 1: Results of Marxan User Survey*). There is often much confusion on the implications of the difference between the two when interpreting results. Caution is raised when comparing the "best" solution to the selection frequency as the results offer a different meaning. This is discussed fully in *Chapter 9: Interpreting and Communicating Outputs*, and a brief overview is also provided below.

The term "best" solution can be misleading. In effect, it is the most efficient solution from all those generated from a set of runs. Most efficient is defined as having the least cost. Therefore, it is important to have an understanding of cost measured by least area or other metric. Another set of runs may generate a different "best" solution. In most cases, the "best solution" is statistically not significantly different, or only slightly so, from the others in the top grouping of solutions. The 2^{nd} or 6^{th} best solutions, for example, may actually be more feasible or otherwise more appropriate in the real world.

The selection frequency reports the number of times or frequency each planning unit was selected in all solutions for a set of runs. It is one way to explore the usefulness of planning units to achieving efficient solutions.

Which output is most useful? As indicated in the user survey (*Appendix 1: Results of Marxan User Survey*) both are valued. In using SPEXAN to design a network of reserve networks in the Channel Islands National Marine Sanctuary, the selection frequency was noted to be one of the most useful outputs for advancing discussion. Biodiversity hotspots were identified as planning units selected for a large number of solutions (Airame 2005). Comments from the Marxan user survey respondents suggested that there is a preference for using the selection frequency and overall best output together to complement one another.

10.3.7 Explain the meaning behind the maps

Marxan can be a powerful tool and its map outputs can be visually very appealing, but ultimately stakeholders will ask the question "What does the map mean?" To answer this question, analysts and those communicating the results to stakeholders need to have a firm understanding of the results (see *Chapter 9: Interpreting and Communicating Outputs*). This includes understanding the strengths and weaknesses of assumptions, available data, sensitivity of the output to variations in data, targets, costs and penalties by exploring various scenarios. It also requires the ability to not get lost in details, but to instead focus on key factors that affect the outputs. Rigorous and defensible results are better than "trial balloons" that can cause more harm than help. Results should be understandable and make visual sense to experts and locals alike.

Stakeholders will want to know how the results reflect their own interests, and compare this to how other stakeholders or other regions are affected. Were targets achieved? Where in the region does a particular target exist? Why are certain areas selected? What is driving the output? These were common questions asked by a group of conservation stakeholders engaged in a planning process in Southern British Columbia. They had an expectation that special or unique sites and areas that reflected local knowledge would be represented in the results. However, the analysis and their targets were driven by representativeness. It was therefore important to explain how target components inter-relate and that in a reserve system the value of a site depends on what else is in the system.

Tables that annotate maps and link to mapped output can assist in answering the questions above and explaining the results. Linking tabular outputs of Marxan into result maps through a GIS is relatively straightforward, and by highlighting rows in the attribute table is one way of interpreting data in depth. Tools like CLUZ and PANDA can help to answer these questions on the fly and can link tables to planning units to answer what target features are found in a given planning unit. CLUZ can also help in working out if areas are selected because of the presence of a particular feature or because of wider representation goals.

10.3.8 Ensure that cartographic styles do not mislead the reader

When communicating with maps to a broader audience, be aware that you can lose control of the communication process. In other words, maps can speak by themselves. Much can be interpreted and misinterpreted from the colours, symbols and other cartographic characteristics of maps. For example, solid lines on a map can invoke "lines drawn in the sand". Whereas dotted lines or faded boundaries can relay areas that are open for discussion. Viewers may not pause to read a legend or fine detail but will form an immediate impression from the spatial patterns, colours and titles, usually focusing on that part of study area most familiar to them and their interests.

To minimise the risk that maps can be misleading or misinterpreted distribute the maps to a working group or representatives from different stakeholder groups for feedback and to anticipate reaction. Cartography is also discussed in *Chapter 9: Interpreting and Communicating Outputs*.

10.3.9 Select communicators who understand the technical aspect as well as the perspective of the target audience

The discussion so far has focused on what to communicate. Equally important is who communicates. In many cases scientists or government staff have been responsible for communicating with stakeholder groups. However, they may not necessarily be the most appropriate. The right person to communicate to stakeholders is someone who:

- has a good relationship (i.e., trust) with a stakeholder group;
- understands its values and interests and is willing to listen;
- can explain the results in non-technical terminology; and
- is not confrontational or defensive about the scenarios.

More often than not this requires a communication team comprised of members of the target stakeholder group including scientists, analysts and policy makers. While the Marxan analyst probably should participate on this team, it should be anticipated that s/he may be sensitive to certain criticisms, and that another member may be better suited to communicate directly with the larger stakeholder group.

10.4 Summary of Good Practices

- Strive for broad representation of stakeholders.
- Prepare a stakeholder engagement plan at the onset.
- Use a range of multiple stakeholder engagement methods.
- Engage crucial stakeholders at the outset once overall process objectives have been defined.
- Introduce Marxan according to the level of involvement.
- Translate stakeholder goals and values into Marxan objectives and parameters.
- Systematically generate alternative scenarios.
- Incorporate communication into initial planning.
- Target the outputs and interpretation for each stakeholder audience.
- Understand the difference between "best" solution and selection frequency.
- Explain the meaning behind the maps.

- Ensure that cartographic styles do not mislead the reader.
- Select communicators who understand the technical aspect as well as the perspective of the target audience.

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Appendix 1: Results of Marxan User Survey

Natalie C. Ban

ABSTRACT

In the fall and winter of 2006, an electronic survey was developed to identify how Marxan had been used to date, and to identify themes and user needs. Results from this survey helped shape the PacMARA expert workshop 2-5 April 2007, in Vancouver, BC, Canada, and subsequently the writing of this Good Practices Handbook.

A1-1 METHODS

An online survey was used to gather information about the current use of Marxan. Invitations for participation in the survey were given through the Marxan listserv, which includes all who have downloaded Marxan. Participation in the survey was voluntary. Survey questions focused on the scope and outcomes of Marxan projects, the data and parameters applied, and the perceived strengths and weaknesses of the program. *For most questions, participants were allowed to multiple responses, and therefore most answers exceed 100%.*

A1-2 RESULTS

Seventy-seven Marxan users participated in the survey, involving projects from all continents except Antarctica. The majority (71%) of participants use Marxan in a scientific capacity, followed by planners (31%), technical operators (26%). Very few managers or senior decision-makers used Marxan. Most projects were conducted at a regional scale (74%), with fewer at national (21%), international (16%) or local (13%) scales. Users of Marxan were relatively evenly split amongst various levels of government (57%, or which 26% are federal or national agencies, 26% regional, and 5% local), non-profit organisations (49%), and academia (47%). Many of the projects are collaborations involving more than one of these categories. Most applications covered terrestrial environments (68%), followed by marine (51%) and freshwater (22%) environments. Projects commonly tool three to six months to complete (28%), with some taking less than three months (16%), six months to one year (20%), between one and three years (17%), and very few took more than three years (1%). However, most projects (31%) were not yet completed. Participants commented that most time is spent gathering, collating, and otherwise preparing the input data and files. Refinement of Marxan parameters was also noted to be time-consuming.

Marxan was chosen because of its ability to provide multiple solutions (56%), its scientific rigor (53%), its ability to handle large amounts of data (53%), the provision of near-optimal solutions (52%), and its reputation (45%). A few respondents (3%) also noted political pressure as a determining factor for choosing Marxan. Additional comments on the choice of Marxan included its reputation as the "industry standard" for conservation planning, the ability to cluster solutions, and the ability for post-hoc analysis. Most users consider Marxan's ease of use to be moderate or moderately difficult (76%), with several comments that the generation of input files is the most challenging aspect.

Biodiversity conservation (88%) and establishment of protected areas (72%) were the most common planning objectives. Other objectives include ecosystem functioning (36%), research (35%), and sustainable fisheries (19%). Less common responses cover community development (7%), recreation and education (4% each), and aesthetic and spiritual objectives (3% each). The objectives set in the Marxan projects were primarily set by scientists/experts (97%), followed by decision-makers (40%) and stakeholders (39%). Results were communicated to scientists/experts (91%), decision-makers (77%), stakeholders (57%), and the general public (28%).

Most participants (66%) had not completed their Marxan projects, and were therefore unable to answer whether their project had resulted in a conservation gain. Twenty-four percent indicated that their project had resulted in a conservation gain, whereas ten percent said that it had not. Comments suggest a mixed experience in the influence Marxan projects had on decisions. Some projects were designed as research projects that were not intended to provide recommendations. Some Marxan users found their results being integrated into conservation plans and protected area designs, whereas others' recommendations were ignored, or projects cancelled upon realisation of the area required for meeting objectives.

The size of the study areas and planning units used varied widely (Table 1), with an average of about 1 million square kilometres. Hexagons and squares were almost equally popular for planning units (46% and 44%), followed by irregular units (35%). Some participants also indicated using triangles.

Table A1.1: Study area details (n=61).

	Study area size (km^2)	Planning unit size (km^2)
Minimum	40	0.0001
Maximum	30 000 000	10 000
Mean	955 503	260
Standard deviation	4 024 649	1502

Most users applied all of Marxan's basic options, but less than half used advanced options for either all or some conservation features (Table 2). The majority of participants used the adaptive simulated annealing function (81%), followed by *iterative improvement* (44%) and simulated annealing while setting the initial temperature (22%). The heuristic options were used, but were not as popular (ranging from 17% to 6%).

Table A1.2: Marxan options.

Basic options	Used	Not used
Boundary length modifier	89%	11%
Repeated runs	98%	0%
Planning Unit Cost	87%	13%
Boundary Cost	79%	18%
Planning Unit Status	87%	10%
Penalty factor for conservation features (SPF)	88%	12%

Advanced options	Used for all targets	Used for some targets	Not used
Block definitions	13%	22%	65%
Cost threshold	25%	11%	64%
Separation distance (sepdistance)	5%	26%	68%
Separation number (sepnum)	4%	15%	82%
Minimum clump size (target2)	9%	30%	61%
Number of occurrences required (targetocc)	25%	27%	47%
Minimum viable population size	11%	16%	73%

A variety of data inputs were used (Table 3). Other data inputs that were used include sites of fisheries importance, land cover classifications, soils data, spawning aggregations, landscape matrices, hydrological functions, marine landscape and benthic terrain models, and the output of population viability analyses. The majority of respondents used a variety of targets for features (65%) rather than uniform targets. Targets were set based on the commonness or rarity of features, ecological values, estimates of minimum viable populations, proportions of original abundance, the results of gap analyses, and species-area relationships.

Table A1.3: Data inputs.

	Used	Not used
Species distributions (models and/or surveys)	88%	12%
Habitat distributions (models and/or surveys)	81%	19%
Species Abundance (surveyed populations)	54%	46%
Species presence/absence (surveys)	47%	51%
Species presence only (sightings)	74%	25%
Species/habitat incomplete coverage	46%	50%
• If yes, were any estimated to cover less than 75% of the study area?	50%	30%
Geophysical data (e.g., topography, salinity, currents)	64%	34%
Habitat classifications	82%	18%
Biogeographic zones	62%	38%
Economic data (e.g., cost of land, value of fisheries)	43%	57%
Land/marine human use data	62%	38%
Traditional (indigenous) ecological knowledge	17%	83%
Local Ecological Knowledge	40%	60%
Expert Scientific opinion	64%	36%
3D data converted into 2D (e.g., topography, bathymetry)	43%	55%
Temporal data	12%	85%
Connectivity	37%	61%
Genetic information	6%	94%
Ecosystem services/processes information (e.g., pollination, carbon sequestration rates)	19%	81%
Others	18%	70%

The most common data weighting options were those of relative importance (48%), expert opinion (47%), and data reliability (40%). Other weightings included commonness of features, vulnerability or rareness of features, and the viability rankings for targets. Most participants assigned the same penalties to all features (54), with some applying different values (33%). When different penalty values were used, they were mostly based on the relative importance of features or the confidence in the datasets. Other approaches include ratings according to relative vulnerability and rareness. Many Marxan users reported undertaking sensitivity analyses to determine what values to use as the penalties.

Planning unit area was the most commonly applied cost, followed by equal costs, and economic data (Table 4). Other costs applied primarily relate to threats to ecological integrity (including proxies such as proximity to urban areas, roads).

Table A1.4: Cost.

	Used	Not used
Equal cost	55%	45%
Planning unit area	76%	24%
Economic data (e.g., cost of land, value of fisheries)	51%	49%
Naturalness	44%	49%
Expert Scientific opinion	17%	77%
Local Knowledge	14%	83%
Traditional (indigenous) ecological knowledge	9%	85%
Others	50%	47%

Most participants did not undertake sensitivity analyses (60%). Those that did reported testing the effects of planning unit shapes and sizes, grouping different features, adjusting the boundary length modifier, applying a variety of costs, changing species penalty factors, locking features in or out, randomly deleting data, and changing targets and estimates of populations.

Both the selection frequency and the overall best run were the outputs most commonly used (83% and 77%), with fewer respondents using individual runs (27%). Comments suggest that there is a preference for using the selection frequency and overall best output together to complement one another.

A1-3 CONCLUSIONS

Participants listed many strengths and weaknesses of Marxan (Table 5). The most commonly listed strength is the flexibility of Marxan in providing multiple solutions, whereas the most listed weakness is insufficient guidance for adjusting the required settings. Additional responses about which Marxan parameters are not explained well indicates that most survey respondents feel that most parameters could benefit from additional explanation and examples. In particular, responses suggest that a detailed description is needed of how various Marxan parameters interact.

<u>Table A1.5</u>: Strengths and weaknesses of Marxan as expressed by survey participants.

Strengths (n=53)		Weaknesses (n=49)	
Flexibility / variety of options	62%	Insufficient guidance for adjusting settings	43%
Handling of large amounts of data	30%	Errors/bugs	39%
Near-optimal solutions	25%	Preparing the input files	37%
Repeatability/transparency	19%	Steep learning curve	16%
Selection frequencies output	17%	Converting outputs to GIS	14%
Reputation	13%	Interpreting/explaining results	14%
Speed	13%	User interface	12%
Explicit targets	11%	Determining input targets/features	10%
Inclusion of costs	11%	how parameters interact	10%
Systematic approach	11%	Defining cost parameter	8%
Ability to create graphical outputs	9%	Inability to consider multiple zones	8%
Ease of use	9%	Slow with complex/large problems	8%
Objective data analysis	9%	Connectivity	6%
Ability to batch files	8%	Data availability	6%
Ease of post-hoc analysis	8%	Data management	6%
Forces evaluation of data inputs	6%	Limits of planning units, features	6%
Ability to update inputs	4%	Lack of a help tool	4%
Boundary length modifier	4%	Manual	4%
Free tool	4%	Verifying results	4%
Arc interface extensions	2%	Black box	2%
Documentation	2%	Data weighting	2%
Minimum area option	2%	Difficult to batch	2%
User support	2%	Screening out poor solutions	2%

Participants made several recommendations for issues and practicalities that should be addressed in a good practices handbook (Table 6). The most common need was seen to be assistance with setting of all Marxan parameters, including those that some users noted having difficulty with (i.e., that for them resulted in unexplained crashes) such as separation distance.[17]

[17] Editors' note: these widespread concerns related to the setting up and running of Marxan led to the re-writing of the Marxan User Manual, in a joint project between the University of Queensland and PacMARA.

Table A1.6: Suggestions for inclusions in a good practices handbook

Setting Marxan parameters (e.g., SPF, BLM, cost, separation distance)	37%
Setting up input files / tutorial	21%
Communication and interpretation of results	19%
Ensuring robust analyses / explaining inherent biases	16%
Provide practical examples	16%
Undertaking sensitivity analyses and which parameters to test	16%
Addressing data issues (e.g., quality, coverage, management, etc.)	14%
Explanation of settings	14%
Rules of thumb for a starting point for inputs	14%
Determining realistic project goals	9%
Parameter interactions	9%
Using the annealing settings	9%
Why and when to use Marxan	9%
Explanation of errors and troubleshooting steps	7%
Known limits of Marxan (e.g., planning units, features)	7%
Engaging with stakeholders and interest through Marxan	5%
Improving the GUI	5%
Incorporating connectivity and other network design considerations	5%
Incorporating stochasticity and temporal variability	5%
Assessing solution quality	2%
Function and focus of each algorithm	2%
How far from optimal is the best solution?	2%
Improving speed	2%
Incorporating vulnerability	2%

Appendix 2: Literature Cited, References & Resources

Compiled by Falk Huettmann and contributing authors of all chapters

A2-1 LITERATURE CITED

Airame S., Dugan, J.E., Lafferty, K.D., Leslie, H., McArdle, D.A., and Warner, R.R. 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications, 13, S170–S184.

Airame, S. 2005. Channel Islands National Marine Sanctuary: Advancing the Science and Policy of Marine Protected Areas. In Scholz, A.J. and Wright, D. (eds). Place Matters: Geospatial Tools for Marine Science, Conservation, and Management in the Pacific Northwest. Oregon State University Press, Corvallis, 91-124.

Alonso, D., Castillo, P., Segura, C., and Gerhartz, J.L. 2008. Diseño de una red de áreas marinas protegidas: estrategia de conservación para el norte del Caribe continental colombiano. Bol. Invest. Mar. Cost., 37, 129-156.

Anderson, D.R., Cooch, E.G., Gutierrez, R.J., Krebs, C.J., Lindberg, M.S., Pollock, K.H., Ribic, C.A., and Shenck, T.M. 2003. Rigorous science: suggestions on how to raise the bar. Wildlife Society Bulletin, 31, 296-305.

Ando, A., Camm, L., Polasky, S. and Solow, A. 1998. Species distributions, land values and efficient conservation. Science, 279, 2126-2128.

Ardron, J.A, Lash, J., Haggarty, D. 2000. Designing a Network of Marine Protected Areas for the Central Coast of British Columbia. Volume 1: Overview; Volume 2: Data and Classification Details; Volume 3: Analyses and Results. Living Oceans Society, Sointula, BC, Canada.

Ardron, J.A. 2003. BC Coast Information Team Marine Ecosystem Spatial Analysis, v. 1.2. Excerpted and revised from: Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Doyle, F., Ferdana, Z., Hamilton, T., Heinemyer, K., Iachetti, P., Jeo, R., Kaiser, G., Narver, D., Noss, R., Sizemore, D., Tautz, A., Tingey, R., and Vance-Borland, K. An ecosystem analysis for Haida Gwaii, Central Coast, and North Coast British Columbia. Sept. 22, 2003, 184.

Ardron, J.A. 2008. Modelling Marine Protected Areas (MPAs) in British Columbia. Proceedings of the Fourth World Fisheries Congress: Reconciling Fisheries with Conservation. American Fisheries Society.

Ardron, J.A. 2008. The challenge of assessing whether the OSPAR Network of Marine Protected Areas is ecologically coherent. Hydrobiologica, 606:1, 45-53.

Ardron, J.A., Lash, J., Haggarty, D. 2002. Modelling a Network of Marine Protected Areas for the Central Coast of British Columbia. Version 3.1. Living Oceans Society, Sointula, BC, Canada.

Arnstein, S.R. 1969. A ladder of citizen participation. JAIP, 35, 216-224.

Ball, I.R. 2000. Mathematical applications for conservation ecology: the dynamics of tree hollows and the design of nature reserves. PhD Thesis, The University of Adelaide.

Ball, I.R. and Possingham, H.P. 2000. Marxan (V1.8.2): Marine Reserve Design Using Spatially Explicit Annealing, a Manual.

Balmford, A., Gaston, K.J., Blyth, S., James, A., and Kapos, V. 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. Proc. Natl. Acad. Sci. U. S. A., 100, 1046-1050.

Beck, M.W. and Odaya, M. 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico. Aquatic Conservation: Marine and Freshwater Ecosystems, 11, 235–242.

Bedward, M., Pressey, R.L., and Nicholls, A.O. 1991. Scores and score classes for evaluation criteria - A comparison based on the cost of reserving all natural features. Biological Conservation, 56, 281-294.

Brooks, C.P. 2003. A scalar analysis of landscape connectivity. Oikos 102, 433-439.

Brown, K., Adger, N., Tompkins, E., Bacon, P., Shim, D., and Young, K. 2001. Trade-off analysis for MPA management. Ecological Economics, 37, 417-434.

Bruce, E.M. and Eliot, I.G. 2006. A spatial model for marine park zoning. Coastal Management, 34, 17-38.

Cain, S.A. 1938. The Species-Area Curve. American Midland Naturalist, Vol. 19: 3, 573-581.

California Department of Fish and Game. 2005. California Marine Life Protection Act Initiative Draft Master Plan Framework: A Recommendation to the California Fish and Game Commission. California Department of Fish and Game.

Cameron, S.E., Mitchell, D.K., and Williams, K.J. 2008. Efficiency and concordance of alternative methods for minimizing opportunity costs in conservation planning. Conservation Biology, 22 (4), 886-896.

Carroll, C., Noss, R.F., Paquet, P.C., and Schumaker, N.H. 2003. Use of population viability analysis and reserve selection algorithms in regional conservation plans. Ecological Applications, 13, S1773-S1789.

Carwardine, J., Rochester, W.A., Richardson, K.S., Williams, K.J., Pressey, R.L., and Possingham, H.P. 2006. Conservation planning with irreplaceability: Does the method matter? Biodiversity and Conservation, 16 (1), 245-258.

Carwardine, J., Wilson, K., Watts, M., Etter, A., Tremblay-Boyar, L., Hajkowicz, S., and Possingham, H. 2006. Where do we act to get the biggest conservation bang for our buck? A systematic spatial prioritisation approach for Australia. Report to The Department of Environment and Heritage.

Caswell, H. 1989. Matrix Population Models. Sunderland, MA: Sinauer Associates.

CBD. 2008. Report of the Subsidiary Body on Scientific, Technical and Technological Advice, on the work of its thirteenth meeting. Ninth meeting of the Conference of the Parties to the Convention on Biological Diversity, 19-30 May 2008, Bonn, Germany. UNEP/CBD/COP/9/3.

Cerdeira, J.O., Gaston, K.J., and Pinto, L.S. 2005. Connectivity in priority area selection for conservation. Environmental Modeling and Assessment, 10, 183-192.

Chan, A., Cundiff, A., Gardner, N., Hrovat, Y., Kircher, L., and Klein, C. 2006. Marine Protected Areas Along California's Central Coast: A Multicriteria Analysis of Network Design. Page 196. Donald Bren School of Environmental Science and Management. University of California at Santat Barbara, Santa Barbara, CA. Available from http://www.bren.ucsb.edu/research/documents/MLPAThesis041206.pdf

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C. 2006. Conservation Planning for Ecosystem Services. PLoS Biology Vol. 4, No. 11, e379 doi:10.1371/journal.pbio.0040379.

Chen, C. October 2007. Personal communication to D. Fischer, Bren School of Environmental Science and Management, University of California, Santa Barbara.

Chromitz, K. M., Alger, K., Thomas, T. S., Orlando, H. and Vila Nova, P. 2005. Opportunity costs of conservation in a biodiversity hotspot: the case of southern Bahia. Environ. Dev. Econ., 10, 293-312.

Church, R.L. and Gerrard, R.A. 2003. The Multi-Level Location Set Covering Model. Geographical Analysis, 35, 277-290.

Clark, B.M. and Lombard, A.T. 2007. A marine conservation plan for the agulhas bioregion: options and opportunities for enhancing the exisitng MPA network. Anchor Environmental Consultants CC, Rhodes Gift.

CLF, WWF. 2006. Marine Ecosystem Conservation for New England and Maritime Canada: a science based approach to identifying priority areas for conservation.

Cocks, K.D. and Baird, I.A. 1989. Using mathematical programming to address the multiple reserve selection problem: an example from the Eyre Peninsula, South Australia. Biological Conservation, 49, 113–30.

Cohon, J.L., Church, R.L. and Sheer, D.P. 1979. Generating multiobjective trade-offs: an algorithm for bicriterion problems. Water Resources Research, 15, 1001-1010.

Costello, C. and Polasky, S. 2004. Dynamic reserve site selection. Res. Energy Econ., 26, 157-174.

Cowen, R.K., Lwiza, K.M.M., Sponaugle, S., Paris, C.B., and Olson, D.B. 2000. Connectivity of marine populations: Open or closed? Science, 287, 857-859.

Cowen, R.K., Paris, C.B., and Srinivasan, A. 2006. "Scaling of connectivity in marine populations." Science, 311.5760, 522-27.

Cowling, R.M., Pressey, R.L., Lombard, A.T., Desmet P.G. and Ellis, A.G. 1999. From representation to persistence: requirements for a sustainable system of conservation areas in the species-rich Mediterranean-climate desert of southern Africa. Diversity and Distributions, 5, 51-71.

Cowling, R.M., Pressey, R.L., Sims-Castley, R., le Roux, A., Baard, E., Burgers, C.J., and Palmer, G. 2003. The expert or the algorithm? - comparison of priority conservation areas in the Cape Floristic Region identified by park managers and reserve selection software. Biological Conservation, 112, 147-167.

Davey, A.G. 1998. National system Planning for Protected Areas. Gland, Switzerland: IUCN – World Conservation Union.

Department of Conservation and Ministry of Fisheries (New Zealand). 2005. Marine Protected Areas: Policy and Implementation Plan. Wellington, New Zealand.

Desmet, P. and Cowling, R. 2004. Using the species–area relationship to set baseline targets for conservation. Ecology and Society, 9(2), 11. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art11/

Evans, S.M.J., Jamieson, G.S., Ardron, J., Patterson, M., and Jessen, S. 2004. Evaluation of Site Selection Methodologies for Use in Marine Protected Area network design. Report prepared for the Pacific Scientific Advice Review Committee, Fisheries and Oceans Canada.

Faith, D.P. and Walker, P.A. 1996. Integrating conservation and development: Effective trade-offs between biodiversity and cost in the selection of protected areas. Biodiversity and Conservation, 5, 431-446.

Ferdaña, Z. 2005. Nearshore marine conservation planning in the Pacific Northwest: Exploring the use of a siting algorithm for representing marine biodiversity. In: Wright, Scholz, A.J. (eds). Place matters: geospatial tools for marine science, conservation, and management in the pacific northwest. OSU Press, Corvallis, 150-195

Fernandes, L., Day, J., Lewis, A., Slegers, S., Kerrigan, B., Breen, D., Cameron, D., Jago, B., Hall, J., Lowe, D., Innes, J., Tanzer, J., Chadwick, V., Thompson, L., Gorman, K., Simmons, M., Barnett, B., Sampson, K., De'ath, G., Mapstone, B., Marsh, H., Possingham, H., Ball, I., Ward, T., Dobbs, K., Aumend, J., Slater, D., and Stapleton, K. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conservation Biology, 19 (6).

Ferrar, A.A., and Lőtter, M.C. 2007. Mpumalanga Biodiversity Conservation Plan Handbook. Mpumalanga Tourism & Parks Agency, Nelspruit, South Africa.

Ferrier S., Pressey, R.L. and Barrett, T.W. 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biological Conservation, 93, 303-325.

Fischer, D.T. and Church, R.L. 2003. Clustering and compactness in reserve site selection: An extension of the Biodiversity management area selection model. Forest Science, 49, 555-564.

Fischer, D.T. and Church, R.L. 2005. The SITES reserve selection system: A critical review. Environmental Modeling and Assessment, 10, 215-228.

Frazee, S.R., Cowling, R.M., Pressey, R.L., Turpie, J.K. and Lindenberg, N. 2003. Estimating the costs of conserving a biodiversity hotspot: a case-study of the Cape Floristic Region, South Africa. Biological Conservation 112, 275-290.

Geselbracht, L., Torres, R., Cumming, G.S., Dorfman, D., and Beck, M. 2005. Marine/Estuarine Site Assessment for Florida: A Framework for Site Prioritization. Final Report for Florida's Wildlife Legacy Initiative, a program of the Florida Fish and Wildlife Conservation Commission.

Groves, C.R., Jensen, D.B., Valutis, L.L., Redford, K.H., Shaffer, M.L., Scott, J.M., Baumgartner, J.V, Higgins, J.V., Beck, M.W., and Anderson, M.G. 2002. Planning for Biodiversity Conservation: Putting Conservation Science into Practice. BioScience, 52, 499-512.

Groves, D.R. 2003. Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity. Washington, Covelo, London, Island Press.

Hajkowicz, S.A. and Young, M.D. (eds). 2002. Value of returns and costs of resource degradation. Report to National Land and Water Resources Audit, CSIRO, Canberra.

Hajkowicz, S.A., Perraud, J.M., Dawes, W. and DeRose, R. 2005. The strategic landscape investment model: a tool for mapping optimal environmental expenditure. Environ. Model. Software 20, 1251-1262.

Halidina, H., Gerhartz, J.L., Areces, A., and Durhuit, R. 2004 unpublished. "Diseño de una red representativa de áreas marinas protegidas en Cuba" Informe Técnico. Centro Nacional de Áreas Protegidas de Cuba. 1-25.

Halpern, B.S. and Warner, R.R. 2003. Matching marine reserve design to reserve objectives. Proceedings of The Royal Society, London. 270, 1871-1878.

Helvey, M. 2004a. Seeking Consensus on Designing MPAs: Keeping the Fishing Community Engaged. Coastal Management, 32, 173-190.

Huettmann, F. 2005. Databases and science-based management in the context of wildlife and habitat: towards a certified ISO standard for objective decision-making for the global community by using the internet. Journal of Wildlife Management, 69(20), 466-472.

Huettmann, F. 2007a. The digital teaching legacy of the International Polar Year (IPY): Details of a present to the global village for achieving sustainability. In Tjoa, M., Wagner, R.R. (eds). Proceedings 18th International Workshop on Database and Expert Systems Applications (DEXA) 3-7 September 2007, Regensburg, Germany. IEEE Computer Society, Los Alamitos, 673-677.

Huettmann, F. 2007b. Constraints, suggested solutions and an outlook towards a new digital culture for the oceans and beyond: experiences from five predictive GIS models that contribute to global management, conservation and study of marine wildlife and habitat. In Vanden Berghe E, Appeltans W, Costello MJ, Pissierssens P (eds) Proceedings of 'Ocean Biodiversity Informatics': an international conference on marine biodiversity data management Hamburg, Germany, 29 November – 1 December, 2004. IOC Workshop Report, 202, VLIZ Special Publication 37, 49-61.

Johnson, M.P., Crowe, T.P., McAllen, R., and Allcock, A.L. 2008. Characterizing the marine Natura 2000 network for the Atlantic region. Aquatic Conservation: marine and freshwater ecosystems. 18, 86-97.

Justus, J., and Sarkar, S. 2002. The principle of complementarity in the design of reserve networks to conserve biodiversity: a preliminary history. Journal of Biosciences, 27, 421-435.

Kessler, B. 2004. Stakeholder Participation: A Synthesis of Current Literature. National Oceanic and Atmospheric Administration and National Marine Protected Areas Center, Silver Spring, MD.

Kirkpatrick, S., Gelatt, C.D., and Vecchi, M.P. 1983. Optimization by Simulated Annealing, Science 220(4598), 671-680. http://citeseer.ist.psu.edu/kirkpatrick83optimization.html

Klein, C., Chan, A., Kircher, L., Cundiff, A., Hrovat, Y., Gardner, N., Scholz, A., Kendall, B., and Airame, S. 2008. Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. Conservation Biology, DOI: 10.1111/j.1523-1739.2008.00896.x.

Klein, C., Wilson, K.A., Watts, M., Stein, J., Berry, S., Carwardine, J., Stafford Smith, D.M., Mackey, B., and Possingham, H. 2009. Incorporating ecological and evolutionary processes into continental-scale conservation planning. Ecological Applications, 19(1), 206–217.

Leis, J.M. 2002. Pacific coral-reef fishes: the implications of behaviour and ecology of larvae for biodiversity and conservation, and a reassessment of the open population paradigm. Environmental Biology of Fishes, 65.2, 199-208.

Leslie, H., Ruckelshaus, M., Ball, I.R., Andelman, S., and Possingham, H.P. 2003. Using siting algorithms in the design of marine reserve networks. Ecological Applications, 13, S185-S198.

Leslie, H.M. 2005. A synthesis of marine conservation planning approaches. Conservation Biology, 19(6), 1701-1713.

Lewis, A., Slegers, S., Lowe, D., Muller, L., Fernandes, L., and Day, J. 2003. Use of Spatial Analysis and GIS techniques to Re-Zone the Great Barrier Reef Marine Park. Coastal GIS Workshop, July 7-8 2003, University of Wollongong, Australia.

Lieberknecht, L.M., Carwardine, J., Connor, D., Vincent, M.A., Atkins, S.M., and Lumb, C.M. 2004. The Irish Sea Pilot - Report on the identification of nationally important marine areas in the Irish Sea. Joint Nature Conservation Committee, Peterborough, UK (http://www.jncc.gov.uk/page-1621).

Lien, J. 1999. When Marine Conservation Efforts Sink: What can be Learned from the Abandoned Effort to Examine the Feasibility of a National Marine Conservation Area on the NE Coast of Newfoundland. Canadian Council on Ecological Areas, Ottawa.

Loos, S. 2006. Exploration of Marxan for Utility in Marine Protected Area Zoning. MSc Thesis – University of Victoria (Geography).

Mace, G.M., Possingham, H.P., and Leader-Williams, N. 2006. Prioritizing choices in conservation. In McDonald, D.W. and Service, K. (eds). Key Topics in Conservation Biology. Blackwell Publishing, Malden, MA USA, 17-34.

Margules, C.R. 1989. Introduction to Some Australian Developments in Conservation Evaluation. Biological Conservation, 50, 1-11.

Margules, C.R. and Pressey, R.L. 2000. Systematic Conservation Planning. Nature, 405, 243-253.

Margules, C.R., and Sarkar, S. 2007. Systematic Conservation Planning. Cambridge University Press, New York.

McDonnell, M.D., Possingham, H.P., Ball, I.R. and Cousins, E.A. 2002. Mathematical Methods for Spatially Cohesive Reserve Design. Environmental Modeling and Assessment, 7, 107-114.

Morin, T. 2001. Sanctuary Advisory Councils: Involving the public in the National Marine Sanctuary Program. Coastal Management, 29, 327-339.

Munro, K.G. 2006. Evaluating Marxan as a Terrestrial Conservation Planning Tool. MA Thesis. University of British Columbia. School of Community and Regional Planning.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H., and Rouget, M. 2006. Integrating economic costs into conservation planning. Trends in Ecology & Evolution, 21, 682-687.

NOAA Coastal Services Center, in cooperation with the National Marine Protected Areas Center. 2003. Marine Protected Areas Needs Assessment, Final Report. Charleston, SC, NOAA Coastal Services Center.

Noss, R. 2003. A checklist for wildlands network designs. Conservation Biology 17(5), 1-7.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology, 4, 355-364.

Noss, R.F., and Cooperrider, A.Y. 1994. Saving Nature's Legacy: Protecting and Restoring Biodiverity. Washington, DC, Island Press.

Noss, R.F., Carroll, C., Vance-Borland, K., and Wuerthner, G. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. Conservation Biology, 16, 895-908.

Oetting, J. and Knight, A. 2003. F-TRAC: Florida Forever Tool for Efficient resource Acquisition and Conservation. Model Documentation and Project Evaluation. Florida Natural Areas Inventory, Florida.

Oetting, J.B., Knight, A.L., and Knight, G.R. 2006. Systematic reserve design as a dynamic process: F-TRAC and the Florida Forever program. Biological Conservation, 128, 37-46.

OSPAR. 2007. Background document to support the Assessment of whether the OSPAR Network of Marine Protected Areas is Ecologically Coherent. OSPAR Convention for the Protection of the Marine environment of the Northeast Atlantic. Biodiversity Series, Publication Number: 2007/320. www.ospar.org.

Pattison, D., dosReis, D., and Smilie, H. 2004. An Inventory of GIS-Based Decision-Support Tools for MPAs. Prepared by the National Marine Protected Areas Center in cooperation with the national oceanic and Atmospheric Administration Coastal services Center.

Pence, G.Q.K. 2008. C.A.P.E. Fine-Scale Biodiversity Assessment Technical Report. Prepared for CapeNature. Cape Town, South Africa.

Poiani, K.A., Richter, B.C., Anderson, M.G., and Richter, H.E. 2000. Biodiversity Conservation at Multiple Scales: Functional Sites, Landscapes, and Networks. BioScience, 50, 133-146.

Polasky, S., Camm, J. D. and Garber-Yonts, B. 2001. Selecting biological reserves cost effectively: an application to terrestrial vertebrate conservation in Oregon. Land Econ. 77, 68-78.

Possingham, H., Day, J., Goldfinch, M., and Salzborn, F. 1993. The mathematics of designing a network of protected areas for conservation. In Sutton, D., Cousins, E., and Pierce, C. (eds). Decision sciences, tools for today. Proceedings of the 12th Australian Operations Research Conference. Adelaide, Australia: Australian Society for Operations Research, 536–545.

Possingham, H.P., Ball, I.R. and Andelman, S. 2000. Mathematical Methods for Identifying Representative Reserve Networks. In Ferson, S., and Burgman, M. (eds). Quantitative Methods for Conservation Biology. Springer-Verlag, New York, 291-305.

Possingham, H.P., Franklin, J., Wilson, K., and Regan, T.J. 2005. The roles of spatial heterogeneity and ecological processes in conservation planning. In Lovett, G.M., Jones, C.G., Turner, M.G., and Weathers, K.C. (eds). Ecosystem Function in Heterogeneous Landscapes. Springer-Verlag, New York, 389-406.

Possingham, H.P., Wilson, K.A., Andelman, S.J. and Vynne, C.H. 2006. Protected areas: goals, limitations, and design. In Groom, M.J., Meffe, G.K., and Carroll, C.R. (eds). Principles of Conservation Biology. Sinauer Associates Inc., Sundaland, MA, 509-533.

Post, A.L., Wassenberg, T., and Passlow, V. 2006. Physical surrogates for macrofaunal distributions and abundance in a tropical gulf. Marine and Freshwater Research, 57, 469-483.

Pressey R.L., Johnson I.R. & Wilson P.D. (1994) Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiversity and Conservation, 3, 242-262

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., and Williams P.H. 1993. Beyond Opportunism: Key Principles for Systematic Reserve Selection. TREE, 8(4) 124-128.

Pressey, R.L. 1994. Ad Hoc Reservations: Forward or Backward Steps in Developing Representative Reserve Systems? Conservation Biology, 8, 662-668.

Pressey, R.L. 2005. Short Course on Systematic Conservation Planning - Concepts and Case Studies. Presentation during Society for Conservation Biology annual General Meeting, Brasilia, Brazil.

Pressey, R.L., and Cowling, R.M. 2001. Reserve selection algorithms and the real world. Conservation Biology, 15, 275-277.

Pressey, R.L., Cabeza, M., Watts, M.E., Cowling, R.M., and Wilson, K.A. 2007. Conservation planning in a changing world. Trends in Ecology & Evolution, 22, 583-592.

Pressey, R.L., Cowling, R.M. and Rouget, M. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation, 112, 99-127.

Pressey, R.L., Johnson, I.R., and Wilson, P.D. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiversity and Conservation, 3(3), 242-262.

Pressey, R.L. and Logan, V.S. 1998. Size of selection units for future reserves and its influence on actual vs. targeted representation of features: a case study in Western New south Wales. Biological Conservation, 85, 305-319.

Pressey, R.L., Possingham, H.P., and Margules, C.R. 1996. Optimality in reserve selection algorithms: When does it matter and how much. Biological Conservation, 96, 259-267.

Pressey, R.L., Whish, G.L., Barrett, T.W. and Watts, M.E. 2002. Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. Biological Conservation, 106, 57-69.

Pressey. R.L. 1999. Editorial – systematic conservation planning for the real world. Parks 9, 1.

Pryce, B., Iachetti, P., Wilhere, G., Ciruna, K., Floberg, J., Crawford, R., Dye, R., Fairbarns, M., Farone, S., Ford, S., Goering, M., Heiner, M., Kittel, G., Lewis, J., Nicolson, D., and Warner, N. 2006. Okanagan Ecoregional Assessment, Volume 2 – Appendices. Prepared by Nature Conservancy of Canada, The Nature Conservancy of Washington, and the Washington Department of Fish and Wildlife with support from the British Columbia Conservation Data Centre, Washington Department of Natural Resources Natural Heritage Program, and NatureServe. Nature Conservancy of Canada, Victoria, British Columbia.

Pyke, C.R. and Fischer, D.T. 2005. Selection of bioclimatically representative biological reserve systems under climate change. Biological Conservation, 121: 429-441.

Pyke, C.R., Andelman, S.J., and Midgley, G. 2005. Identifying priority areas for bioclimatic representation under climate change: a case study for Proteaceae in the Cape Floristic Region, South Africa. Biological Conservation, 125, 1-9.

Ramey, P.A. and Snelgrove, P.V.R. 2003. Spatial patterns in sedimentary macrofaunal communities on the south coast of Newfoundland in relation to surface oceanography and sediment characteristics. Marine Ecology Progress Series, 262, 215-227.

Ramírez de Arellano, P.I. 2007. Systematic conservation planning in Chile: Sensitivity of reserve selection procedures to target choices, cost surface, and spatial scale. PhD Thesis. College of Environmental Science and Forestry. State University of New York, 133.

Richardson, E., Kaiser, M., Edwards-Jones, G., and Possingham, H. 2006. Sensitivity of marine-reserve design to the spatial resolution of socioeconomic data. Conservation Biology, 20, 1191-1202.

Rodrigues, A.S.L. and Brooks, T.M. 2007. Shortcuts for Biodiversity Conservation Planning: The Effectiveness of Surrogates. Annual Review of Ecology, Evolution, and Systematics, 38, 717-737.

Roff, J.C., Taylor, M.E., and Laughren, J. 2003. Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities. Aquatic Conservation: Marine and Freshwater Ecosystems, 13, 77-90.

Rondinini, C., Stuart, S., and Boitani, L. 2005. Habitat Suitability Models and the Shortfall in Conservation Planning for African Vertebrates. Conservation Biology, 19, 1488-1497.

Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Ferdaña, Z., Hamilton, T., Heinemeyer, K., Iachetti, P., Jeo, R., Kaiser, G., Narver, D., Noss, R., Sizemore, D., Tautz, A., Tingey, R., and Vance-Borland, K. 2004. An Ecosystem Spatial Analysis for Haida Gwaii, Central Coast, and North Coast BC. Report prepared for the Coast Ecosystem Team (available at www.citbc.org).

Sala, E., Aburto-Oropeza, O., Paredes, G., Parra, I., Barrera, J.C., and Dayton, P.K. 2002. A General Model for Designing Networks of Marine Reserves. Science, 1991-1993.

Sarkar, S., Moffett, A. Sierra, R., Fuller, T., Cameron, S., and Garson, J. 2004. Incorporating Multiple Criteria into the Design of Conservation Area Networks. Endangered Species Update, 21, 100-107.

Sarkar, S., Pressey, R. L., Faith, D. P., Margules, C. R., Fuller, T., Stoms, D. M., Moffett, A., Wilson, K. A., Williams, K. J., Williams, P. H. and Andelman, S. 2006 Biodiversity conservation planning tools: Present status and challenges for the future. Annual Review of Environment and Resources, 31, 123-159.

Scheiner, S.M. 2003. Six types of species-area curves. Global Ecology and Biogeography, 12 (6), 441–447.

Scholz, A., Bonzon, K., Fujita, R., Benjamin, N., Woodling, N., Black, P., and Steinback, C. 2004. Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. Marine Policy, 28, 335-349.

Simberloff, D. 1998. Flagships, umbrellas and keystones: is single species management passe in the landscape era? Biological Conservation, 83, 247-257.

Smith, J.L., Lewis, K., and Laughren, J. 2006. A Policy and Planning Frameowrk for Marine Protected Area Networks in Canada's Oceans. WWF-Canada, Halifax, 105.

Smith, P.G.R., and Theberge, J.B. 1986. A review of criteria for evaluating natural areas. Environmental Management, 10, 715–34.

Solanki, R.S., Appino, P.A. and Cohon, J.L. 1993. Approximating the noninferior set in multiobjective linear programming problems. European journal of operational research, 68, 356-373.

Soulé, M., and Noss, R.F. 1998. Rewilding and Biodiversity: Complementary Goals for Continental Conservation. Wild Earth Fall, 18-28.

Soulé, M., and Terborgh, J. (eds). 1999. Continental conservation: scientific foundations of regional reserve networks. Wathington DC, Island Press.

Stewart, R.R., and Possingham, H.P. 2005. Efficiency, costs and trade-offs in marine reserve system design. Environmental Modeling and Assessment, 10, 203-213.

Stewart, R.R., Noyce, T., and Possingham, H.P. 2003. Opportunity cost of ad hoc marine reserve design decisions: an example from South Australia. Marine Ecology Progress Series 253, 25-38.

Stewart, R.R. and Possingham, H.P. 2003. A framework for systematic marine reserve design in South Australia: A case study. Proceedings of the Inaugural World Congress on Aquatic Protected Areas, Cairns - August 2002.

Stoms, D.M. 1994. Scale-Dependence of Species Richness Maps. The Professional Geographer, 46, 346-358

Swearer, S.E., Caselle, J.E., Lea, D.W., and Warner, R.R. 1999. Larval retention and recruitment in an island population of a coral-reef fish. Nature, 402, 799-802.

Tallis, H., Ferdaña, Z,. and Gray, E. 2008. Linking Terrestrial and Marine Conservation Planning and Threats Analysis. Conservation Biology, 22, 1, 120-130 (11).

Taylor, P.D., Fahrig, L., Henein, K., and Merriam, G. 1993. Connectivity is a vital element of landscape structure. Oikos, 68, 571-573.

Tear, H.T., Kareiva, P., Angermeier, P.L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshaus, J., Scott, J.M., and Wilhere, G. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. BioScience 55, 10.

Tjørve, E. 2003. Shapes and functions of species-area curves: a review of possible models. Journal of Biogeography, 30 (6), 827–835.

United States Environmental Protection Agency (USEPA), Western Ecology Division. 2004. Program to Assist in Tracking Critical Habitat (PATCH). Available from www.epa.gov/wed/pages/models/patch/patchmain.htm (Accessed September 2004).

Vane-Wright, R. I., C. J. Humphries, and Williams. P.H. 1991. What to Protect? Systematics and the agony of choice. Biological Conservation, 55, 235-254.

Walters, C., Pauly, D., and Christensen, V. 1999. Ecospace: Prediction of mesoscale spatial pattern in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems, 2, 539-554.

Warwick, R.M. and Clarke, K.R. 2001. Practical measures of marine biodiversity based on relatedness of species. Oceanography and Marine Biology Annual Review, 39, 207-231.

WCPA/IUCN. 2007. Establishing networks of protected areas: A guide for developing national and regional capacity for building MPA networks. Non-technical summary report.

Wells, S., and White, A.T. 1995. Involving the community in S. Gubbay, editor. Marine Protected Areas: Principles and Techniques for Management. Chapman & Hall, London.

Williams, J.C., ReVelle, C.S. and Levin, S.A. 2005. Spatial attributes and reserve design: A review. Environmental Modeling & Assessment.

Williams, J.C., ReVelle, C.S. and Levin, S.A. 2004. Using mathematical optimization models to design nature reserves. Frontiers in Ecology and the Environment, 2(2), 98-105.

Wilson, K.A., McBride, M., Bode, M. and Possingham, H.P. 2006. Prioritising global conservation efforts. Nature, 40, 337-340.

A2-2 Other Related References

Araújo, M.B. 2004. Matching species with reserves - uncertainties from using data at different resolutions. Biological Conservation, 118, 533-538.

Armsworth P.R., Daily, G.C., Kareiva, P., and Sanchirico, J.N. 2006. Land market feedbacks can undermine biodiversity conservation. PNAS 103, 5403-5408.

Balmford, A., Gaston, K.J., Rodrigues, A.S.L., and James, A. 2000. Integrating costs of conservation into international priority setting. Conservation Biology, 14, 1-9.

Burgman, M.A., Possingham, H.P., Lynch, A.J.J., Keith, D.A., McCarthy, M.A., Hopper, S.D., Drury, W.L., Passioura, J.A., Devries, R.J. 2001. A method for setting the size of plant conservation target areas. Conservation Biology, 15, 603-616.

Cabeza, M. and Moilanen, A. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution, 16, 242-248.

Camm, J.D., Polasky, S., Solow, A., and Csuti, B. 1996. A note on optimal algorithms to reserve selection. Biological Conservation, 78, 353-355.

Church, R.L., Stoms, D.M., and Davis, F.W. 1996. Reserve selection as a maximal covering location problem, Biological Conservation, 76, 105-112.

ConserveOnline focusing on stakeholder engagement in the Nature Conservancy's Conservation by Design process with a broad selection of relevant links and an extensive reference section - http://conserveonline.org/workspaces/cbdgateway/era/standards/std_2

Cook, R. and Auster, P.J. 2006. Developing Alternatives for Optimal Representation of Seafloor Habitats and Associated Communities in Stellwagen Bank National Marine Sanctuary. U.S. Dept of Commerce, Office of National Marine Sanctuaries. Marine Conservation Series ONMS-06-02.

Cook, R.R. and Auster, P.J. 2005. Use of Simulated Annealing for Identifying Essential Fish Habitat in a Multispecies Context. Conservation Biology, 19, 876-886.

Cowling, R.M. and Pressey, R.L. 2003. Introduction to systematic conservation planning in the Cape Floristic Region. Biological Conservation, 112, 1-13.

Cowling, R.M. et al. 2003. A conservation plan for a global biodiversity hotspot - the Cape Floristic Region, South Africa. Biological Conservation, 112, 191-216.

Cowling, R.M., Knight, A.T., Faith, D.P., Ferrier, S., Lombard, A.T., Driver, A., Rouget, M., Maze, K., and Desmet, P.G. 2004. Nature conservation requires more than a passion for species. Conservation Biology, 18, 1674-1676.

Csuti, B., Polasky, S., Williams,.P.H., Pressey, R.L., Camm, J.D., Kershaw, M., Kiester, A.R., Downs, B., Hamilton, R., Huso, M., and Sahr, K. 1997. A Comparison of Reserve Selection Algorithms Using Data on terrestrial vertebrates in Oregon. Biological Conservation, 80, 83- 97.

Erasmus, B.F.N., Freitag, S., Gaston, K.J., Erasmus, B.H., and van Jaarsveld, A.S. 1999. Scale and conservation planning in the real world. Proceedings of the Royal Society of London Series B-Biological Sciences, 266, 315-319.

Ferrier, S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: Where to from here? Systematic Biology 51, 331-363.

Ferrier, S. et al. 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. I. Species-level modelling Biodiversity and Conservation, 11, 2275-2307.

Ferrier, S. et al. 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. II. Community-level modeling. Biodiversity and Conservation, 11, 2309-2338.

Gonzales, E.K, Arcese, P., Schulz, R., and Bunnel, F. 2003. Strategic reserve design in the central coast of British Columbia; integrating ecological and industrial goals. Can J For Res 33, 2129-2140.

Higgins, J.V., Bryer, M.T., Khoury, M.L., Fitzhugh, T.W. 2005. A freshwater classification approach for biodiversity conservation planning Conservation Biology, 19, 432-445.

Kirkpatrick, J.B. 1983. An Iterative Method for Establishing Priorities for Selection of Nature Reserves: An Example From Tasmania, Biological Conservation, 25, 127-134.

Kirkpatrick, J.B. and Brown, M.J. 1994. A comparison of direct and environmental domain approaches to planning reservation of forest higher plant communities in Tasmania. Conservation Biology 8, 217-224.

Knight, A.T., Cowling, R.M., and Campbell, B.M. 2006. An operational model for implementing conservation action. Conservation Biology, 20, 408-419.

Lombard, A.T., Cowling, R.M., Pressey, R.L., and Rebelo, A.G. 2003. Effectiveness of land classes as surrogates for species in conservation planning for the Cape Floristic Region. Biological Conservation, 112, 45-62.

McDonald, R., McKnight, M., Weiss, D., Selig, E., O'Connor, M., Violin, C., and Moody, A. 2005. Species compositional similarity and ecoregions: Do ecoregion boundaries represent zones of high species turnover? Biological Conservation, 126, 24-40.

Meir, E., Andelman, S., and Possingham, H.P. 2004. Does conservation planning matter in a dynamic and uncertain world? Ecology Letters, 7, 615-622.

Naidoo, R. and Adamowicz, W.L. 2006. Modeling Opportunity Costs of Conservation in Transitional Landscapes. Conservation Biology, 20, 490-500.

Nicholls, A.O. and Margules, C.R. 1993. An Upgraded Reserve Selection Algorithm, Biological Conservation, 64, 165-169.

Nicholson, E. and Possingham, H.P. 2006. Objectives for multiple species conservation planning. Conservation Biology, 20, 871-881.

Noss, R.F. 2004. Conservation targets and information needs for regional conservation planning. Natural Areas Journal, 24, 223-231.

Oenal, H. and Briers, R.A. 2005. Designing a conservation reserve network with minimum fragmentation: A linear integer approach. Env Model and Assess, 10, 193-202.

Pierce, S.M., Cowling, R.M., Knight, A.T., Lombard, A.T., Rouget, M., and Wolf, T. 2005. Systematic conservation planning products for land-use planning: interpretation for implementation Biological Conservation, 125, 441-458.

Possingham, H.P., Ball, I.R., and Andelman, S. 2000. Mathematical methods for identifying representative reserve networks. In: Ferson, S. and Burgman, M. (eds). Quantitative methods for conservation biology. Springer-Verlag, New York, 291-305.

Possingham, H.P., Day, J.R., Goldfinch, M., and Salzborn, F. 1993. The mathematics of designing a network of protected areas for conservation. In: Sutton, D.J., Pearce, C.E.M., and Cousins, E.A. (eds). Decision Sciences: Tools for Today. Proceedings of 12th National ASOR Conference. ASOR, Adelaide, 536-545.

Pressey, L., Possingham, H., Margueles, C.R. 1996. Optimality in Reserve Selection algorithms: When does it matter and how much? Biological Conservation, 259-267.

Pressey, R.L. 2002. The first reserve selection algorithm Progress in Physical Geography, 26, 434-441.

Pressey, R.L. 2004. Conservation planning and biodiversity: Assembling the best data for the job. Conservation Biology, 18, 1677-1681.

Pressey, R.L. and Taffs, K.H. 2001. Scheduling conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. Biological Conservation, 100, 355-376.

Pressey, R.L., Cabeza, M., Watts, M.E., Cowling, R.M., and Wilson, K.A. 2007. Conservation planning in a changing world. Trends in Ecology & Evolution, 22(11), 583-92.

Pressey, R.L. and Logan, V.S. 1994. Level of geographical subdivision and its effects on assessments of reserve coverage: a review of regional studies. Conservation Biology, 8, 1037-1046.

Pressey, R.L., Possingham, P.H., and Day, R.J. 1997. Effectiveness of Alternative Heuristic Algorithms for Identifying Indicative Minimum Requirements for Conservation Reserves. Biological Conservation, 80, 207-219.

Pressey, R.L., Watts, M.E., and Barret, T.W. 2004. Is maximizing protection the same as minimizing loss? Efficiency and retention as alternative measures of the effectiveness of proposed reserves. Ecology Letters, 7, 1035-1046.

Pressey, R.L., Whish, G.L., Barrett, T.W., and Watts, M.E. 2002. Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. Biological Conservation, 106, 57-69.

Rebelo, A.G. and Siegfried, W.R. 1992. Where Should Nature Reserves be Located in the Cape Floristic Region, South Africa? Models for the Spatial Configuration of a Reserve Network Aimed at Maximizing the Protection of Floral Diversity. Conservation Biology, 6, 243-252

Rodriguez, A.S.L. and Gaston, K.J. 2002. Optimisation in reserve selection procedures – why not? Biological Conservation, 107, 123-129.

Rondinini C. et al. 2006. Tradeoffs of different types of species occurrence data for use in systematic conservation planning. Ecology Letters, 9, 1136-1145.

Sarkar, S., Justus, J., Fuller, R., Kelley, C., Garson, J., and Mayfield, M. 2005. Effectiveness of environmental surrogates for the selection of conservation area networks. Conservation Biology, 19, 815-825.

Smith, R., Goodman, P., and Matthews, W. 2006. Systematic conservation planning: a review of perceived limitations and an illustration of the benefits using a case study from Maputaland, South Africa. Oryx, 40, 400-410.

Stewart, R.R. 2003. Opportunity cost of ad hoc marine reserve design decisions: an example from South Australia. Marine Ecology Progress Series, 253, 25-38

The Nature Conservancy 2000. Stakeholders Analysis Exercise - A quick process for identifying stakeholders and developing community outreach strategies. Arlington, VA: Home Office Government Relations Department, The Nature Conservancy. Available at: http://conserveonline.org/workspaces/ecotools/Std2materials/StakeholderAnalysisExercise.pdf

Turner, W.R, Wilcove, D.S. 2006. Adaptive Decision Rules for the Acquisition of Nature Reserves. Conservation Biology, 20, 527-537.

Underhill, L.G. 1994. Optimal and suboptimal reserve selection algorithms, Biological Conservation, 70, 85-87.

Vanderkam, R.P.D., Wiersma, Y.F., and King, D.J. In review. Heuristic Algorithms vs. Linear Programs for Designing Efficient Conservation Reserve Networks: Evaluation of Solution Optimality and Processing Time. Conservation Biology.

Warman, L.D., Sinclair, A.R.E., Scudder, G.G.E., Klinkenberg, B., and Pressey, R.L. 2004. Sensitivity of Systematic Reserve Selection to Decisions about Scale, Biological Data, and Targets: Case Study from Southern British Columbia. Conservation Biology, 18, 655-666.

Wilson, K.A., Newton, A.N., Echeverría, C., Weston, C.J., and Burgman, M.A. 2005. A vulnerability analysis of the temperate forests of south central Chile. Biological Conservation, 122, 9-21.

Wilson, K.A., Pressey, R.L., Newton, A.N., Burgman, M.A., Possingham, H.P., and Weston, C.J. 2005. Measuring and incorporating vulnerability into conservation planning Environmental Management 35, 527-543.

Wilson, K.A., Westphal, M.I., Possingham, H.P., and Elith, J. 2005. Sensitivity of conservation planning to different approaches to using predicted species distribution data. Biological Conservation, 122, 99-112.

Winter, S.J., Esler, K.J., and Kidd, M. 2005. An index to measure the conservation attitudes of landowners towards Overberg Coastal Renosterveld, a critically endangered vegetation type in the Cape Floral Kingdom, South Africa. Biological Conservation, 126, 383-394.

Zacharias, M.A. and Roff, J.C. 2000. A hierarchiacal ecological approach to conserving marine biodiversity. Conservation Biology, 14, 1327-1334.

Zacharias, M.A. and Roff, J.C. 2001. Use of focal species in marine conservation and management: a review and critique. Aquatic Conservation: Marine and Freshwater Ecosystems, 11, 59-76.

A2-3 Some Online Resources

Marxan main page, including links to software download and training

http://www.uq.edu.au/marxan/

Marxan User Manual and wiki (alternative site to above, PacMARA)

http://www.pacmara.org/

CLUZ software download

http://www.mosaic-conservation.org/cluz/

- CLUZ software, Arcview support for Marxan (accessed 31 October 2007)

PANDA software download

http://www.mappamondogis.it/panda_en.htm

- PANDA software, ArcGIS support for Marxan (accessed 31 October 2007)

Sites software download

http://www.biogeog.ucsb.edu/projects/tnc/toolbox.html

- TNC Sites software, GIS (accessed 31 October 2007)

The Nature Conservancy ArcGIS 9.1 extension, Protected Area Gap Decision Support Tool:

http://conserveonline.org/workspaces/macr.gis/Protected_Area_Gap_DSS_Nov06.zip/view

(accessed 20 January 2008)

C-Plan software download

http://www.uq.edu.au/~uqmwatts/cplan.html

- C-Plan, also a site selection software, and provides file linkage with Marxan (accessed 31 October 2007)

Other site selection and related tools can be found on the EBM Tools Network

http://www.ebmtools.org/

(accessed 20 January 2008)

Appendix 3: Glossary

Algorithm: A mathematical process that systematically solves a problem using well-defined rules or processes. Marxan can use several optimisation algorithms (exact algorithm, heuristic algorithm, simulated annealing and iterative improvement) to identify reserve design solutions for a minimum cost, subject to the constraint that stated objectives are achieved.

Boundary cost: Also referred to as boundary length. A boundary cost is specified between two planning units. When one of the two planning units is included in the reserve system, the boundary cost is a relative measure of the importance of also including the other planning unit, and vice versa. Although the relationship between two planning units is typically the length of the shared boundary, boundary costs can also be specified between non-adjacent planning units reflecting ecological or economic factors.

Boundary Length Modifier (BLM): A variable controlling how much emphasis to place on minimising the overall reserve system boundary length relative to the reserve system cost. Higher BLM values will produce a more compact reserve system.

Clumping: The minimum amount of a conservation feature required within adjacent planning units before that 'clump' is considered to effectively contribute towards achieving the representation target for that feature. A number of unique clumps of a conservation feature can also be assigned (see *separation distance*).

Conservation feature: An element of biodiversity selected as a focus for conservation planning or action. This can include ecological classifications, habitat types, species, physical features, processes or any element that can be measured in a planning unit.

Conservation feature penalty factor: See species penalty factor

Cost: The cost of including a planning unit in a reserve system. This cost should reflect the socio-political constraints to setting aside that planning unit for conservation actions. This could be: total area, cost of acquisition or any other relative social, economic or ecological measure. Each planning unit is assigned one cost, although several measures can be combined to create a cost metric.

Compactness: A measure of the clustering or grouping of planning units in a reserve solution. It is calculated as a ratio of the total boundary length of a reserve system to the total area of the reserve system. Stewart and Possingham (2005) describe this concept in more detail.

Decision support software: A computer-based application that uses information on possible actions and constraints on these actions in order to aid the process of decision-making in pursuit of a stated objective.

Efficiency: Property of a reserve system solution which meets all conservation targets (e.g., ecosystems, habitats, species) at an acceptable cost and compactness.

Geographic Information System (GIS): A computer-based system consisting of hardware and software required for the capture, storage, management, analysis and presentation of geographic (spatial) data.

Heuristic algorithm: General class of sub-optimal algorithms which use time-saving strategies, or "rules of thumb," to solve problems. If used in Marxan, planning units are added until biodiversity targets are met.

Irreplaceability: See selection frequency.

Iterative improvement: A simple heuristic wherein the algorithm will consider a random change to see if it will improve the value of the objective function if that change were made. If the change improves the system, then it is made. In Marxan, iterative improvement can be used to discard redundant planning units from the solutions.

Kappa statistic: An index which compares the spatial overlap / similarity of two reserve systems against that which might be expected by chance alone.

Local minimum/Local optimum: A local minimum occurs at the point where simply adding one favourable planning unit or removing one unfavourable planning unit from a reserve system can no longer improve the objective function value. This essentially means the reserve system cannot be improved without substantially changing its structure.

Maximum coverage problem: The objective of the maximal coverage problem is to maximize protection of features subject to the constraint that the resources expended do not exceed a fixed cost. Marxan can approximate the maximum coverage problem using the Cost Threshold function; however, the result will likely be sub-optimal.

Minimum set problem: The objective of the minimum-set problem is to minimize resources expended, subject to the constraint that all features meet their conservation objectives. Marxan was designed to solve this type of conservation problem.

Objective function: An equation associated with an optimisation problem which determines how good a solution is at solving the problem. In Marxan, the value of the equation is a function of planning unit costs, boundary costs, and penalties. Each solution to reserve design is assigned a objective function value; a solution with a low value is more optimal than a solution with a high value.

Planning units: Planning units are the building blocks of a reserve system. A study area is divided into planning units that are smaller geographic parcels of regular or irregular shapes. Examples include squares, hexagons, cadastral parcels and hydrological units.

Relative Target Values: The approach of ranking feature targets relative to one another as a whole set, before applying individual numerical values. For example, features A & B could be ranked as about the same, requiring "moderate" protection, but feature C is ranked as needing more protection than A & B, hence a "high" ranking. The numerical values of "moderate" and "high" could vary depending on the scenario, but moderate would always be lower than high.

Reserve system design: The approach used to design a network of areas that collectively address the objective of the conservation problem.

Run: The term used to describe the analysis of a particular scenario. A run will continue for a set number of ***iterations***. Several runs are conducted for each scenario. Because there are an almost infinite number of solutions for a Marxan analysis the number of runs should be adequate to provide a representative sample of the solutions available. This is sometimes also referred to as ***restarts***.

Selection frequency: How often a given planning unit is selected in the final reserve system across a series of Marxan solutions. This value is reported in the "Summed Solutions" output file. Also sometimes referred to (incorrectly) as irreplaceability.

Sensitivity analysis: The process of modifying input parameters, constraints and data to quantitatively assess the influence of different variables on the final solution; that is, the degree to which the outputs are "sensitive" to variations in these various parameters.

Separation distance: Defines the minimum distance that distinct clumps of a feature should be from one another in order to be considered as separate representations. This could be considered a type of risk spreading.

Simulated annealing: An optimisation method (algorithm) based on iterative improvement but with stochastic (random) acceptance of bad moves early on in the process to help avoid getting stuck prematurely at local minimum objective function value.

Species Penalty Factor (SPF): A user-defined multiplier for the penalty applied to the objective function when a conservation feature target is not met in the current reserve scenario.

Systematic conservation planning: Formal method for identifying potential areas for conservation management that will most efficiently achieve a specific set of objectives, commonly some minimum representation of biodiversity. The process, involves a clear and structured approach to priority setting, and is now the standard for both terrestrial and marine conservation. The effectiveness of systematic conservation planning stems from its ability to make the best use of limited fiscal resources towards achieving conservation goals and do so in a manner that is defensible, accountable, and transparently recognises the requirements of different resource users.

Target / Representation target: Targets are the quantitative values (amounts) of each conservation feature to be achieved in the final reserve solution.

User interface: The means by which people interact with a particular software application. A Graphical User Interface (GUI) presents information in a user-friendly way using graphics, menus and icons.