Marxan with Zones - software for optimal conservation-based land- and sea-use zoning.

Matthew E. Watts*[+], Ian R. Ball**, Romola S. Stewart[+], Carissa J. Klein[+], Kerrie Wilson[+], Charles Steinback[#], Reinaldo Lourival[++], Lindsay Kircher[+], Hugh P. Possingham[+]

*Corresponding author, m.watts@uq.edu.au, Fax +61 7 3365 1655

+The University of Queensland[+]; Applied Environmental Decision Analysis; University of Queensland; St. Lucia, Queensland 4072; Australia

** Australian Antarctic Division, Channel Highway, Kingston Tasmania 7050; Australia

#Ecotrust; 721 NW Ninth Avenue, Suite 200; Portland, Oregon 97209; USA

++The Nature Conservancy, SACR - Amazon**;** Avenida Nazare, 280; Belem – Para; and Capes Foundation - Brazil

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Abstract

In this paper we present a substantial extension of Marxan, Marxan with Zones, a decision support tool that provides land-use zoning options in geographical regions for conservation. We describe novel functionalities designed to enhance the original Marxan software, the most widely used conservation planning software in the world, and expand on its utility as a decision support tool for complex conservation planning problems in landscapes and seascapes. The primary new element of the decision problem is allowing any parcel of land or sea to be allocated to a specific zone, not just reserved or unreserved. Each zone then has the option of its own actions, objectives and constraints, with the flexibility to define the contribution of each zone to achieve targets for pre-specified features. The cost of implementing each zone in any location is then minimized while achieving a variety of conservation and land-use objectives. We outline the capabilities, limitations and additional data requirements of this new software and perform a comparison with the original version of Marxan. We feature a number of case studies to demonstrate the functionality of the software and highlight its flexibility to address a range of complex spatial planning problems. These studies range from the design of multiple-use marine parks in Western Australia to a terrestrial multiple use forestry application from East Kalimantan.

Keywords

Biodiversity; Zoning; Marxan; systematic conservation planning; decision support; optimization; simulated annealing; natural resource management

Software availability

Name of software: Marxan with Zones 1.0
Developers: Matthew Watts, Ian Ball, Hugh Possingham
Email: m.watts@uq.edu.au
Year first available: 2009
Program language: C++
Software required: 32 bit microsoft windows operating system or compatible emulator
Program size: 2 megabytes
Availability: Compiled binary available at http://www.uq.edu.au/marxan
Cost: nil

Introduction

Systematic conservation planning involves finding efficient sets of areas to protect biodiversity. One goal of systematic conservation planning is to meet quantitative conservation objectives, such as conserving 30% of the range of each species, as cheaply as possible (Possingham et al. 1993b; McDonnell et al. 2002; Klein et al 2008d). This is referred to as the minimum-set problem.

Recent research efforts have focused on developing computer software to solve the minimum-set problem (Sarkar 2006). This problem can be expressed as an integer linear programming problem if the cost is a linear function of the number of sites in the system (Cocks and Baird 1989; Possingham et al. 1993; Underhill 1994; Willis et al. 1996). Numerous algorithms can find solutions to the minimum-set problem (Margules et al. 1988; Rebelo and Siegfied 1992; Nicholls and Margules 1993; Csuti et al. 1997; Pressey et al. 1997). The large number of possible solutions makes some iterative and optimizing algorithms unsuitable for conservation planning problems. They often are slow to find solutions, find only inefficient solutions or find only single solutions. An advantage of simulated annealing algorithms is their ability to find many near-optimal solutions to large problems in a reasonable amount of time. Marxan, the most widely used software for conservation planning, uses a simulated annealing algorithm (Ball and Possingham 2000; Possingham et al. 2000). To date, over seventeen hundred individuals from more than one hundred countries and over twelve hundred organisations have used Marxan.

A major limitation of existing analytical approaches to spatial planning is their inability to simultaneously consider different types of zones to reflect the range of management actions or conservation activities being considered as part of a conservation plan. Indeed, conservation practitioners implement a diversity of management actions, ranging from fire management and predator control, to restoration and reservation (Wilson et al. 2007). Furthermore conservation activities occur in a matrix of alternative land and sea uses, many of which are contrary to conservation objectives. Zoning is a common management practice to spatially and temporally designate areas for specific purposes (Anon 1977; Korhonen 1996; Liffmann et al. 2000; Day et al. 2002; Russ and Zeller 2003; Airame 2005; Foster et al. 2005). Zoning plans provide an explicit approach to resolving conflicts between activities and determining trade-offs when balancing these competing interests (Halpern et al. 2008).

The original Marxan software could only include or exclude a planning unit from being reserved, implicitly assuming two zones: reserved or not reserved. Furthermore all conservation features are fully protected in a reserve and all conservation features outside a reserve are lost – an assumption which does not match reality. Multiple zoning could be achieved by iterative application of the software (Loos 2006) however that is clumsy and sub-optimal. The need for a more realistic and comprehensive definition of the conservation planning problem has been highlighted on numerous occasions (Bos 1993; Sabatini et al. 2007).

In this paper we introduce Marxan with Zones; an analytic tool that expands on the basic reserve design problem to incorporate new functionality and broaden its utility for practical application. The new functionality shifts away from the binary decision framework of conservation planning tools towards a multi-use landscape and seascape planning paradigm supporting the efficient allocation of planning units (i.e. the units of land or sea available for selection) to a range of different management actions that may offer different levels of protection. We present Marxan with Zones as a tool for systematic zoning; not only to improve planning for reserves systems but also with application to a wider range of natural resource management and spatial planning problems.

First we describe the mathematical formulation of the problem for which Marxan finds solutions and the new decision problem addressed by Marxan with Zones. Additional data requirements are discussed and example applications illustrate new functionalities of the software. We conclude by discussing of some challenges and potential applications of Marxan with Zones in conservation planning. The software is of interest to systematic conservation planning practitioners, policy makers and natural resource managers.

Mathematical formulation of Marxan with Zones

The original Marxan software aims to minimize the sum of the site-specific costs and connectivity costs of the selected planning units, subject to the representation targets being met. This is the Marxan minimum representation problem, formally defined as:

$$\text{minimize} \quad \sum_{i=1}^{m} c_i x_i + b \sum_{i1=1}^{m} \sum_{i2=1}^{m} x_{i1} (1 - x_{i2}) cv_{i1,i2} \qquad (1)$$

$$\text{subject to} \quad \sum_{i=1}^{m} a_{ij} x_i \geq t_j \quad \forall j \qquad (2)$$

where there are m planning units and n features under consideration. The first term of equation 1 represents the sum of the selected planning unit costs, where the control variable x_i=1 if planning unit i is selected and 0 if planning unit i is not selected. The planning unit dependent parameter c_i is the cost of selecting planning unit i.

The second term of equation 1 is the weighted connectivity cost of the reserve system configuration, where b is the connectivity weighting factor to control its relative importance in the objective function and $cv_{i1,i2}$ is the connectivity value associated with having planning unit $i1$ selected and planning unit $i2$ not selected. In other words, the connectivity value describes the connections between planning units and we pay a cost if only one of the pair is selected, but not if both or neither are selected. This can be the monetary, distance or other value associated with a connection or adjacent boundary between a planning unit within the configuration and one without, and can also be applied to more general ideas of connectivity (Klein et al. 2008b). The parameter b is referred to as the boundary length modifier and can be varied for more or less connected reserve systems.

In equation 2, a_{ij} is the amount of each feature j held in each planning unit i, and t_j is the amount of each feature j that must be selected.

We use a representation shortfall penalty equation to implement the target constraint in the Marxan objective function:

$$\sum_{j=1}^{n} FPF_j FR_j H\left(t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i\right)\left(\frac{t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i}{t_j}\right) \qquad (3)$$

This penalty is zero if every feature *j* has met its representation target in the selected reserve system. It is greater than zero if the targets are not met, and gets larger as the gap between the target and the conserved amount increases.

The terms FPF_j and FR_j are the feature penalty factor and feature representation respectively, which are the scaling factors used when a feature has not met its representation targets. FPF_j is a scaling factor which determines the relative importance of meeting the representation target for feature *j* and FR_j is computed within the software as the cost of the selected planning units designed to meet the representation target of only feature *j*. This cost is given in terms of the configuration cost plus the connectivity cost. The Heaviside function, *H(x)*, is a step function which takes a value of zero when $t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i \le 0$ and 1 otherwise. The feature specific parameter t_j is the target representation for feature *j*. The expression $\left(\frac{t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i}{t_j}\right)$ is the measure of the shortfall in representation for feature *j*. It is reported as a proportion and equals 1 when feature *j* is not represented within the configuration and 0 when the level of representation is equal to or greater than the targets.

We combine equations 1 and 3 to get the objective function. It gives a score to configurations of selected planning units.

Marxan objective function
Hence, the whole Marxan objective function is:

$$\sum_{i=1}^{m} \mathrm{c}_i x_i + b\sum_{i1=1}^{m}\sum_{i2=1}^{m} x_{i1}(1 - x_{i2}) cv_{i1,i2} + \sum_{j=1}^{n} FPF_j FR_j H\left(t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i\right)\left(\frac{t_j - \sum_{i=1}^{m} \mathrm{a}_{ij} x_i}{t_j}\right) \qquad .(4)$$

Marxan uses the simulated annealing algorithm (Kirkpatrick et al. 1983) to minimize the objective function score (equation 4) by varying the control variables which tell us which planning unit is in, or out, of the reserve system, x_i.

Marxan with Zones generalizes this approach by increasing the number of states or zones to which a planning unit can be assigned. Each term of the objective function is increased in complexity. Furthermore, two types of representation targets are allowed and consequently the representation shortfall penalty reflects two types of shortfall.

Marxan with Zones Equations
The aim of the Marxan with Zones software is to minimize the sum of costs and connectivity costs of the zone configuration of planning units, subject to meeting the representation targets and zone targets. This is the Marxan with Zones minimum representation problem, formally defined as:

$$\text{minimize} \quad \sum_{i=1}^{m}\sum_{k=1}^{p} c_{ik}\, x_{ik} + \sum_{i1=1}^{m}\sum_{i2=1}^{m}\sum_{k1=1}^{p}\sum_{k2=1}^{p} cv_{i1,i2,k1,k2}\, x_{i1,k1}\, x_{i2,k2} \qquad (5)$$

$$\text{subject to} \quad \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij}\, ca_{jk}\, x_{ik} \geq t1_{j} \quad \forall\, j \qquad (6)$$

$$\text{and subject to} \quad \sum_{i=1}^{m} a_{ij}\, x_{ik} \geq t2_{jk} \quad \forall\, j \text{ and } \forall\, k \qquad (7)$$

In this case there are *m* planning units and *p* zones. The first term of equation 5 represents the sum of the costs for a configuration of planning units where each planning unit is allocated to a particular zone, and is composed of a control variable and cost matrix. The control variable records which planning unit *i* is in which zone *k*, $x_{ik} \in \{0,1\}$, its value is 1 if the planning unit *i* is in zone *k*, and 0 if the planning unit *i* is not in zone *k*. Each planning unit can be in only a single zone, $\sum_{k=1}^{p} x_{ik} = 1 \quad \forall\, i$. We define a cost matrix c_{ik}, which is the cost of placing each planning unit *i* in each zone *k*.

The second term of equation 5 represents the connectivity cost of a configuration of planning units assigned to particular zones, and is composed of a connectivity matrix $cv_{i1,i2,k1,k2}$ recording the cost of the connections between planning units *i1* and *i2* if and only if *i1* is in zone *k1*, and *i2* is in zone *k2*. In practice, many of the entries of this connectivity matrix are zero.

In equation 6, a_{ij} is a feature matrix that records the amount of each feature *j* in each planning unit *i*, the parameter $t1_{j}$ is a representation target objective vector that records the amount of each feature *j* required to be protected in the zone configuration, and ca_{jk} is a contribution matrix that records the level of protection offered to each feature *j* by each zone *k*. Typically this contribution will be 1 for zones in which the feature enjoys full representation, 0 for zones which do not count towards a features representation and an intermediate value for a zone that offers partial protection for a feature. For example a conservation feature might enjoy full representation in a conservation zone and no representation in zones where natural resources (e.g. timber, fish etc) are extracted, but partial protection where sensitive natural resource extraction is allowed.

In equation 7, $t2_{jk}$ is a zone target objective matrix that records the amount of each feature *j* required to be captured in a particular zone *k*. For example we may demand that a particular species has at least half of its feature target conserved in full no-take reserves.

We use a feature penalty equation below to implement the two target constraints in the Marxan with Zones objective function:

$$\sum_{j=1}^{n} FPF_j FR_j \left(\begin{array}{l} H\left(t1_j - \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij} ca_{jk} x_{ik}\right)\left(\dfrac{t1_j - \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij} ca_{jk} x_{ik}}{t1_j}\right) + \\ \sum_{k=1}^{p} H\left(t2_{jk} - \sum_{i=1}^{m} a_{ij} x_{ik}\right)\left(\dfrac{t2_{jk} - \sum_{i=1}^{m} a_{ij} x_{ik}}{t2_{jk}}\right) \end{array} \right) . \qquad (8)$$

This is the sum of two different representation targets. Both are weighted by the feature dependent factors of FPF_j and FR_j as they were previously. There are *n* features under consideration.

Marxan with Zones Objective Function

Combining equations 5 and 8 gives the objective function for Marxan with Zones:

$$\sum_{i=1}^{m}\sum_{k=1}^{p} c_{ik} x_{ik} + \sum_{i1=1}^{m}\sum_{i2=1}^{m}\sum_{k1=1}^{p}\sum_{k2=1}^{p} cv_{i1,i2,k1,k2}\, x_{i1,k1} x_{i2,k2} +$$
$$\sum_{j=1}^{n} FPF_j FR_j \left(\begin{array}{l} H\left(t1_j - \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij} ca_{jk} x_{ik}\right)\left(\dfrac{t1_j - \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij} ca_{jk} x_{ik}}{t1_j}\right) + \\ \sum_{k=1}^{p} H\left(t2_{jk} - \sum_{i=1}^{m} a_{ij} x_{ik}\right)\left(\dfrac{t2_{jk} - \sum_{i=1}^{m} a_{ij} x_{ik}}{t2_{jk}}\right) \end{array} \right) . \qquad (9)$$

This is identical to the Marxan objective function in equation (4) when; there are two zones (p = 2), zone 1 is an unreserved zone with a contribution of zero for all features and zone 2 is a reserved zone with a contribution of 1 for all features ($ca = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$), the cost of the unreserved zone is 0 for all planning units ($c_{i1} = 0 \ \ \forall i$), and there are no zone specific targets for all features and both zones ($t2_{jk} = 0 \ \forall j$ and $\forall k$).

Additional information requirements for Marxan with Zones

Marxan with Zones has a number of information requirements beyond those used in Marxan. Individual planning problems will determine the amount of additional information required. At a minimum, the number of zones and the costs of assigning each planning unit to each zone must be defined. In this section, we describe the additional information requirements and introduce five case studies. The case studies demonstrate a practical application of at least one Marxan with Zones functionality. A detailed description of how to use Marxan with Zones is provided in the on-line manual (Klein et al. 2008a).

Multiple Zones

A list of all possible zones must be defined. These can range from high quality conservation zones (e.g. well managed national park) to extractive use zones (e.g. intensive agriculture, forestry, and fishing). The user can specify zone-specific targets to prescribe how feature targets are achieved (see Case Study 1). For example, given an overall target of 20% for each habitat type, which could be met across three different conservation zones, you may require at least 10% of the overall target to be met in the zone offering the highest level of protection. Not specifying a zone-specific target means that the overall target for a feature can be achieved across all zones.

Furthermore, Marxan with Zones allows the user to prescribe the spatial relationship between each zone (see Case Study 2). This is useful if you want two zones to be adjacent or spatially separated. For example we may prefer national parks to be buffered by sustainable low intensity logging rather than intensive agriculture. This functionality is similar to the boundary cost in original Marxan but it relates to the shared boundaries between zones rather than between individual planning units.

Costs

The cost of allocating each planning unit to each zone must be defined. Marxan with Zones can accommodate multiple costs for individual planning units (see Case Study 3), with the total cost of assigning of a planning unit to a particular zone measured as the sum of the individual costs. Costs can also be zone-specific, with the cost depending on the zone a planning unit is allocated to as determined by economic or social expenses associated with allocating an individual planning unit to that zone. For example, there may be purchasing, opportunity, and management costs associated with designating a planning unit as a national park (Naidoo et al. 2006). A weighting factor for each cost in each zone may also be applied. All costs in a given zone will be weighted by the zone-specific multiplier, and then summed to give a total cost for each planning unit, which is zone-specific.

Features
Features may be defined as elements that we would like to occur in particular zones (see Case Study 4). These spatially-specific elements may include for example; habitat types, elevation gradients, soil types, and species distributions. The current use of each planning unit (e.g. protection, agriculture, recreation) may also be described as a feature and used to constrain the allocation of planning units to particular zones (or it can be used to inform the cost of a planning unit). For example we may wish to ensure that at least 20% of a landscape is forestry, or the expected timber production is above a certain level.

Relationship between zones and features
In some cases, it may be useful to define the relationship between each zone and feature. The contribution of a zone towards achieving feature targets can be indicated by the user (see Case Study 5). Feature targets can be achieved across a combination of zones, with the potential for some zones to contribute more to feature targets than others. For example, in case study 1, the fishing and recreational zones represent management regimes offering different levels of protection to biodiversity features. This information is determines how much of each feature in each zone is needed for target achievement.

Software Evaluation
System testing of Marxan with Zones used a staged approach. Multiple scenarios were constructed, starting with the standard Marxan dataset, and then incrementally adding new zoning and cost data structures. Using this method, we determined the influence of each new data structure on the resulting spatial configurations and summary outputs. This simplified the sensitivity analysis and identity of the cause for observed bugs and discrepancies. The software was tested on a range of problems relating to biosphere reserves, marine planning, integrated natural resource management, and multiple use forestry planning (see case studies). The case studies represent realistic problems dealt with in spatial planning and Marxan with Zones works robustly in solving these problems. The number of zones, planning units, features, and costs that can be input into Marxan with Zones is limited only by the address space, which is two gigabytes. In addition, we developed a systematic validation software system for Marxan with Zones that reproduces every computation at each step of the algorithm in an alternative software system. This extremely robust validation technique gives us confidence in the reliability of Marxan with Zones.

Discussion
Marxan with Zones offers key improvements to the Marxan software by extending the range of problems to which the software can be applied. The in-built flexibility for users to define multiple objectives, multiple zones and accept multiple costs makes the software versatile and suitable for a wide range of resource management problems. These problems need to better integrate the management of multiple-uses and account for the different types of interactions between and among activities. An effective zoning plan must not only separate conflicting activities but explicitly balance competing interests in a way that delivers acceptable trade-offs. Brokering trade-offs is no trivial task and will most likely be guided by government policy. Marxan with Zones provides a systematic planning framework to evaluate the consequences and trade-offs of alternative zoning configurations, which is critical for informed decision-making.

A further advance is the ability of the software to accept varying contributions to overall targets from different zones. This optional feature of the software calls for a quantitative measure of how individual zones contribute towards feature targets.

The ability to specify zone-specific planning unit costs presents a number of potential uses. It could support the design of conservation landscapes and seascapes that include both communally- and privately managed areas, where the costs of conservation actions differ, but the conservation outcomes are equivalent. It also allows for complex natural resource management situations where costs and biodiversity benefits vary depending on the land and sea use or management action. For example, conservation actions such as weed control, protected area establishment, and the creation of conservation easements could be spatially assigned in a zoning configuration. Moreover, this approach could prioritize actions based on ecosystem services, where biodiversity benefits and management costs of the delivery of one ecosystem service such as carbon sequestration could differ from others such as pollination or water filtration services (Chan et al. 2006). Marxan with Zones could help identify which parts of the planning region are most suitable for providing each ecosystem service.

Marxan with Zones can support many types of decision making including; landscape ecology, land use planning, marine planning, urban and regional planning, and support for group decision making in a multi-stakeholder context. More generally, the software can solve spatial resource allocation problems involving multiple actions, objectives and constraints. The objectives and constraints can be based on economic, social, cultural or biological spatial features. We hope the novel functionality of Marxan with Zones will attract wide use in a range of conservation planning problems beyond those solvable by Marxan.

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Boxes, Case Studies (insert as boxes through text, where relevant)

Case Study 1 - Planning a Multiple-Use Marine Park: an example from Rottnest Island Western Australia (Stewart et al. 2008)

The primary objective of this study was to identify a zoning configuration for a multiple-use park that comprised highly protected marine sanctuaries to conserve marine biodiversity whilst also providing for ongoing recreational and fishing activities to the extent that they do not conflict with the conservation objectives. This emphasizes the requirement to spatially separate areas dedicated for the conservation of coastal and marine biodiversity from recreational and fishing activities.

The problem presented multiple objectives with zone-specific targets defined for biodiversity (i.e. the Marine Sanctuary zone was required to capture 30% of the current distribution of biodiversity features (N=23)), recreational activities (i.e. Restricted Use zone to capture 80% of recreational features (N=4)) and fishing (i.e. General use zone required to capture 80% of the current extent of fishing features (N=19)). Contributions towards biodiversity feature targets could be achieved from a combination of the Marine Sanctuary zone (where contributions count as 100% of feature amount held) and the Restricted Use zone (where contributions count as 20% of feature amount held). We also stated a preference for the Marine Sanctuary zones to be adjacent to the Restricted use Zone, to act as a buffer to the effects of fishing activities occurring in the General Use zone.

Because the zoning problem is constrained around achieving multiple objectives, meeting spatial requirements and minimising cost, the best solution does not always satisfy all feature targets. We used Marxan with Zones to identify a zoning configuration that delivers the optimal trade-off of fishing and recreational activities with biodiversity objectives (Figure 1). Results supported exploration of how to optimally achieve an explicit set of management outcomes that recognize the achievable objectives for biodiversity features in the context of existing uses.

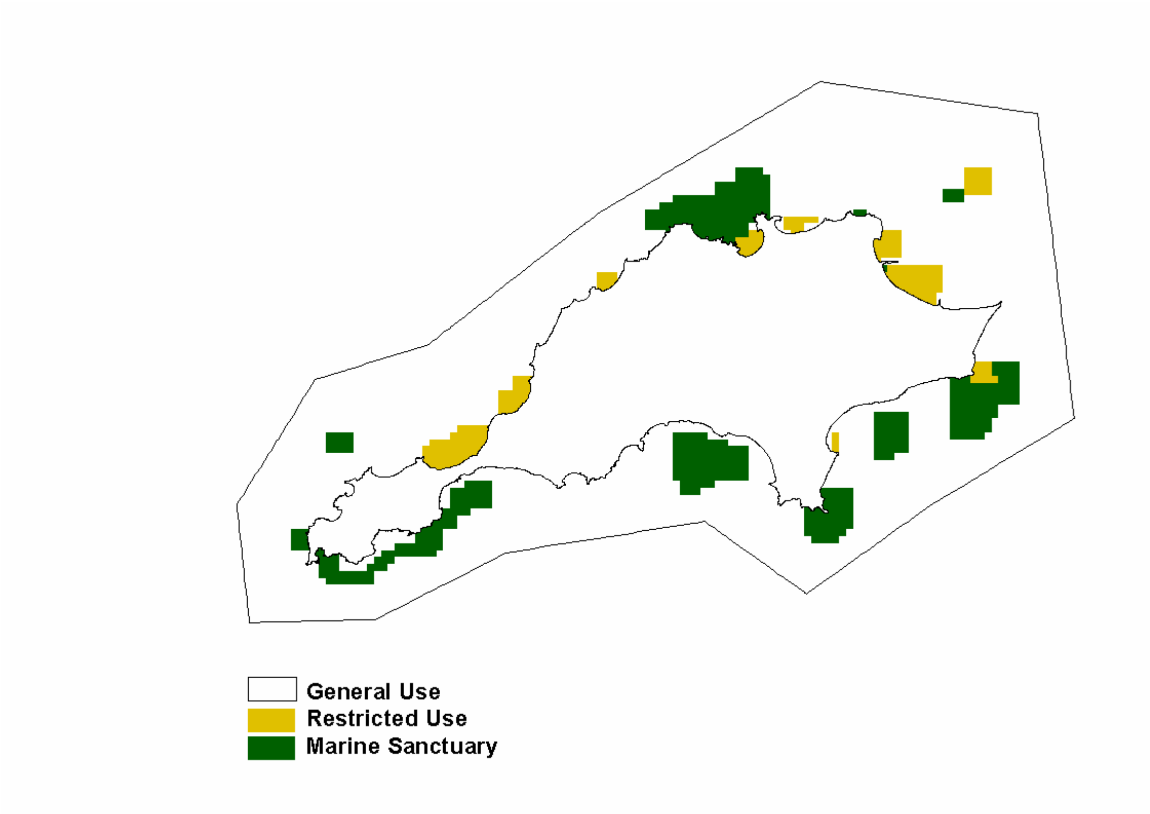

Figure 1. Example of a Marine Zoning Plan for a Multiple-Use Marine Park at Rottnest Island, Western Australia

Case Study 2 - Systematic zoning applied to Biosphere Reserves, protecting the Pantanal wetland heritage of Brazil.

Our aim in this study was to provide the framework and guidelines to systematically zone Biosphere Reserves (UNESCO 2007). This involved evaluation of existing biosphere reserves, and support for the design and rezoning of biosphere reserves that incorporated the principles of systematic conservation planning. We specifically responded to two questions relating to the Biosphere Reserve model (West 2006); how to optimize spatially explicit compromises of representation under a multi-zone and multi-objective context, and how to incorporate spatially nested and compact zones.

We investigated the compatibility between zones in the Pantanal biosphere reserve in Brazil to provide alternative zone configurations based on the biosphere reserve zonation model. The zone compatibility matrix of Marxan with Zones allowed us to explore and evaluate the effect of differing levels of nested and compact spatial configurations of zones. We fixed parameters such as: targets, costs, boundary length in our scenarios and varied the zone compatibility matrix values to evaluate their performances on the basis of differing levels of nested and compact spatial configurations. Adjusting the compatibility value through the term $cv_{i1,i2,k1,k2}$ (in Equation 5) enables zone juxtaposition to differing degrees, offering planners the opportunity to explore the spatial assignment of planning units according to the compatibility between land uses and biodiversity and cultural attributes. The values for compatibility vary between zero and one, where zero means compatibility between two zones and one mean incompatibility between them. Our results also showed how the effectiveness of biosphere reserves can increase when they are systematically designed. After revising objective achievements of the biosphere reserves we identified a shortfall of 325,000 hectares to reaching the biodiversity targets. Systematically designed biosphere reserves configurations with the same targets and costs reduced shortfalls to 99,000 hectares. This is less than a third of the target shortfall of the current ad hoc biosphere reserves, a substantial increase in effectiveness.

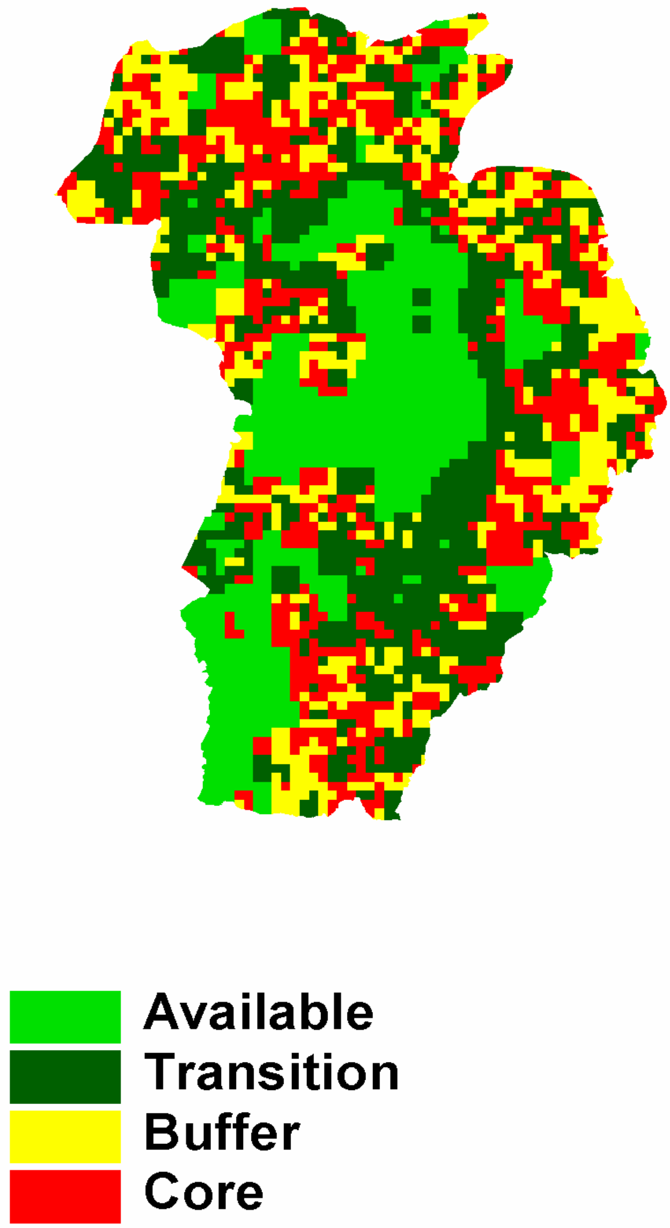

Figure 2 – Example of a biosphere reserve plan considering compatibility between zones.

Case Study 3 - Using economic data on eight commercial fisheries to plan for multiple types of marine protected areas: a case study from California (Klein et al. 2008c)

We used spatially explicit data on the value of each planning unit to eight commercial fisheries to inform the zoning of marine protected areas in California. We planned for 5 zones, each restricted to different commercial fisheries and applied two types of zone-specific targets: 1) Biodiversity targets for protected areas and 2) Fishery targets in zones where fishing is allowed. We aimed to minimize the impact of marine protected areas on commercial fishermen, subject to the constraint that biodiversity conservation objectives were achieved (Klein et al. 2008c, in press). Although the original version of Marxan solves this problem, it can only identify one type of protected area and use one single cost.

Using Marxan with Zones, we produced several possible zoning configurations (Figure 2) that satisfied biodiversity and socioeconomic goals and objectives of multiple stakeholders. The zone assignments were driven by the fishing restrictions in each zone and informed by fine-scale spatially explicit information across multiple commercial fisheries. Results from this application of Marxan with Zones will inform California's Marine Life Protection Act Initiative's stakeholders, staff, and scientific advisors in designing marine protected areas that efficiently achieve the biodiversity conservation and socioeconomic objectives.

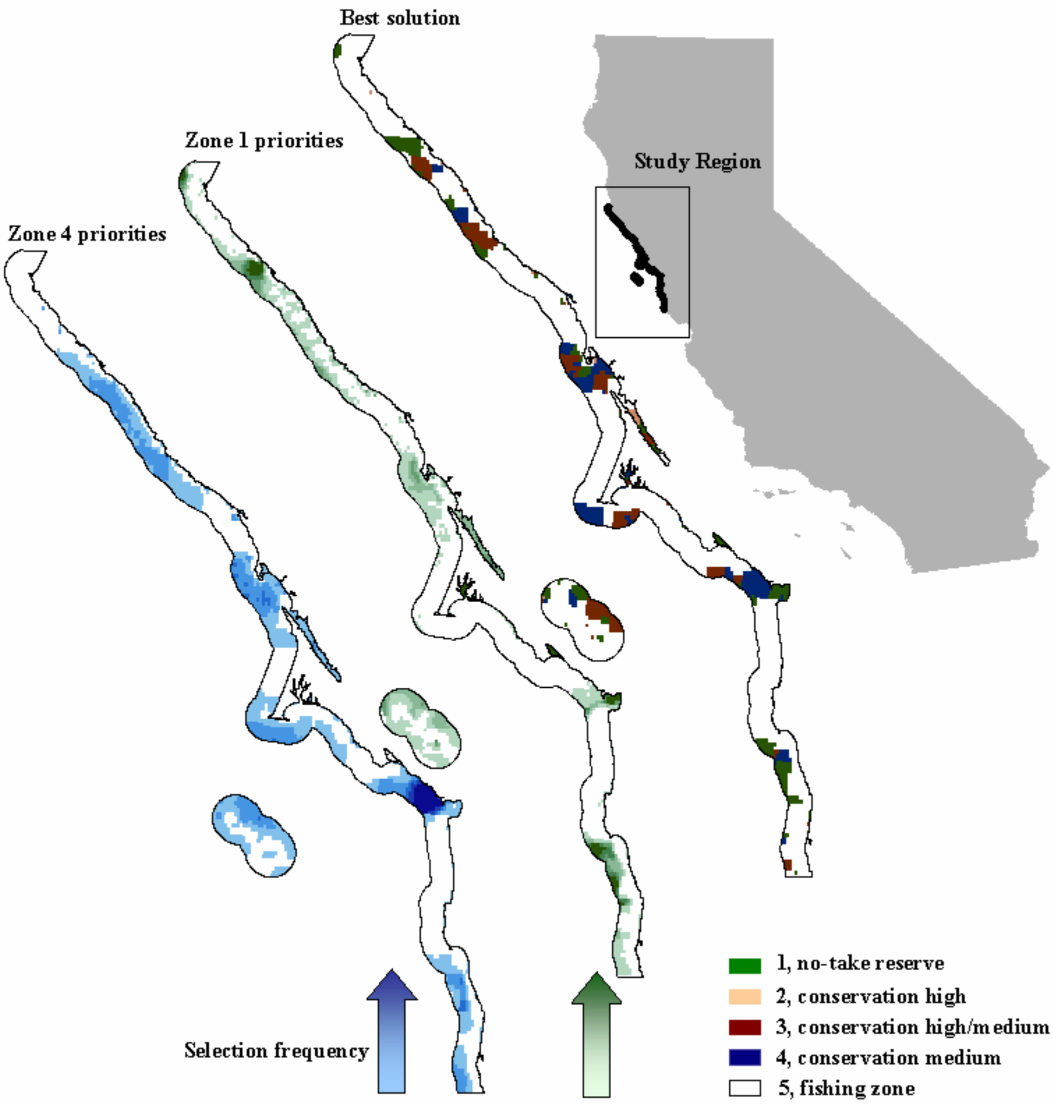

Figure 3 - The study region with priority areas for 2 zones as well as one example of a protected area zoning solution.

Case Study 4 - A multiple-use planning framework for management of the natural resources of Cockburn Sound (Stewart et al. 2008)

Cockburn Sound is Western Australia's most intensively used marine embayment. The range of uses includes a port, heavy industrial area and a strategic naval base, together with recreational swimming, sailing, fishing, aquaculture and tourism. We apply Marxan with Zones to specify a multiple-use planning framework for Cockburn Sound that integrates the different types of resource uses, ranging from high level protection (eg. conservation) to exclusive types of use (eg ports).

The multi-objective problem was constrained around the requirement to meet objectives for existing commercial uses. In addition, we sought to examine the potential impact of a number of proposed developments on the conservation of biodiversity features in the Sound. Hence, contributions to biodiversity targets could not be accepted from areas in which either commercial activities or proposed developments occur.

A zonation scheme was devised, with zone-specific targets defined for biodiversity features (conservation zone), existing uses (ports and infrastructure zone), development proposals (development proposal zone), recreational fishing (recreational fishing zone) passive recreational uses (general use zone). In this way, the proposed zones can better manage areas of multiple-use, minimise potential for conflict and be explicit about how management of these areas contributes towards biodiversity objectives.

We apply Marxan with Zones to identify a zoning configuration that reflects the achievable objectives for biodiversity features in the context of existing and proposed uses. This involves delivering the near optimal trade-off of existing and proposed uses with biodiversity features. Furthermore, Marxan with Zones provides a platform for exploring the alternative configurations of development proposals to optimally retain the existing biodiversity features of the Sound, even where complete retention of those features cannot be achieved because of the development pressures.

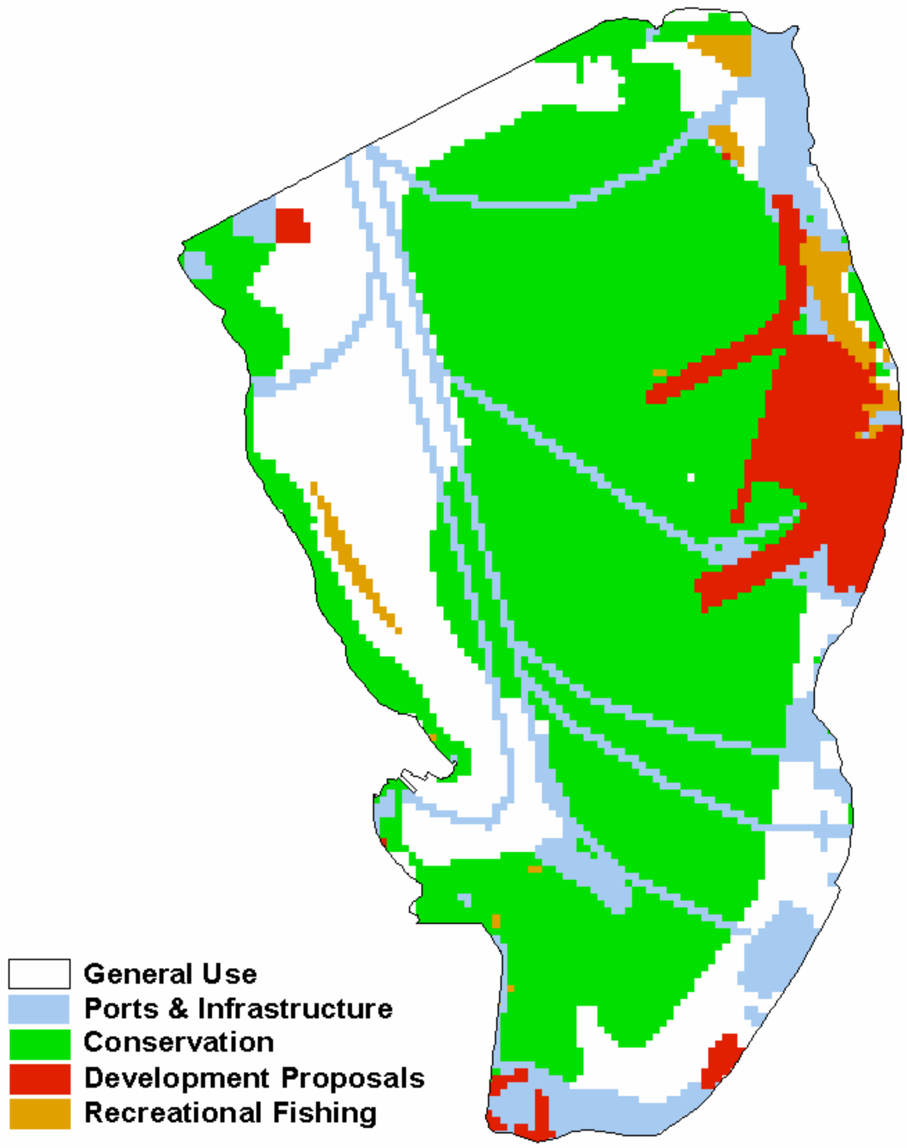

Figure 4. Example multiple-use planning framework to support integrated natural resource management of the Cockburn Sound, Western Australia

Case Study 5 - A Zoning Configuration of multiple uses and protected area networks in East Kalimantan (Wilson et al. in prep)

Tropical rainforest habitat is used for a diversity of land uses ranging from protected areas to production forests. Each alternative land use makes a different contribution to the conservation of biodiversity. First, the degree of protection offered by different land uses varies, and a high protection status may not be necessarily synonymous with a large contribution to biodiversity conservation. In some situations production forests may offer more protection than protected forests. Second, the contribution of different land uses to the conservation of species varies depending on the relative sensitivity of species to habitat modification and degradation. Some land uses provide habitat throughout all levels of forest strata, along with a diversity of food sources for fauna species occupying the forest. Other land uses are more restricted in their provision of habitat and food sources with the resultant floristic and faunal diversity reflecting these differences.

We applied Marxan with Zones to prioritize conservation investments in East Kalimantan by accounting for the relative costs and benefits of four land uses, modified according to the level of forest cover (Figure 5). We obtained data on the distribution of 187 mammal species that occur in the study region and evaluated their relative sensitivity to forest conversion and degradation. We assigned species-specific conservation targets that accounts for their relative sensitivity and determined the contribution of each land use zone to achieving targets for each species. We prioritised investments in each alternative land use in a spatially-explicit manner, in order to achieve the conservation targets cost-effectively. This analysis has allowed us to evaluate not only where to act, but how to act in order to effectively and efficiently conserve South East Asian mammals in East Kalimantan.

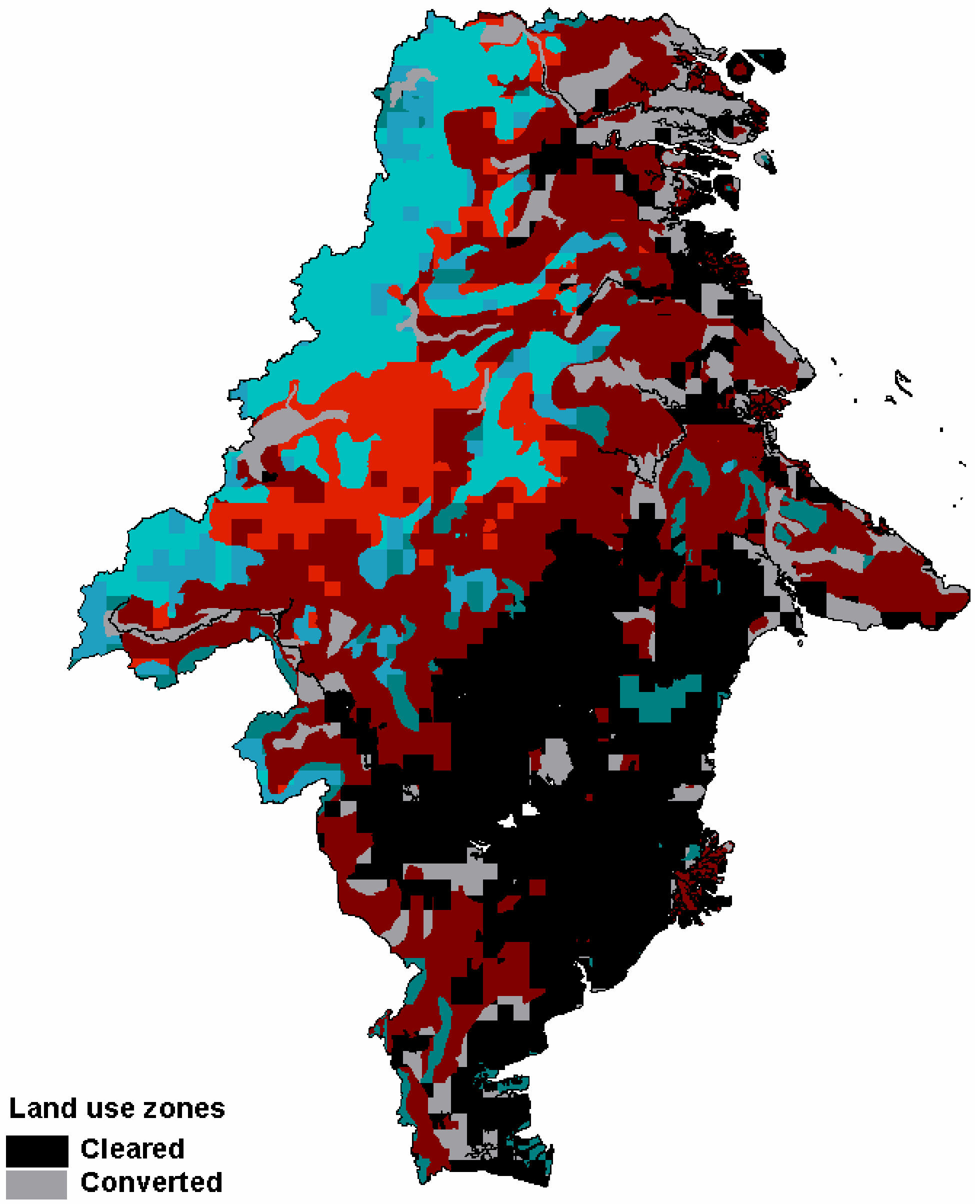

Figure 5. Land uses in the Indonesian province of East Kalimantan.