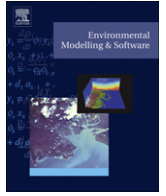


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An interoperable decision support tool for conservation planning

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ABSTRACT

Zonae Cogito is a free software package that couples Marxan with a MapWindow GIS interface to provide practitioners with an easy to use GIS to support Marxan analysis. In addition to providing a method for visualizing Marxan output, Zonae Cogito extends the basic Marxan functionality to better support an iterative and interactive design process. Zonae Cogito introduces the ability to modify and refine networks identified in Marxan, and extends the basic reporting functionality of Marxan beyond features directly considered in the analysis. Zonae Cogito also introduces new tools that allow spatial flexibility in the proposed protected area networks to be more effectively leveraged during the design process, and facilitates better information flow through interoperability with other software packages.

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1. Software availability

Name: Zonae Cogito

Developer: Matthew E. Watts

Email: m.watts@uq.edu.au

First available: 2008

Availability: <http://www.uq.edu.au/marxan/>

Cost: Free

Language: Pascal

Minimum hardware requirements: 1 GHz, 256 MB RAM

Software requirements: 32 bit Microsoft Windows Operating system Win 2000, NT, XP, Vista, 7, or a compatible emulator

Language: English

2. Introduction

The objective of systematic conservation planning is to ensure the persistence of biodiversity (Moilanen et al., 2009). Early efforts to protect biodiversity in situ through the establishment of

protected areas (PAs) were characterized by an ad-hoc designation process, often driven by concerns other than the persistence of biodiversity (Pressey and Tully, 1994). This resulted in PA networks that did not reflect the diversity of ecological systems (Joppa and Pfaff, 2009) and were biased toward areas of limited commercial value (Pressey, 1994). Systematic conservation planning developed in response to this ad-hoc and biased conservation investment.

The concept of complementarity is central to systematic conservation planning; it describes the extent to which a site complements other proposed or existing PAs in representing the full range of biodiversity. Complementarity requires potential PAs be evaluated in the context of their contribution toward larger network level objectives, rather than as isolated units (Sarkar et al., 2006). The clear articulation of these network level objectives allowed the conservation community to formulate PA selection as a well defined mathematical problem. Two common variations of the PA selection problem exist (Camm et al., 1996): The ‘minimum set’ problem, where the objective is to select the smallest, or cheapest, combination of sites that will capture the desired amount of biodiversity. And the ‘maximal coverage’ problem, which aims to capture as much biodiversity as possible beneath a pre-established budget (Possingham et al., 2006).

The clarity of these problems belies their complexity. Even to modest PA selection problems, finding good solutions typically

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requires integrating large biologic and socio-economic data sets, and searching a potentially vast solution space. A variety of automated methods, generically known as ‘decision support tools’, have been proposed to help find solutions to these problems (Leslie et al., 2003; Possingham et al., 2000), for example, C-plan (Pressey et al., 2009), Zonation (Moilanen, 2007), and ConsNet (Sarkar et al., 2009). By and large, these tools have been heuristic (non-exact) algorithms adapted from the field of operations research, their usefulness in solving conservation problems being first described by Kirkpatrick (Kirkpatrick, 1983).

The Marxan decision support system was originally designed to solve the minimum set problem (Ball et al., 2009; Ball and Possingham, 2000; Watts et al., 2009). Since its release, Marxan has been used in over 100 countries by over 1000 organizations to support marine, terrestrial and freshwater conservation planning. Marxan provided support to the re-zoning of the Great Barrier Reef in Australia (Fernandes et al., 2005), the establishment of marine protected areas in the channel islands in the United States of America (Airame, 2005) and Kimbe Bay in Papua New Guinea (Green et al., 2009), and is integrated in The Nature Conservancy’s (TNC) Ecoregional Assessment framework (Groves et al., 2002).

Marxan is a standalone executable, whose input and output are entirely text-file based. While this frees the software from dependence on a single GIS it is also creates additional workflow for users who need to view output spatially. The nature of a Marxan database is such that GIS expertise is required to build the necessary input files. The Marxan program provides no support for the development of input files or for the viewing of output. To fill this void a number of extensions have been developed to support the use of Marxan. CLUZ is an ArcView extension that assists in the construction and editing of Marxan input files, as well as the display and manipulation of Marxan results (Smith, 2004). The PANDA package performs similar functions in ArcGIS 9.X (Riolo, 2005). Both packages help reduce the GIS expertise needed to successfully use Marxan, but are reliant on commercial GIS packages that are often expensive and have substantial hardware requirements.

3. Need

The widespread adoption of Marxan by the global conservation planning community can in part be attributed to the fact that it is freely available, requires only a small amount of computing memory, and for most planning problems is fast and efficient to run regardless of hardware speed. In application however, its benefits can be limited by the need for users to interact with an independent GIS in order to manipulate databases and visualize results. Although a number of freely available front-ends aid this interaction, they also rely on users having access to commercial GIS packages. The cost and size of commercial GIS software mean their use is limited in the developing world, especially in the conservation community where budgets are typically smaller than in other sectors.

Even in well funded projects, those employed as conservation planners are not necessarily GIS experts. The skills required to use a GIS are not the same required of an effective planner, and following initial development of the input databases the standard operation of Marxan requires only a limited set of GIS functionality. This is unfortunate because it often limits the ability of conservation planners to manipulate Marxan to find reasonable solutions to their problems.

Conservation planning problems are inherently spatial, and understanding what a solution looks like in space is a critical starting point for evaluation and stakeholder engagement. On their own, the text file outputs from Marxan fail to provide stakeholders with the information they require to evaluate proposals. Although

with some technical knowledge and access to a GIS, figures of Marxan solutions can be produced, the contextual information (e.g., the relationship of selected areas to other landscape features) is static, set by those producing the figures, limiting the flow of information to planners and stakeholders.

Solutions from systematic conservation plans are rarely implemented at a single point in time. In the rare cases where this does happen (e.g., Australia’s Great Barrier Reef Marine Park), significant stakeholder negotiation is still required to move from a Marxan generated solution to an implementable network design (Fernandes et al., 2005). The importance of finding the mathematically optimal network configuration pales in comparison with the importance of finding an implementable and workable network design (Pressey et al., 1996). Arriving at a network that will be accepted by stakeholders requires negotiation and modification of optimized solutions (Lagabriele et al., 2010). The process of exploring stakeholder driven changes to Marxan identified solutions can be too slow for a workshop setting because of the need to go back and forth between a GIS and Marxan. Similarly, exploring how a proposed change (either into or out of a solution) will influence the target achievement of the protected area network is not a straight forward procedure in Marxan. Because Marxan finds cost efficient solutions even small changes can result in gaps in target achievement. Even with well developed systematic plans, many conservation investments reflect opportunistic decisions and are outside those sites originally identified in the plan. Effective conservation commonly requires embracing opportunities outside planned sites (Knight and Cowling, 2007), but doing so can quickly make conservation plans obsolete, reducing their relevance for future decisions and diminishing the incentive to update them. The effort and expertise needed to edit and update Marxan developed plans has no doubt contributed to their lack of longevity in many cases.

Part of the demand from conservation planners for rapid visualization of results is so that they can quickly explore the impact of parameter changes. Calibrating control parameters typically requires editing these parameters in the input text files, rerunning Marxan, and then visually inspecting the output from multiple runs in a GIS. This routine operation typically requires three independent software applications to complete. Similarly, although there are well established practices for calibrating Marxan parameters, they require extracting the results of multiple calibration runs and importing these into a fourth software application for graphing (Ardron et al., 2008).

The Marxan user community has an active list-serve whose members share problems, and offer advice on solving these problems. Drawing from this resource and our discussions with users, a number of themes frequently emerged as challenges to working with Marxan. These include; reliance on commercial GIS software, difficulty in making modifications to Marxan solutions, interacting with stakeholders, and the calibration of key input parameters.

Zonae Cogito (ZC) was conceived of in response to these needs, and extended through the direct support and recommendations of the users profiled in the two case studies of this paper. Zonae Cogito was designed to extend the capabilities of the Marxan decision support tool beyond generation of static output, toward support for an iterative, interactive, and transparent planning process.

4. Design

Zonae Cogito delivers two major benefits to Marxan supported conservation planning projects. It provides a graphical user interface (GUI) with a freely available GIS, and a toolset for modifying, interrogating and sharing results to facilitate interactive network design.

4.1. Marxan runtime support

4.1.1. Graphical user interface

The existing Marxan file structure is used to develop a ZC project, with the additional requirement of a planning unit shapefile to display results. Once initiated the ZC GUI has two primary modules; a GIS map of the planning region and a Marxan interface module. The GIS module provides basic mapping functionality for the project, which at a minimum displays the project's planning units. The Marxan module provides users access to the most commonly viewed and modified Marxan input and output files. Modification of input files and parameters is possible through the interface, as is the ability to view key output files through tabular display or customizable graphing of the results. With the ZC front end, users not comfortable with text editing can work exclusively through the ZC GUI, and users without access to a GIS can review and edit output spatially (Fig. 1).

4.1.2. GIS platform

The primary design requirement for ZC was the ability to visualize Marxan output. Basic GIS functionality is implemented through the MapWindow Active X control, a free, open source GIS package (Ames, 2007). The interface provides the GIS functionality required for running Marxan, but is not intended to be a full replacement for a standalone GIS. Core functionality includes viewing Marxan output, modifying the field of view, changing display colors and the ability to select planning units. The GIS also supports display of additional layers in the form of aerial imagery in georeferenced bitmap format (.bmp), or additional shapefiles to

provide contextual overlays for viewing results or refining analysis. This basic GIS functionality means that after a Marxan database is developed, no external GIS is necessary. Even with ZC, an external GIS is still required for the spatial calculations required to generate Marxan input files.

4.1.3. Database development

Zonae Cogito facilitates Marxan database development in three ways; 1) though legacy support for older versions of Marxan, 2) assembly tools for creation of new Marxan databases, and 3) C-plan interoperability. The original release of Marxan (1.8.2) utilized a different database structure than the current 'optimized' release that supports analysis of large datasets. Legacy support includes conversion of databases formatted for the original version of Marxan to the new database format, and backwards compatibility to save to the older format. The tools also provide compatibility with C-plan, through single click conversion to a C-plan database. Because C-plan allows saving to the older Marxan 1.8.2 format, this means the two tools are entirely compatible. A C-plan analysis can also be run within ZC through a loose coupling that allows the ZC GIS to be used as the primary GIS for C-plan.

The Marxan database structure requires all conservation features and costs be summarized by planning unit. The *Zonal Statistics* and *Tabulate Area* tools in ArcGIS (ESRI, 2009) are commonly used to summarize data for inclusion in a Marxan database, the Zonal Statistics tool for summarizing continuous data, and the Tabulate Area tool for categorical data. The ZC 'JoinDBF Tables puvsp' tool joins a set of Tabulate Area tables (.dbf format, or converted Zonal Statistics tables) into a complete Marxan database.

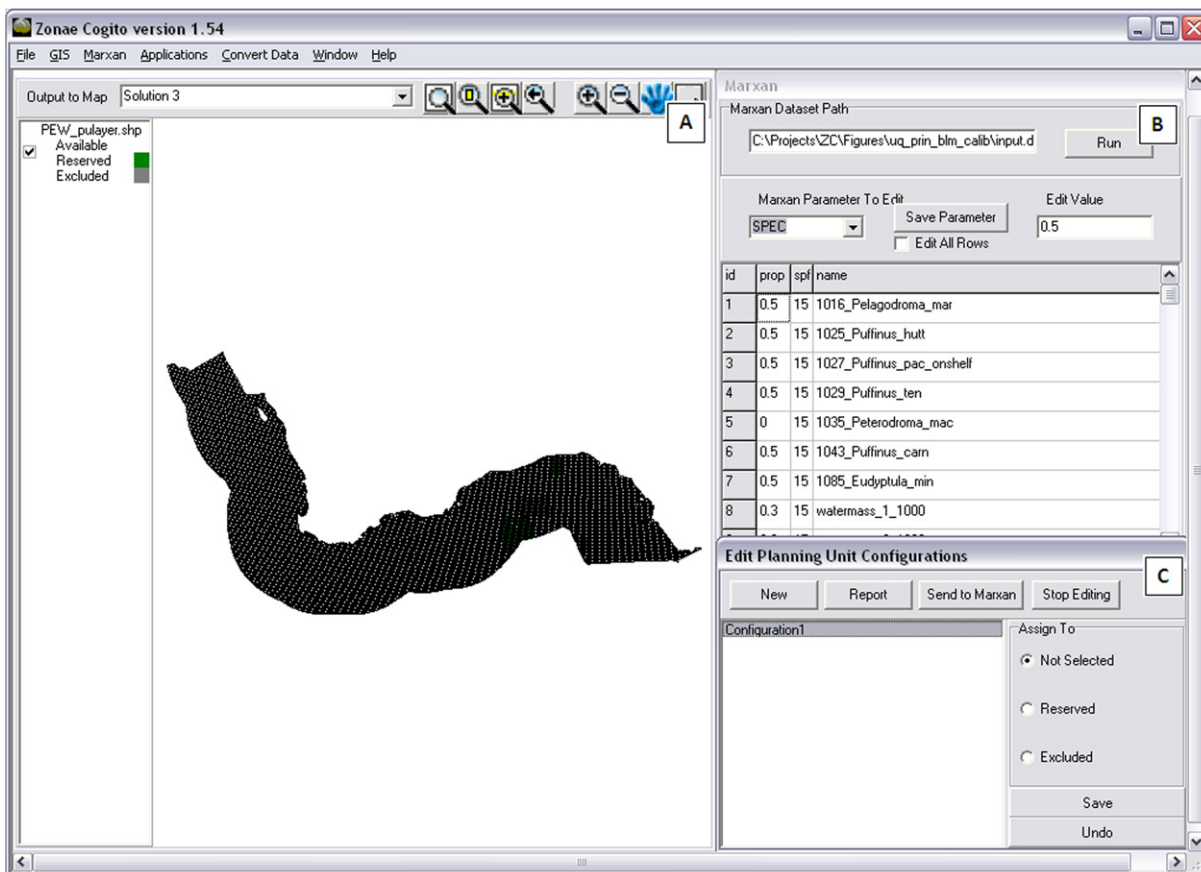


Fig. 1. A screenshot of the Zonae Cogito graphical user interface. Three modules are pictured here; A- the GIS display, B- the Marxan parameter modification module, and C- the configuration editor.

The tool iterates through each .dbf table in the specified folder, and converts the full relational matrix into the necessary Marxan input files. The ZC 'convert ZStats' tool converts the output of the ArcGIS Zonal Statistics tool to a format consistent with the JoinDBF Tables puvspr tool.

The tools facilitate the assembly of new databases, by easing the process of adding, updating or removing features from the analysis. The tools do not obviate the need for a commercial GIS in pre-processing of data for Marxan, but rather simplify the construction of databases once the necessary geoprocessing has been performed. By separating the GIS intensive data synthesis process from the database selection and development process, the tools offer increased flexibility in Marxan database design even for non-GIS savvy users. Through the use of these tools Marxan end users can ask a GIS user to summarize all potential features of interest in advance, and then subsequently select only a subset of those features to include in a Marxan database.

4.1.4. Calibration support

Marxan calibration can be divided into two general categories; annealing and runtime calibration – which includes the cooling rate, number of steps in a run, and number of runs; and objective function calibration – where the relative weighting of the individual components of the objective function are adjusted. The current release of ZC provides assistance for objective function calibration, with additional support for runtime parameters planned in future releases.

Marxan's objective function combines planning unit cost, boundary length, and conservation feature target shortfall into a single score to evaluate solution quality. Proper calibration can be difficult because there is no fundamental ecological or economic theory that tells us how to weight the length of the reserve system boundary relative to economic costs or missing biodiversity targets. Calibration can be tedious and time consuming because suggested calibration routines require numerous iterations and repetitive manual manipulation of input and output (Ardron et al., 2008).

The calibration support tool in ZC is essentially a looping engine that generates new Marxan databases and populates them with the values of the calibration parameter from a range specified by the user. The output is automatically summarized for the user to review, freeing users from the tedious process of compiling calibration runs manually. In addition to calibration, the tool can also support exploratory analysis of systematically increasing or decreasing targets. We have found that such feedback is important to planners, who are often asked to choose targets with little knowledge about the likely costs or spatial requirements of achieving those objectives (Moilanen and Arponen, 2011).

4.1.5. Graphing engine

The ZC graphing functionality can be used to generate bar and scatter plot graphs. Simple bar graphs can quickly be generated to compare solutions based on cost, boundary length, and target shortfall, or to review target achievement within a solution (Fig. 2). The graphing engine can also be used to generate scatter plot graphs, useful in reviewing calibration output. All graphs can be exported to images (.bmp format) to share with non ZC users.

4.2. Interactive network design

4.2.1. Configuration editor

The *Configuration editor* allows modification of Marxan solutions through interactive selection of planning units via the mapping interface or by attribute specification through database query. New configurations can be populated with previously

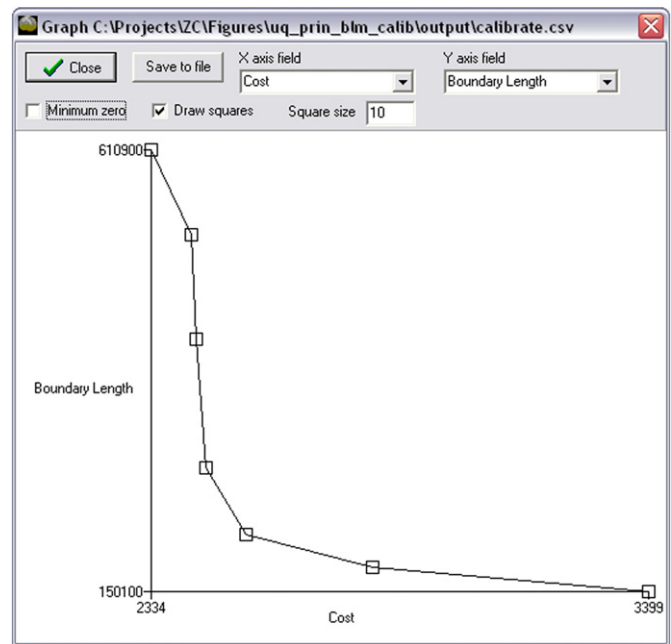


Fig. 2. Calibration results summary table graphed using the Zonae Cogito graphing functionality (screen shot). Here a trade off curve has been plotted between boundary length and cost, a common approach to calibrating the boundary length modifier parameter in Marxan.

generated solutions, or through any other attribute of the planning unit shapefile. Multiple configurations can be created within an individual project to explore a variety of alternative PA networks. After creation of a configuration, the status of the planning units within the configuration can be altered without impacting the original PA network. Planning units selected based on individual attributes or spatial location can be assigned to any status available in the analysis. The set of possible planning unit states is fixed for Marxan users (available, reserved, excluded) but can be dynamically defined in Marxan with Zones projects. After editing a configuration, the Marxan reporting engine is used to provide the same feedback as a Marxan generated solution. This allows users to interactively explore what happens to target achievement or total cost, as individual planning units are added or removed from a network. Modified network configurations can then be used as the starting point for a new Marxan analysis. This allows an interactive network design processes to be combined with Marxan's optimization capabilities. The interactive design process facilitated by such tools has been recognized by practitioners as a preferred design approach to simply presenting solutions and asking for approval or disapproval (Ardron et al., 2008).

4.2.2. Summarize zones tool

The summarize zones tool was designed to expand the scope of information available to planners, and to facilitate evaluation of proposals generated outside of the ZC framework. It allows the user to quickly generate gap analyses to compare proposed networks to the project's objectives (Scott et al., 1993). The tool uses the project's planning unit shapefile and two additional files consistent with the base Marxan database. The tool generates a report summarizing feature representation by aggregating planning units into zones as specified by an attribute of the planning unit shapefile. Zones can be thought of as a classification structure into which each planning unit is placed. Planning units can belong to one and only one zone. The report calculates both the proportion and

absolute amount of each feature that occurs in each zone. The features to report on do not need to be included in the Marxan database, but they must be in a format consistent with the Marxan `puvsp.dat` and `spec.dat` files. This allows the flexibility to report on features that were not included or targeted in the original Marxan analysis. In addition to leveraging additional data for the spatial planning team, interaction with stakeholders groups not familiar with Marxan is facilitated through the use of a standard GIS file format for reporting. Stakeholder groups can submit a GIS based network proposal and quickly have it evaluated against the representation, cost and other assessment criteria in the analysis.

4.2.3. Export results

The spatial prioritization aspect of systematic conservation planning is one step in a larger process that draws on a variety of skill sets and expertise (Pressey and Bottrill, 2009). During the identification of possible networks, there is often a need to communicate network options to other members of the planning team (not directly involved in the prioritization work) as well as external stakeholders. ZC offers the ability to export proposed configurations as shapefiles or in keyhole markup language (.kml). Shapefiles are compatible with most GIS packages, and .kml is used by Google Earth and Google Maps. The .kml export ability allows users to utilize the freely available and interactive Google tools for desktop and web based mapping. Results can also be exported as an image (.bmp format) for users without any access to a GIS.

4.2.4. Cluster analysis & solution similarity

Marxan analysis frequently produces hundreds of potential network solutions. While the opportunity to choose from a wide variety of potential solutions is good for beginning negotiation, it can be daunting to select a small set of solutions as a starting point for discussion. The problem of selecting a single solution from a large set of near optimal solutions is not unique to Marxan, and it exists in many protected area selection problems of substantial size (Sarkar et al., 2009). Marxan identifies the *best* solution (the solution with the lowest objective function value), but this is highly sensitive to the tool calibration, and is often not the lowest cost solution or the solution judged as best by other criteria or stakeholders. The cluster analysis tool in ZC aims to provide practitioners

with a manageable set of distinctly different options from which to start a dialog amongst stakeholders.

The tool uses automated classification and ordination methods to cluster Marxan solutions, from which a smaller set of solutions can be identified that captures the greatest diversity in the solution space. This is accomplished by dividing the solutions based on the number of shared planning units, thus offering users a way to explore solutions that are the most spatially distinct. This technique was used successfully to identify candidate solutions for working group evaluation during the development of the Channel Islands National Marine Sanctuary in the United States (Airame, 2005).

Cluster analysis within Zonae Cogito is automated by leveraging the R Project Statistical Computing package (Linke et al., 2011; R Development Core Team, 2006) and three associated packages, `vegan` for dissimilarity and clustering (Oksanen et al., 2009), `labdsv` for non-metric multidimensional scaling (NMDS) (Roberts, 2010), and `rgl` for 3-D visualization of output (Adler and Murdoch, 2005). To create the clusters the solutions matrix is used to calculate a Bray–Curtis dissimilarity matrix. The Bray–Curtis dissimilarity is favored as a dissimilarity measure because it ignores joint absences (Faith et al., 1987), when sites are not selected in either solution which is predominantly the case in a Marxan solutions matrix. Hierarchical cluster analysis is used to partition the Bray–Curtis dissimilarity matrix into the specified number of clusters (Becker et al., 1988). Clustering begins with each solution being assigned to its own cluster. Clusters are then iteratively generated by merging the two most similar clusters at each stage and then recalculating the inter-cluster distance. Complete linkage clustering is used to merge classes by taking the maximum distance between cluster elements.

In addition to cluster identification for individual solutions, three visualizations of solution similarity are automatically generated to aid users in selecting representative solutions from each cluster. The first is a dendrogram of the hierarchical cluster analysis described above (Fig. 3). The other two use Kruskal's NMDS to generate two and three dimensional plots of the solutions (Cox and Cox, 2001). The R script used to generate clustering is written to a text file, so that users can easily modify clustering parameters or method.

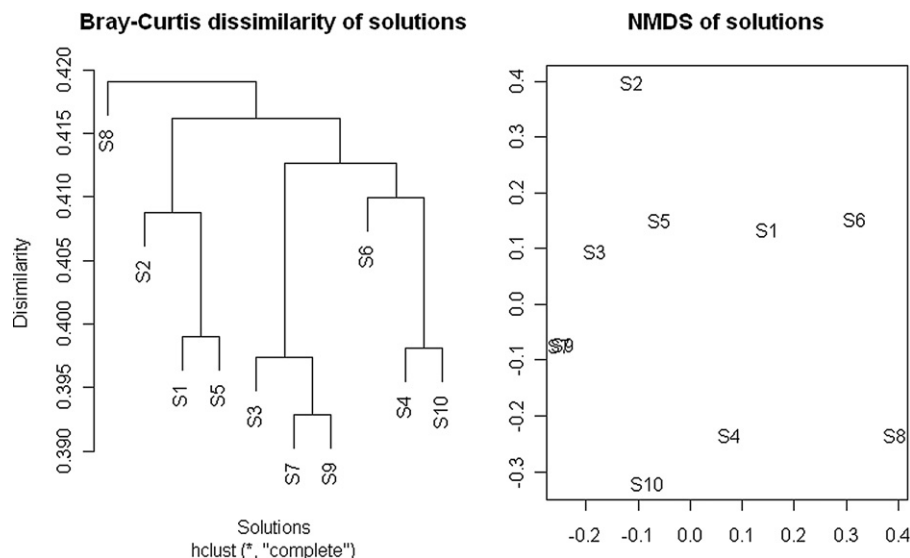


Fig. 3. Sample output from cluster analysis toolset in Zonae Cogito. On the left is a dendrogram of Bray–Curtis dissimilarity of 10 solutions; on the right is a two dimensional plot of solution similarity in NMDS space. Both are produced automatically when Marxan is run through ZC for all users with R installed.

5. Future development

We have utilized an open source GIS engine in the software (MapWindow ActiveX Control) to facilitate free use by users that do not own commercial GIS packages. We plan to migrate the source code for the tools to a platform independent compiler so the software can be run on a range of operating systems. We view the software as a generic toolkit for conservation planning and will continue to integrate additional algorithms and software systems. These changes will enhance both functionality and utility, and expand the scope of problems that it can help users to solve.

6. Case studies

6.1. Supporting community driven protected areas in the Solomon Islands

In the Solomon Islands province of Choiseul, The Nature Conservancy (TNC) has worked closely with the Luru Land Conference of Tribal Communities (LLCTC) for nine years to build bottom-up support for a network of locally implemented and managed protected areas. Through the LLCTC, the communities of Choiseul have committed to designating at least one marine and one terrestrial protected area (PA) in each of the island's 12 wards, by the end of 2012. These PAs are intended to form a network that conserves at least 10% of all habitats on Choiseul, as well as a range of culturally and economically important natural resources such as fish spawning aggregations and turtle rookeries. Conservation capacity within the LLCTC remains limited and the development of the network is incremental by necessity and dependent on community driven opportunities which are largely unpredictable. Because of this need for opportunism, a conventional, static systematic conservation plan does not represent an effective decision support system. *Zonae Cogito* (ZC) was used to enable the LLCTC and local TNC staff to work with communities in the field to rapidly identify the best placement of PAs when opportunities arise. This process is described in detail in Game et al. (Game et al., 2011).

The following features of ZC made the software uniquely appropriate for decision support in the Solomon Islands context. ZC's small size and computing requirements meant it could be easily used on the basic laptops of LLCTC field staff. Initial data manipulation and Marxan database development was supported by TNC staff, so there was no need for LLCTC staff to learn or use a sophisticated GIS package.

The *GIS platform* enabled display of Marxan solution outputs overlaid on a satellite image of the area. This provided communities with the contextual information needed to recognize the areas captured by selected planning units, and which planning units contained those sites proposed by the communities. While the use of planning units is essential to the mathematical formulation of systematic conservation planning problems, the impact of placing an individual planning unit into a PA is often abstract to planners and stakeholders. By looking at the planning units in the context of additional map features that community members were more familiar with, members were able to move beyond the abstraction of the planning unit and consider the impact of proposed PA networks.

The *Configuration editor* and *Summarize Zones* tools provided the ability to edit Marxan scenarios live, and enabled communities to rapidly explore what proposed PAs would contribute toward overall network goals, and what the consequences of excluding areas from the network would be for target achievement. This commitment to dynamic and locally contextualized decision making, avoided the need to present conservation priority maps which can be easily misinterpreted and cause conflict.

The *graphing engine*, facilitated reporting on target achievement graphically rather than in text format. This enabled these results to be easily interpreted and shared with the communities and LLCTC. Similarly, because the assessment is always up to date, it is straightforward for the LLCTC to report on the current level of representation within the network, and highlight remaining gaps in meeting targets. As such, the process also serves as a continuous gap assessment. This information can also be rapidly rolled-up to help report on national conservation achievements required under international agreements such as the Convention on Biological Diversity (CBD, 2006). Finally, the *export results* tool provided the ability to export the current solution set as a .kml. This facilitated the rapid sharing of LLCTC identified PA networks and proposed sites with TNC, the government, and private donors.

6.2. Marine protected area design in the Commonwealth waters of Australia

The Australian exclusive economic zone (EEZ), the marine area within 200 nautical miles of the coast, is the 3rd largest in the world, covering an area larger than the land mass of Australia itself. In both national and international agreements, Australia has committed to the establishment of a comprehensive, adequate, and representative (CAR) network of marine protected areas by 2012. Within commonwealth waters this commitment is led by the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), formerly the Department of Environment, Water, Heritage and the Arts (Commonwealth of Australia, 2010). Marxan was chosen as a decision support tool for the process because the objective of the tool aligned closely with the CAR principles guiding the network identification process (Commonwealth of Australia, 1999).

The EEZ was divided into five marine planning regions each of which had a dedicated marine planning team within SEWPaC, responsible for the planning in the region. The Commonwealth partnered with The University of Queensland (UQ) in 2008, to provide technical support for the implementation of Marxan. At the time only a beta version of *Zonae Cogito* (ZC) was available. Three elements of the planning process directed development of additional ZC functionality to support the SEWPaC:

- 1 Division of labor – The SEWPaC planning teams were responsible for running Marxan and modifying its output, but the technical processing of the Marxan input files was completed by the Environmental Resources Information Network (ERIN, the spatial data and analysis agency of the Australian government), and UQ.
- 2 Real time accounting – Marxan produces static network solutions, but the planning teams needed the ability to modify network proposals and then report against target achievement based on modifications to the network.
- 3 Detailed cost reporting – Marxan minimizes cost to a single cost surface, which is often an aggregation of number of different factors. The planning teams required the ability to segregate the overall cost into its individual factors.

The structure of the process meant that SEWPaC planning teams (who ran Marxan) did not have access to the GIS software used by ERIN and UQ to develop the databases. Because they did not have desktop GIS software, the teams used the *GIS platform* of ZC to visualize Marxan output. This allowed the planning teams to review spatial configurations without having to install and learn a GIS, or send the Marxan results off to another department for processing. The use of the ZC GIS platform did not replace the GIS platform used to develop the input files or create display quality

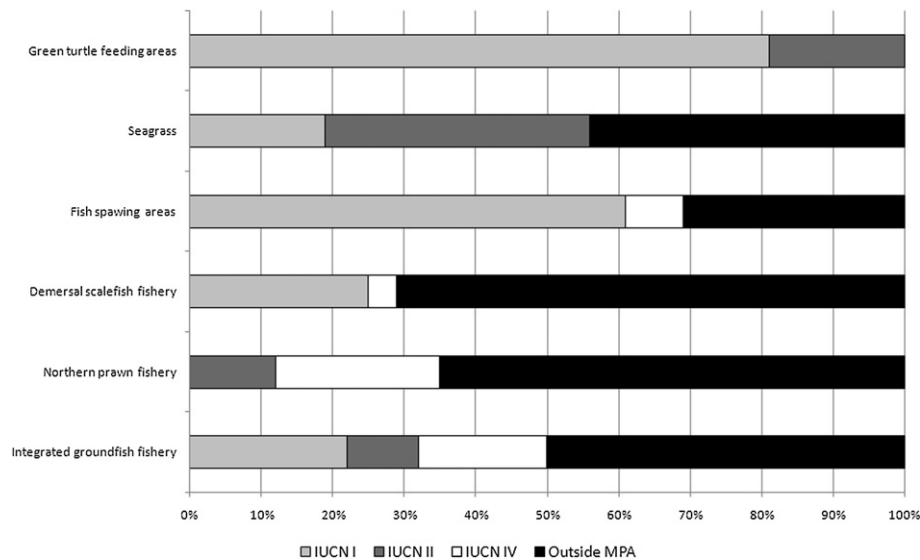


Fig. 4. Example output from the *Summarize Zones* tool. The proportion of each feature is reported based on extent within the management areas considered in the analysis. The tool provides coverage for both biodiversity and socio-economic features.

maps for the planning process. It allowed the planning teams to focus on the planning process rather than attempting to become technically proficient in a GIS. It also allowed the teams to take advantage of the technical expertise of ERIN for tasks that required that expertise, while not burdening them with generating a display for every solution from the Marxan analysis.

The *Configuration editor* was used to make changes to network proposals and evaluate those changes in real time. The tool provided real time feedback to planning teams about the impact of adding or removing planning units from a network proposal on each conservation feature. By altering a configuration within the tool and sending the output back to Marxan, the most efficient areas for meeting targets not already represented within the modified network could be identified. Once a proposed network configuration was developed, the proposal could be exported to a shapefile for compatibility with the GIS software used by ERIN for developing detailed maps and conducting additional analysis.

The *Summarize Zones* tool was designed to provide more detailed feedback on target achievement and costs of different regions or zones within the network. This tool was designed to meet the requirements of a multiple-use zoning process, with a particular focus on the socio-economic impacts of zoning. In addition to reporting on conservation features and aggregate cost (using the Marxan engine), here the summarize zones tool was used with more detailed socio-economic information than was included in the original Marxan database. Because Marxan uses a single cost surface against which to minimize impact, the actual impacts to individual stakeholders can be hard to decipher by looking only at the provided Marxan output. This difficulty was further compounded because the cost used in any single run was an aggregate of multiple different interests, and in this aggregated form the units did not easily translate into a meaningful index of overall cost. The raw data on each individual socio-economic feature was summarized for use within the tool. The *Summarize Zones* tool used the absolute value of each individual feature of interest, while the Marxan cost surface dealt with weighted aggregate cost. The absolute values were important in reporting because they were the closest estimates of expected impacts to the individual stakeholders. For commercial fisheries this meant summarizing Gross Value of Product (GVP) for each fishery by method of catch, while for petroleum leases, it meant summarizing data on both the extent and number of leases present in each

planning unit. Zones on which to report were defined based on the planning units of the analysis. Simple reports were generated based directly upon Marxan output to provide more detailed information about individual Marxan solutions. More complex reports considered multiple-use zoning to provide network level reporting (Fig. 4).

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References

- Adler, D., Murdoch, D., 2005. rgl: 3D Visualization Device System (OpenGL).
- Airame, S., 2005. Channel islands national marine Sanctuary: advancing the science and Policy of marine protected areas. In: Wright, D., Scholz, A. (Eds.), *Place Matters*. Oregon State University Press, Corvallis.
- Ames, D.P., 2007. MapWinGIS Reference Manual: A Function Guide for the Free MapWindow GIS ActiveX map Component. Idaho State University, Idaho Falls, ID.
- Ardron, J.A., Possingham, H.P., Klein, C.J., 2008. Marxan Good Practices Handbook. External review version: May 17 2008. Pacific Marine Analysis and Research Association, Vancouver, BC, Canada. www.pacmara.org 155.
- Ball, I., Possingham, H.P., Watts, M.E., 2009. Marxan and relatives: software for spatial conservation prioritization. In: Moilanen, A., Possingham, H.P., Wilson, K.A. (Eds.), *Spatial Conservation Prioritization*. Oxford University Press, Oxford.
- Ball, I.R., Possingham, H.P., 2000. MARXAN (V1.8.2): Marine Reserve Design using Spatially Explicit Annealing, A Manual.
- Becker, R.A., Chambers, J.M., Wilks, A.R., 1988. *The New S Language*. Wadsworth & Brooks/Cole.
- Camm, J.D., Polasky, S., Solow, A., Csuti, B., 1996. A note on optimal algorithms for reserve site selection. *Biological Conservation* 78 (3), 353–355.
- CBD, 2006. Decisions adopted by the Conference of the Parties to the Convention on Biological Diversity at its eighth meeting (Decision VIII/15, Annex IV). Convention on Biological Diversity Curitiba, Brazil.
- Commonwealth of Australia, 1999. Australian guidelines for establishing the national reserve system. In: Environment Australia. Commonwealth of Australia, Canberra Cat. No. S15910.
- Commonwealth of Australia. 2010. Administrative Arrangements Order. Cat. No. S15910.

- Cox, T.F., Cox, M.A.A., 2001. *Multidimensional Scaling*, second ed. Chapman & Hall/CRC, Boca Raton, FL.
- ESRI, 2009. ArcGIS Desktop 9.3 Redlands, CA.
- Faith, D.P., Minchin, P.R., Belbin, L., 1987. Compositional dissimilarity as a robust measure of ecological distance. *Plant Ecology* 69 (1), 57–68.
- 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., 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), 1733–1744.
- Game, E.T., Lipsett-Moore, G., Hamilton, R., Peterson, N., Kereseke, J., Atu, W., Watts, M., Possingham, H., 2011. Informed opportunism for conservation planning in the Solomon Islands. *Conservation Letters* 4 (1), 38–46.
- Green, A., Smith, S.E., Lipsett-Moore, G., Groves, C., Peterson, N., Sheppard, S., Lokani, P., Hamilton, R., Almany, J., Aitsi, J., Bualia, L., 2009. Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx* 43 (4), 488–498.
- Groves, C.R., Jensen, D.B., Valutis, L.L., Redford, K.H., Shaffer, M.L., Scott, M., Baumgartner, J.V., Higgins, J.V., Beck, M.W., Anderson, M.G., 2002. Planning for biodiversity conservation: putting conservation science into practice. *Bioscience* 52, 499–512.
- Joppa, L.N., Pfaff, A., 2009. High and far: biases in the location of protected areas. *PLoS ONE* 4 (12), e8273.
- Kirkpatrick, J.B., 1983. An iterative method for establishing priorities for the selection of nature reserves: an example from Tasmania. *Biological Conservation* 25, 127–134.
- Knight, A.T., Cowling, R.M., 2007. Embracing opportunism in the selection of priority conservation areas. *Conservation Biology* 21 (4), 1124–1126.
- Lagabrielle, E., Botta, A., Daré, W., David, D., Aubert, S., Fabricius, C., 2010. Modelling with stakeholders to integrate biodiversity into land-use planning - Lessons learned in Réunion Island (Western Indian Ocean). *Environmental Modelling & Software* 25 (11), 1413–1427.
- Leslie, H., Ruckelshaus, M., Ball, I.R., Andelman, S., Possingham, H.P., 2003. Using siting algorithms in the design of marine reserve networks. *Ecological Applications* 13 (1), S185–S198.
- Linke, S., Watts, M., Stewart, R., Possingham, H.P., 2011. Using multivariate analysis to deliver conservation planning products that align with practitioner needs. *Ecography* 34 (2), 203–207.
- Moilanen, A., 2007. Landscape Zonation, benefit functions and target-based planning: unifying reserve selection strategies. *Biological Conservation* 134 (4), 571–579.
- Moilanen, A., Arponen, A., 2011. Setting conservation targets under budgetary constraints. *Biological Conservation* 144 (1), 650–653.
- Moilanen, A., Possingham, H.P., Wilson, K.A., 2009. *Spatial Conservation Prioritization*. Oxford University Press, Oxford.
- Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2009. *Community Ecology Package*.
- Possingham, H.P., Ball, I., Andelman, S., 2000. Mathematical methods for identifying representative reserve networks. In: Ferson, S., Burgman, M. (Eds.), *Quantitative Methods for Conservation Biology*. Springer-Verlag, New York, pp. 291–305.
- Possingham, H.P., Wilson, K.A., Andelman, S.J., Vyne, C.H., 2006. *Protected areas: goals, limitation and design*. In: Groom, M.J., Meffe, G.K., Carroll, C.R. (Eds.), *Principles of Conservation Biology*, third ed. Sinauer Associates, Inc., Sunderland, MA.
- Pressey, R.L., 1994. Ad hoc reservations: forward or backwards steps in developing representative reserve systems? *Conservation Biology* 8, 662–668.
- Pressey, R.L., Bottrill, M.C., 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. *Oryx* 43 (4), 464–475.
- Pressey, R.L., Matthews, W.S., Barrett, T.W., Ridges, M., 2009. The C-Plan conservation planning system: origins, applications, and possible futures. In: Moilanen, H.P., Possingham, H.P., Wilson, K.A. (Eds.), *Spatial models for conservation*. Oxford University Press, Oxford.
- Pressey, R.L., Possingham, H.P., Margules, C.R., 1996. Optimality in reserve selection algorithms: when does it matter and how much? *Biological Conservation* 76 (3), 259–267.
- Pressey, R.L., Tully, S.L., 1994. The cost of ad hoc reservation – a case-study in western New South Wales. *Australian Journal of Ecology* 19 (4), 375–384.
- R Development Core Team, 2006. *R: a language and environment for statistical computing*. In: R Foundation for Statistical Computing Vienna, Austria.
- Riolo, F., 2005. PANDA (Protected Areas Network Design Application). <http://www.mappamondogis.it/>.
- Roberts, D.W., 2010. *Labdsv: Ordination and Multivariate Analysis for Ecology*.
- Sarkar, S., Fuller, T., Aggarwal, A., Moffett, A., Kelley, C.D., 2009. The ConSNet software platform for systematic conservation planning. In: Moilanen, H.P., Possingham, H.P., Wilson, K.A. (Eds.), *Spatial Conservation Prioritization*. Oxford University Press, Oxford.
- 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., Andelman, S., 2006. Biodiversity conservation planning tools: present status and challenges for the future. *Annual Review of Environment and Resources* 31, 123–159.
- Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., D'Erchia, F., Edwards Jr., Thomas C., Ulliman, J., Wright, R.G., 1993. *Gap analysis: a geographic approach to protection of biological diversity*. *Wildlife Monographs* 123, 3–41.
- Smith, R.J., 2004. *Conservation Land-Use Zoning (CLUZ) Software*. Durrell Institute of Conservation and Ecology, Canterbury, UK. <http://www.kent.ac.uk/dice/cluz/>.
- Watts, M.E., Ball, I.R., Stewart, R.S., Klein, C.J., Wilson, K., Steinback, C., Lourival, R., Kircher, L., Possingham, H.P., 2009. Marxan with zones: software for optimal conservation based land- and sea-use zoning. *Environmental Modelling & Software* 24 (12), 1513–1521.