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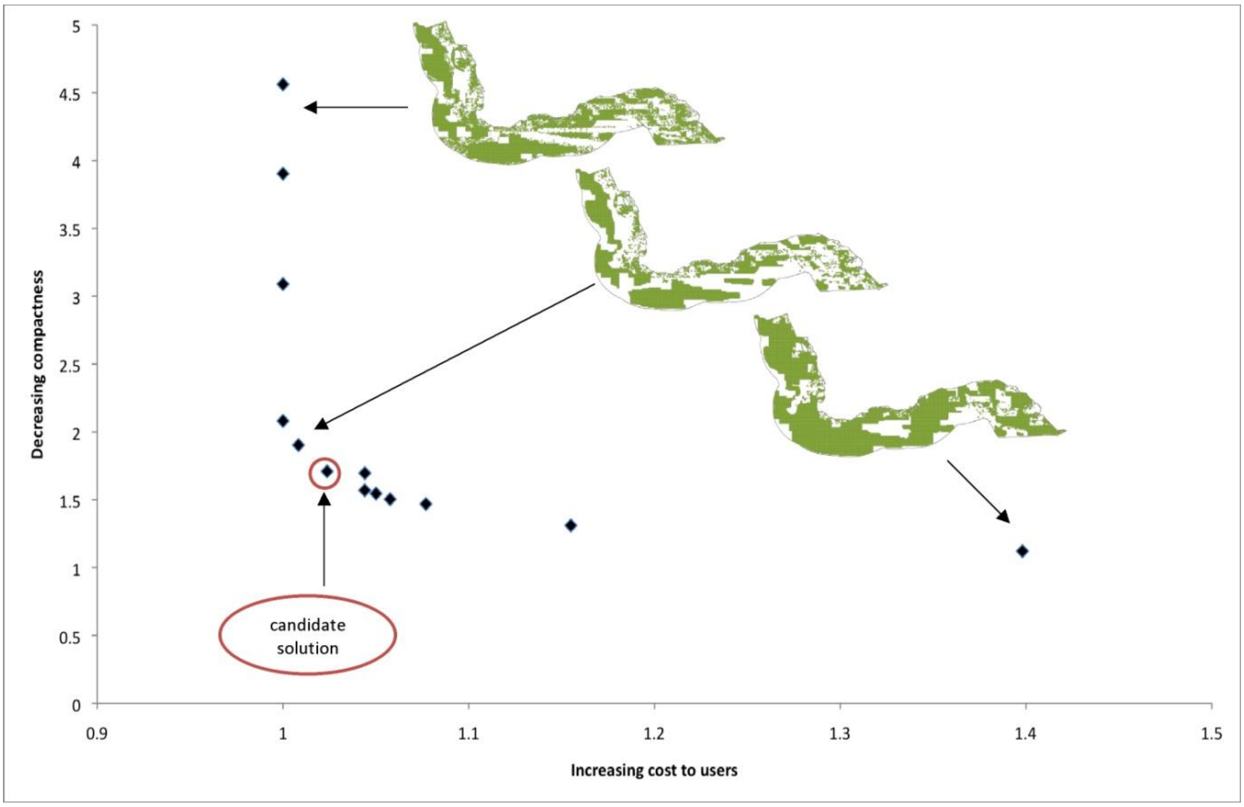


Figure 6.2—increasing the compactness of good sanctuary solutions increases the displacement costs that are imposed on users.

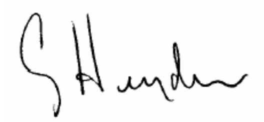
DISCLAIMER

The Pew Charitable Trusts have contracted The Ecology Centre of The University of Queensland to conduct an independent analysis of marine sanctuaries for the Commonwealth's South-west Marine Region. This document reports the findings of this independent analysis. Within the limited time and funding framework for delivery of the outcomes, the approach, structure and parameters to the analysis used by The Ecology Centre have been developed for this project independent of influence from the Pew Charitable Trusts. The outcomes of this project therefore represent the independent application of best scientific practice to the three objectives (described in the text below) as contracted by the Pew Charitable Trusts.

Declaration

This report/proposal has been prepared in accordance with UniQuest's Quality Management System, which is compliant with AS/NZS ISO 9000:2000.

Signed for and on behalf of UniQuest Pty Limited



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SUMMARY

This is the final report for the Pew South-west Australia Science Project, an independent analysis of marine sanctuaries for the Commonwealth's South-west Marine Region conducted by The Ecology Centre under contract to the Pew Charitable Trusts. The report concludes all of the deliverables under the contract terms: Biophysical Resource Assessment of the SW Marine Region, Scientific Consensus Statement, and a Marxan analysis for the SW Marine Region.

The main activities undertaken in the period covered by this contract are:

- one-day workshop of scientists to develop the consensus principles on MPA design
- presentation of a paper to the Australian Protected Areas Congress (APAC)
- a satellite forum convened at APAC to discuss the principles
- extensive email and web-based engagement with Australian scientists to review and revise the principles on MPA design to achieve a form of consensus
- preparation of a literature review of the history of Australia's National Representative System of Marine Protected Areas (NRSMPA)
- identification and negotiation with custodians of potentially suitable biophysical and socio-economic datasets relevant for a systematic conservation planning analysis
- capture of datasets relevant to the problem definition and analysis requirements
- review and assessment of the datasets relative to the design principles
- a Marxan analysis utilising the captured datasets and applying the consensus design principles
- review and synthesis of Marxan scenario outcomes
- presentation of final report to Pew and to DEWHA in Hobart.

Deliverable 1: Biophysical Resource Assessment

This task focused on assessing and securing the available data and information (Chapter 4) to be used as the resource base for the Marxan analysis (Chapter 6). The work involved searching for publicly available datasets and any other easily available datasets that may contain information relevant to the requirements of the SWMR conservation assessment. In total over 3300 individual datasets were identified. These were considered further using three broad categories:

1. Biological data
2. Physical data
3. Socio-economic data

Chapter 4 of this report sets out the approach for the acquisition of data and describes the assessment of data for its accuracy, coverage, and resolution. We report the methods for processing and formatting of data and present our data findings. A key aspect of this project has been the 'principles mapping' which involves mapping of the available datasets to the Scientific Principles (Deliverable 2) to ensure the data and the way we use it are relevant to the design context of the SWMR conservation assessment. This key task is discussed in detail in Chapter 5. It enabled us to identify appropriate datasets and be explicit about the way the datasets, the assumptions and surrogates are used in the Marxan analysis for the design of sanctuary zones in the SWMR.

Deliverable 2: Scientific Consensus Statement

This work has involved making contact with a large number of practicing scientists who work on aspects of MPA design or management. The disciplines involved include biophysical science, operations research and social science. Development of the consensus statement involved an initial workshop with invited scientists from the range of disciplines and an open forum at the Australian Protected Areas Conference, Noosa, November 2008. From these engagements, an initial draft statement was prepared. Subsequently, comments from all those invited or attending the workshop were sought, which resulted in a second version that was then distributed to the original workshop group and four major scientific societies and their list servers. A second round of comments was received from the workshop group, and 28 responses were generated by the web-based call for input. The process resulted in securing input and support from more than 50 practicing scientists, across all three disciplines, drawn from amongst the most credentialed and experienced of Australia's science community.

The consensus statement on MPA design principles that was finalised in May 2009 and published on The Ecology Centre web site (www.uq.edu.au/spatialecology/mpaguidelines) has been designed to provide scientists and scientifically-trained conservation planners with a tool to guide their inputs into MPA design procedures within their own jurisdictions. The model used to guide the development of the statement is the MPA aspect of the federal Australian bioregional planning system, and so the outcome is directly relevant to the SW project operating under this contract.

Deliverable 3: Marxan Analysis

The Marxan analysis addressed the problem of identifying a set of marine sanctuaries for the SW Region within the smallest amount of area that could include each of the conservation features to the required extent for the smallest displacement of existing uses (e.g. recreational fishing). The conservation features to be represented within the sanctuaries were determined and constrained by the best available data, and the extent to which they were included within the sanctuaries was established by reference to the Scientific Principles. Minimising displaced existing uses was also based on and constrained by the available data on costs and values associated with the various activities throughout the region.

The Marxan analysis was conducted by first developing a benchmark scenario to best represent the intent of the Scientific Principles. This scenario resulted in sets of sanctuaries each of which represents a good solution to the problem of identifying a set of sanctuaries that contain the conservation features and provide the smallest possible displacement of uses. We consider this set of solutions as providing one or more good candidate solutions to the problem of extent and location of sanctuaries across the region. Following the benchmark scenario, we develop five further scenarios that explore the issues associated with the cost of user displacement. These scenarios all meet the conservation feature targets and consider, as examples, the effect of providing preferential treatment to one or more uses, at a broad sector level. The scenarios show that it is possible to establish a set of sanctuaries that have lower costs on one use sector (such as the petroleum sector), but that this results in higher costs to the other users. We demonstrate that the benchmark scenario of sanctuaries provides an equitable allocation of reasonably low costs across each of the sectors for which we were able to obtain data.

The different costs to users imposed by the sanctuary solutions, as revealed by the scenario analyses, are most likely to be worst-case costs and we consider them to establish the outer bounds for the possible real costs. Real costs to the users are likely to be considerably less than those resulting from our analyses because the data on costs we have been able to access for this analysis have limitations—typically the cost data are of limited spatial resolution, and are of mixed types (dollar value, area of use, number of households, etc). Therefore, in the actual implementation of sanctuaries across the region, we would expect the costs to be much lower than we indicate in our solutions. This does not greatly affect the robustness of our sanctuaries assessment because we limit our interpretations of impacts on different sectors to the relative costs between those sectors. Nonetheless, we recognise that better data on costs could produce an assessment of this problem at a much finer scale, and provide outcomes more directly applicable to local scale implementation issues.

The benchmark scenario (Principles for Sanctuaries, Figure 6.3) provided a good candidate set of sanctuaries that included more than 30% of the area in the region occupied by each of 1,894 conservation features, and more than 50% of the area of occurrence of each of 57 EPBC listed species. Collectively, these features also represent all the major ecosystem types, gradients and processes found within the region, and we expect to provide for a high level of resilience to the impacts of changing ocean ecosystems. The conservation features in this candidate set of sanctuaries include representation of 1,465 species (mammals, fish, birds, invertebrates) and 486 surrogates (such as depth zones, seascape types, geomorphic structures, fish assemblages). The candidate set of sanctuaries spans about 50% of the area of the region, and at worst would displace users from between 19% (defence activities and commercial trawling) and 37% (shipping activity) of the region, depending on the sector. An adequate amount and type of data were available for 46 types of activities, and we grouped these into eight major classes of activity or use: shipping, defence, petroleum, recreational fishing, population pressure, commercial trawl fishing, commercial non-trawl fishing, and the Western Rock Lobster fishery. The real cost to those sectors/uses will depend on first, the distribution of their activities within the data blocks we use as a basis for estimating costs (costs are assigned homogeneously to a block in our analysis, whereas we know that all uses are actually spatially heterogeneous within a block), and second, on the extent to which displaced activities can be accommodated in non-sanctuary areas of the region.

We consider that the benchmark scenario provides a number of good sanctuary solutions, one of which could robustly form the backbone of a set of MPAs for the South-west Marine Region that included other zones of protection to supplement the sanctuaries. Implementation of the candidate set of sanctuaries, or any of the good solutions chosen from amongst our benchmark scenario, will provide the region with an unparalleled level of biodiversity protection amongst Australia's marine planning regions. No other region has conducted an assessment of this type to identify conservation features, will have achieved these levels of sanctuary protection for the biodiversity, nor have considered implementation of marine sanctuaries on this region-wide scale within the framework of an integrated cost minimisation process. This would make Australia the world leader in marine conservation and marine resource management—applying best scientific practice to achieve high quality cost-effective marine sanctuaries and conservation outcomes in the face of vast uncertainties and ever-growing pressures for economic development.

1. INTRODUCTION

In the early 1990s, the Australian government identified the need for a National Representative System of Marine Protected Areas (NRSMPA). This led to an agreement between the state and national governments to set up a NRSMPA within the Australian marine jurisdiction. The primary goal of the NRSMPA is to establish and manage a comprehensive, adequate and representative system of marine protected areas to:

- contribute to the long-term ecological viability of marine and estuarine systems,
- maintain ecological processes and systems, and
- protect Australia's biological diversity at all levels (DEWHA 2008).

The policy framework underpinning the establishment of the NRSMPA includes several different international and national agreements and strategies, notably the Convention on Biological Diversity and the Inter-governmental Agreement on the Environment (1992). Several guidance documents have been produced to support the development of the NRSMPA, including the Strategic Plan of Action for the NRSMPA and the Guidelines for Establishing the NRSMPA. In addition, the process has produced a bio-regionalisation dataset: the Integrated Marine and Coastal Regionalisation for Australia version 4 (IMCRA).

1.1 The South-West Marine Region

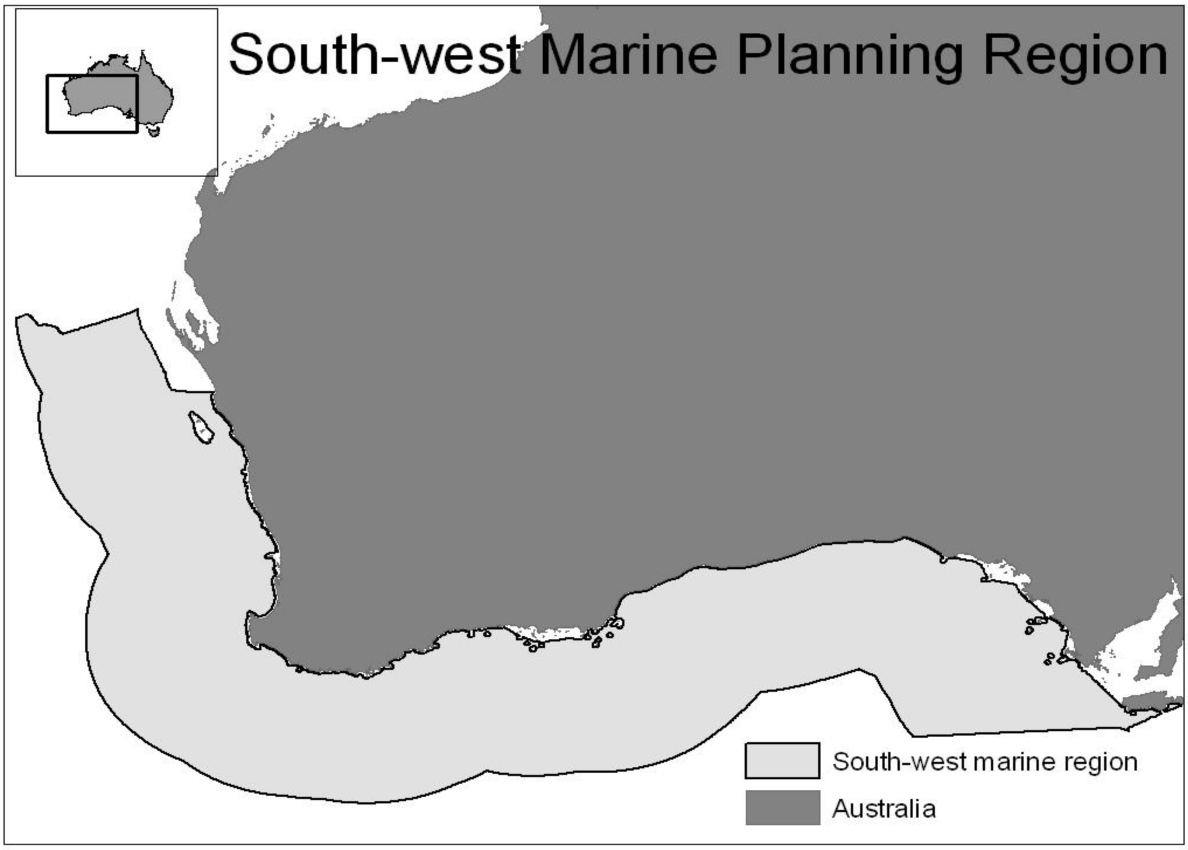
The South-west Marine Region (SWMR) encompasses the Commonwealth waters from near Kangaroo Island in South Australia extending to waters near Shark Bay in Western Australia (Figure 1.1). The SWMR covers about 1.2 million km^2 of coastal waters, continental shelf and deepwater ecosystems, and contains many endemic species, unique features, and highly-valued elements of biodiversity. It is important to note that the SWMR does not include the coastal waters inside the notional 3-nautical mile boundary, which are fully managed by the states of Western Australia and South Australia. The Department of Environment, Water, Heritage and the Arts (DEWHA) created the South-west Marine Bioregional Plan Bioregional Profile in 2007 to identify the values of the SWMR. The conservation values identified in the report include species listed under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, as well as key ecological features. These key ecological features were defined as species, groups of species, communities or unique seafloor features that are nationally or regionally important for:

- their ecological role
- biodiversity
- enhanced or high productivity

- aggregations of marine life, or
- endemism.

The Bioregional Profile also identifies human actions and values in this area, which include commercial fishing, tourism, shipping, petroleum exploration and production, defence activities and aquaculture (DEWHA 2007). The Bioregional Profile and associated reports provided the basis for this project - a review and compilation of available spatial datasets, including regionally significant ecological values as well as spatial representation of socio-economic values.

Figure 1.1. South-west Australia Marine Planning Region



The South-west Planning Region used for this project includes the SWMR, and where necessary/available includes datasets representing aspects of adjacent state waters and terrestrial issues. It is necessary to consider the adjacent terrestrial areas to be able to represent various threats and pressures that may affect the SWMR in a spatially explicit manner. These pressures are taken into account within the Marxan phase of the work to, amongst others, choose solutions that reduce the possible pressures on potential marine sanctuaries and reduce the possible conflict with existing uses and users.

1.2 Marine Protected Area

Throughout this project the term Marine Protected Area (MPA) is used in the sense of a clearly defined geographical area of land and water that is recognised, dedicated and managed through legal or other effective means to achieve the long-term conservation of nature with associated ecosystem services and cultural values (after Dudley 2008). The primary goal of IUCN resolution 17.38 called for "the creation of a global representative network of MPAs" linked to "management in accordance with the principles of the World Conservation Strategy of human activities that use or affect the marine environment" (Resolution 17.38 of the 17th General Assembly of the IUCN, 1988).

The World Conservation Strategy objectives are:

- maintenance of essential ecological processes and life support systems,
- preservation of genetic diversity, and
- sustainable utilisation of species and ecosystems.

An MPA may address or contribute to addressing all of these objectives and may contain dedicated management zones permitting multiple uses, a combination of use and reserve zones, or reserve zones only. Where an MPA contains reserve zones (marine sanctuaries), they must provide for the high protection of biodiversity from threats and human activities.

In the Australian context, MPA networks are *in situ* management tools that can deliver both on- and off-MPA conservation benefits. Connectivity within and across coastal and marine systems requires complementary management arrangements in off-MPA areas to achieve a high level of conservation of Australia's marine biodiversity. Some of the external (off-MPA) human-impact issues are difficult to manage, and it is likely that a number of different types of management strategies , both in terms of MPA design and off-MPA management will be needed to deliver conservation solutions.

Irrespective of the governance or regulatory context, effective marine conservation requires a whole-of-ocean integrated management regime that addresses well-defined conservation objectives. This regime may include a multiple use MPA network, but must always include zones of high protection (sanctuaries) within MPAs that provide for effective conservation outcomes. The management regime should consist of MPAs as well as integrated strategies and actions that operate outside of the MPAs to provide complementary management to assist with achievement of whole-of-ocean conservation outcomes.

The challenge for conservation planners is to design options that meet the needs of intersectoral issues. Working with a range of management tools, including sanctuaries that provide for high-level biodiversity protection, a well-designed MPA network is the cornerstone of the long term conservation of Australia's marine biodiversity.

1.3 Systematic Conservation Planning for Australia's Marine Regions

Systematic conservation planning is characterised by two key elements: first the use of explicit objectives to guide all planning decisions, and second the use of systematic tools to ensure efficient solutions are achieved across all the relevant competing objectives. The application of systematic conservation planning to large marine regions is beset with many problems, which some consider renders these approaches ineffective and too difficult, to the extent that marine conservation planning is typically done in an *ad hoc* process.

At the top of the list of perceived problems is almost always a lack of appropriate data and knowledge to be able to appropriately inform the planning decisions. However, as experience across all of Australia's jurisdictions has shown, such decisions continue to be made, with or without good data/knowledge, leading to (at times) weak conservation outcomes. The other issues often cited as problems include the vast scales of connectedness of the large/migratory species, the very large number of species and the complex structure of their interactions, the large scales and complex structures of the ocean ecosystems, and the inadequacy of the present day models and assumptions that apply to marine ecosystems and their dynamics. All of this is true. But even weak decisions can be improved through careful and structured decision systems, and particularly those that explicitly recognise the many decision uncertainties.

A further dominant issue affecting conservation planning in Australia's marine regions is the substantial commitment to multiple ocean uses that is embedded in legislation, both state and federal. These wealth-generating systems have a proper place in Australia's social and economic development, and the challenge for conservation planners is to create conservation systems that provide for optimisation of both the conservation of, and wealth-generation from, the ocean's resources. From the resource sector perspective, this has been operationalised through regulation and policies of Ecologically Sustainable Development (ESD). From the conservation sector perspective, this is operationalised through the NRSMPA, which is intended to provide conservation outcomes that are consistent with ESD.

From the ESD perspective, most of the focus and activities have been directed towards maintenance of the wealth-generating activities, dealing with conservation issues as a secondary set of issues. This has resulted in a very production-oriented governance framework, together with a strong focus on production criteria and benchmarks. From the conservation perspective, the dominance (in all jurisdictions) of the production ethic has resulted in very strong resistance to effective implementation of the NRSMPA. The net outcome has been that, apart from a few very high profile iconic examples, Australia's MPA system is characterised by two features: it occupies the corners of Australia's ocean realms where there are no or limited uses; and where there are uses, such uses have taken precedence resulting in a predominance of MPAs comprising largely multiple use zones over sanctuary (reserve) zones.

It is widely considered that much of Australia's marine jurisdiction remains in relatively good condition, although an objective analysis indicates that there are many issues and threats, and that there are a large number of localised major issues. These are mostly coastal, and somewhat historic, but there are also a number of key continent-scale issues that affect the Commonwealth's waters. These include climate-driven changes in the dynamics of ocean currents; the highly pervasive and impacting effects of commercial and recreational fishing on a diverse but low-productivity fauna; the site specific issues of oil/gas production; the coastal and shoreline development creep and pollution; and the major land-based sources of sediment and nutrient-laden runoff that extend, in places, well into Commonwealth waters. While these issues would normally indicate a high priority for high quality MPAs to protect and conserve the biodiversity (and the natural resources), they also underpin a highly protective stance that has been taken by the production sectors against establishment of MPAs, which are universally viewed as a process that further alienates existing or potential productive territory. Hence, the planning for MPAs raises many forms of objection from a range of users of the marine ecosystems, many of whom consider (probably correctly) that they have a regulatory and well-established set of rights to continue their intended uses of the oceans irrespective of conservation interests. This sets the stage for competition between the various interests, expressed as competing objectives for the same areas of the ocean ecosystems because of the incompatibility across the number of intended uses.

In Australia's waters, and certainly on the continental shelf, the levels of local endemism in the flora and fauna are extremely high, and so the consequences of weak conservation decisions are often significant. In this high-stakes planning system, the strong push against MPAs can be best dealt with through the systematic and relatively objective approach of systematic conservation planning. This makes the objectives, the input information, the outcomes and the costs and benefits explicit for all to consider. In this planning framework, almost all forms of existing knowledge can be incorporated, providing a platform for the exploration of various different solutions to achieve the conservation objectives.

Systematic conservation planning operates through an explicit and structured approach to the decision problem. In this project, the software package Marxan is used to enable a very large number of conservation features to be included within the decision problem. Like all such planning systems, the software does not produce a definitive solution but provides decision support—in the form of a range of products that present options for planners, managers and stakeholders to work with in reaching final agreement about an MPA system. The software does not provide the single answer, but rather provides a range of good answers to the conservation of biodiversity, leaving the final choice to be resolved through other decision systems (usually the political framework). It also allows users to explore different parts of the conservation problem using scenarios to aid in defining the final structure of a conservation problem, for example, to explore different weightings for socio-economic cost, or different conservation feature targets. To the extent that the final choice is close to one or more of the candidate solutions offered by the software, then the costs and benefits of such a solution can be best understood by all decision makers and the stakeholders. Where a final choice departs from any of the candidate solutions, the implications for both biodiversity and users can be subsequently explored through the use of the decision support 'model' that has been constructed. This can be conducted in near-real time, and is the basis of a number of interactive real-time decision support approaches in natural resource management.

Systematic Conservation Planning

The science of systematic conservation planning is defined by two characteristics. The first is the use of explicit and often quantitative objectives. This means that planners and managers must be clear about what they intend to achieve and be accountable for decisions that should make progress towards achievement of their objectives. The second characteristic is use of the principle of complementarity. Since the first publication in the field (in 1983), systematic methods have identified networks of conservation areas that are complementary to one another in terms of collectively achieving objectives. Areas identified in this way will each contain, for example, different species or complementary portions of the required areas of different habitat types. This represents a major improvement on the simple scoring procedures that were used extensively before the advent of systematic methods.

More generally, systematic conservation planning involves working through a structured, transparent and defensible process of decision making. One of the key outcomes is an integrated system of conservation areas rather than a collection of conservation areas produced by a series of ad hoc decisions, each made more or less in isolation from the others. An integrated system of complementary conservation areas developed from systematic planning procedures is much more effective at achieving objectives for the persistence of biodiversity and other natural values within the limits of available conservation resources.

(Adapted from Pressey and Bottrill 2009)

1.4 This Project

The PEW Charitable Trusts and partners have formed the *Save Our Marine Life* collaboration to ensure that globally important marine processes and features are included within Australia's NRSMPA as part of the South-west Regional Planning process now underway. The University of Queensland's Ecology Centre has been selected to provide a body of work that illustrates scientific best practices for MPA planning in the South-west Marine Region (the second of Australia's Commonwealth marine bioregions to be targeted in the NRSMPA process). The Ecology Centre team was contracted to deliver:

1. A biophysical resource assessment summarising the currently available datasets for the region;
2. A scientific principles consensus statement (developed with input and endorsed by experts in the field) with respect to principles directing the design and implementation of the NRSMPA and how these principles can be applied to the SW Planning Region, and
3. A Marxan analysis for the region using the identified datasets and guided by the principles statement.

2. SCIENTIFIC PRINCIPLES CONSENSUS GUIDANCE STATEMENT

2.1 Background and Approach

The products generated from systematic conservation planning projects using decision support software (such as Marxan) are highly sensitive to the nature of the decisions made in the treatment of inputs. This includes not only sensitivity to the well-known input parameters such as the targets for achievement of specific conservation features, but outputs are also sensitive to the form of the decision problem. It is therefore always important to ensure that there is a relatively balanced decision structure in the input parameters (in the sense of what parameters to include or not include in the decision problem). Also, the presence, absence, extent, quality and surrogacy of data and information that can be used to represent each parameter are primary factors that can influence outputs. As a result, formulating the decision problem to correctly frame the problem to be solved, and making this clear and explicit together with inherent assumptions and underpinning models is always a critical first step in systematic conservation planning. In simple terms, this is to ensure that the decision support problem is reacting to the correct questions being asked of it, and is therefore most likely to provide solutions that are meaningful and of lasting significance.

The science behind the design and management of MPAs in the Australian context is highly complex, and is rapidly developing. The Ecology Centre, led by Hugh Possingham, has a highly experienced team of practicing conservation planning professional scientists, but even so we recognise that in such a dynamic and evolving field of science, there are differing scientific views about some of these structural decision (and other) issues discussed above. So, as in other areas of science (such as human health) where the scientific grounds for various issues and approaches are still developing and there are high risks attached to making a poor judgement, we considered that the correct and cautious approach was to assemble current scientific opinion across all the important issues and formulate a consensus view from a range of qualified and practicing scientists. While there are many basic principles that could have been used to guide the conservation assessment performed in this project, most relate to overseas situations, or to specific circumstances that do not closely match Australia's circumstances (jurisdictionally or ecologically). So, we decided to prepare a specific set of principles that would be especially suited to application in the Australian context to guide this project.

The objective of this work was to assemble a set of operational principles that would both guide the Marxan analysis to be conducted in this project and to provide a much-needed independent compilation of the principles that could be subsequently used by scientists and other conservation planning practitioners operating on aspects of the NRSMPA in Australia. To achieve this we canvassed the opinions and experience of a representative group of scientists currently practicing in the field of marine conservation science and with direct experience in marine protected areas in Australia.

This work has involved making contact with a large number of practicing scientists who work on aspects of MPA design or management. The disciplines involved include biophysical science, operations research and social science. Development of the consensus statement involved an initial workshop with invited scientists from the range of disciplines conducted at the University of Queensland and an open forum at the Australian Protected Areas Conference in late 2008. From these engagements, and based on the outline framework submitted to these two forums for consideration, an initial draft statement was prepared. This was extensively reviewed and revised within the UQ drafting team. Comments from all those invited and attending the workshop were sought by email and this resulted in a second version that was then distributed to the original workshop group and four major scientific societies and their list servers. All comments and resulting alterations have been tracked for auditing/diligence purposes. This call for second-round comments generated 28 responses, which the UQ drafting team then used to draw up the final version. The process overall has secured input from more than 50 practicing scientists in the design/management of MPAs, across all three disciplines, drawn from amongst the most credentialed and experienced of Australia's science community.

The consensus statement is intended to capture and reflect the present-day opinions of the contemporary science practitioners. It serves to provide scientists and scientifically-trained conservation planners with a tool to guide their inputs into MPA design procedures within their own jurisdictions. The statement is not intended to be a complete planning framework for the design/management of MPAs in Australia. The emphasis is on the issues that have a science-content, and where scientists might reasonably be expected and be able to provide input to an MPA design process. For the NRSMPA process outside the current project, the intention is to provide a peer-level document to the Australian science community for their guidance and support when they individually become engaged in MPA design issues within their own jurisdictions.

The model used to guide the development of the statement is the MPA aspect of the Commonwealth's Australian bioregional planning system. This approach was adopted so that principal purpose for the statement—a guidance statement that is directly relevant to the SW project operating under this contract—would also be fulfilled. We use the principles developed in this work to provide direct and explicit guidance for our work in developing scenarios and respective sets of candidate marine sanctuaries for the SWMR. This is termed 'principle mapping', and is discussed in detail in Chapter 5.

To stimulate interest and comment in the principles, the project team presented a paper at the Australian Protected Areas Congress in November 2008: 'What is scientific best practice for MPA design and selection', Stewart, Ward, Barr and Possingham (available at www.apac08.org.au/images/stories/apac%20papers%20web.pdf). The paper was supplemented with a small open forum at APAC, where additional inputs were secured.

2.2 The Guidance Statement

The full final version of the Guidance Statement is provided at Appendix 1, and is also available at www.uq.edu.au/spatialecology/mpaguidelines.

The intention of the guidance statement is to identify a set of science-based operational principles that:

- are flexible to available data, ecosystem types, and Australian jurisdictional settings;
- are robust to scales of planning;
- are practical to implement;
- reflect operational management issues;
- incorporate risk, uncertainty, precaution; and
- lead to measurable criteria for MPA management.

The principles are specifically focused on managing the uncertainty and risks inherent in designing effective and efficient MPAs in the absence of full knowledge of the biodiversity, the contemporary and developing threats, or the effectiveness of management strategies within and outside MPAs. The principles also establish the role for MPA-based conservation to assist in maintaining the resilience of Australia's marine populations, habitats and ecosystems in the face of the world's changing ocean climate.

The principles assume that a jurisdiction's MPA planning framework includes a science-based planning process, using expert-based analytic and systematic conservation planning approaches to MPA design. This guidance document therefore uses the systems logic and lexicon of systematic conservation planning (see Ardron *et al* 2008 for a detailed description).

In the design and planning for MPAs—given that Australian MPAs are legislated as multiple-use protected areas—the decision-making processes should effectively integrate both long term and short term environmental, economic, social and equity considerations. These Principles therefore endorse the concept of 'least cost', or efficiency, where an optimal MPA configuration is established to deliver on defined conservation objectives with the minimal economic and social cost to the community. The Principles presented here provide for the socio-economic values to be considered as an integral part of the design process to ensure that costs can be minimised while meeting quantitative conservation outcomes through zoning configurations.

The Principles strive to provide robust guidance at the operational science level, but they are limited in the extent to which they can assume/anticipate specific MPA design contexts (this also limits the extent to which any generic statement can provide detailed guidance). The intention is to provide a consensus of opinions on operational level science issues *from* current science practitioners *for* scientifically-qualified conservation planners. The guidance provided is expected to inform and contribute to, but not replace, a competent MPA design process operated within a suitable planning framework.

2.3 The Principles

The six Principles (outlined in Table 2.1) describe how to use science to support the design of an MPA network, and specifically in a decision problem of the scale and complexity of the SW Region. After developing these Principles, we have used them to guide the Marxan analysis in this project. The way in which we applied the Principles to the Marxan analysis within this project is termed Principle Mapping, and is described in more detail in Chapter 5.

Table 2.1 Outline of the Principles

(see <www.uq.edu.au/spatialecology/mpaguidelines> for the full description)

1. BIODIVERSITY PRIMACY	1.1 Planning Framework
	1.2 Biodiversity Data
	1.3 Maintaining Biodiversity
	1.4 Levels of Representation
2. MANAGEMENT CONSTRAINTS	2.1 Business Management
	2.2 Complementary Management
	2.3 Management Practicality
3. MULTIPLE OBJECTIVES	3.1 Use of Biodiversity
	3.2 Zoning
	3.3 Support Traditional Owners
	3.4 Support Low-Impact Fisheries
	3.5 Displaced Users
4. MANAGING THE THREATS	4.1 Avoid Known And Potential Threats
	4.2 Build Climate-Change Resilience
	4.3 Identify and Account For The Uncertainty
	4.4 Spread The Risks
5. MONITORING, ASSESSMENT & REPORTING	5.1 Performance Assessment
	5.2 Practical Monitoring
	5.3 Scientific Reference Sites
	5.4 Fund Adaptive Management
6. STAKEHOLDER ENGAGEMENT	6.1 Complementary Local Knowledge
	6.2 Community Acceptance and ‘Ownership’
	6.3 Community Engagement in Management

2.3.1. Biodiversity Primacy

The primary objective of an MPA system is to contribute to the conservation of marine species, habitats and ecosystems, to assist in the maintenance of marine ecosystem health and integrity, and to provide for the conservation needs of terrestrial species (such as seabirds) that may be reliant on marine resources. This Principle has been established so that the focus is kept on the biodiversity throughout the formulation of the MPA decision problem. Without this focus, there is a risk that the decision problem might be strongly influenced by, for example, surrogates that have only a limited linkage to the actual biodiversity patterns. Surrogates will play an important part in the structure of the MPA decision problem, but the surrogates themselves are rarely the actual focus of the conservation problem, so their use must be kept in proper perspective and balance within the problem formulation.

2.3.1.1 Planning Framework

This first section of the Principle provides guidance on the matter of choosing a planning region so that it appropriately represents the scale of the problem to be addressed. This includes ensuring that the planning region is large enough to represent the matters of concern but not so large that capturing data and knowledge to inform the decision problem is impractical.

In this project, the choice of the planning region and the subset of major spatial units were reasonably obvious, given our focus on the Commonwealth's SW region and the availability of the existing bioregional planning framework. We used the Provincial Bioregions as the spatial unit for planning in the off-shelf systems, and the Mesoscale Bioregions as the spatial unit for the on-shelf systems. The shelf bioregions are smaller than those off the shelf, representing the greater level of species turnover that is well recognised in the waters on the shelf compared to the deeper waters off the shelf.

2.3.1.2 Biodiversity Data

This section provides guidance to practitioners about how to deal with the usual problems of marine biodiversity data—such as availability, taxonomic and spatial patchiness, quality of taxonomic resolution, comparability across sampling programs, etc—in the context of making precautionary decisions about what to include or exclude from the decision problem. Amongst other issues, this section provides guidance about avoiding design bias (that may occur through the choice of only a subset of the biodiversity knowledge to represent within a decision problem), how to include elements of biodiversity that may have special importance, and how to provide a 'safety-net' approach to aspects of biodiversity for which only very limited knowledge exists (through the use of different types of surrogates).

For this project, we acquired data on a large range of biodiversity features to consider for inclusion in the decision problem. These data included species-level distribution of fish and invertebrates, the distribution of ecosystem processes such as the presence of persistent features of the Leeuwin Current, locations of important habitats and ecological features, and classifications of the biological, geomorphic and oceanographic systems of the planning region.

2.3.1.3 Maintaining Biodiversity

This section provides guidance about how to represent in the decision problem, the various ecosystem functions that provide for the maintenance of the natural patterns and processes of biodiversity. These include the need to explicitly represent spatial drivers of biodiversity (such as major currents or topographic features) and specific aspects of human use or existing degradation of the ecosystems that could influence the ongoing conservation of biodiversity within the MPA network. Guidance is also provided on how to maximise resilience and the likelihood of persistence through the use of a risk-averse approach to the design problem, such as by providing for explicit replication of features within the MPA network.

In this project, we applied this guidance in a number of ways—inclusion of specific ecosystem level processes such as representing a latitudinal gradient to provide species refuges against climate change impacts, identifying centres of population as a pressure on the ecosystems to be avoided when identifying MPAs, and applying the complementarity tools in Marxan to achieve compact and spatially contiguous solutions.

2.3.1.4 Levels of Representation

This section provides guidance on the question of how much representation is required to achieve conservation outcomes. This is structured as guidance about the needs of individual conservation features, and is broadly based on the experience (in both Australia and overseas) in MPA design to achieve species and habitat-level conservation outcomes. The guidance here is framed as input requirements (such as 30% of the occurrence of a species distribution across the planning region) and as guidance about the levels of outputs that should be achieved (30% of the planning region would normally be expected to be within highly protected MPA zones). It is critical that the decision problem does not confound the inputs with the outputs (the extent of area within an MPA network should not be used as an input feature) because such confounding will down-weight the importance of the conservation of individual features, and may lead to a false sense of confidence about the representativeness of areas included in the MPA outcomes.

In this project, we applied specific quantitative targets to all conservation features included in the decision problem based on the guidance for targets contained in the Principles. Those targets (including the numeric targets) were established recognising other applications of systematic conservation planning and recognising the high levels of uncertainty and requirements for risk-averse solutions. We included key elements of this section in our decision model, including the broadly-based 30% of occurrence of all features within marine sanctuaries, and incrementally higher targets for threatened or otherwise specially important species.

2.3.2. Management Constraints

This Principle recognises that all MPA solutions have to be developed and implemented within a management framework where there may be a number of practical restrictions and impediments to the achievement of good conservation outcomes. To the extent that is practical, the scientific design of such MPAs should therefore try to take such constraints into account in the design phase, and make appropriate trade-offs that maximise the conservation outcomes while minimising the constraints.

2.3.2.1 Business Management

The first section of this Principle provides guidance about the management process for MPAs, and specifically the need for a proper planning, management and evaluation framework to be put into place. The role of the science here is to ensure that there is an effective business framework that embodies performance measures, and that such measures are relevant, measurable, and appropriate to the management of the MPA for conservation purposes.

The majority of this aspect of this Principle lies outside the terms of the current project. However, the establishment of MPAs for which there are clear estimates on representation of conservation features provides a clear framework for the establishment of a performance evaluation system, including parameters that may be measured and benchmarks that may be used to determine if conservation objectives are being achieved within the MPA or the region more broadly. Monitoring and evaluation is more specifically covered in Principle 5 below.

2.3.2.2 Complementary Management

This section of the Principle is focused on identifying, and where possible providing specific arrangements, to maintain the connections/dependencies that the biodiversity in an MPA may have with adjacent areas, with other elements of biodiversity, or with the management regimes that may be applied to areas outside (and possibly remote from) the MPA. Typical examples include the need for watershed management in coastal areas near intended MPAs, the need for better management of exploited fish resources adjacent to MPAs, the possible migration of specific life stages through the MPA to distant areas that are unprotected, the management of habitats outside the MPA/planning region that are known to be important for feeding or spawning etc but could not be included within MPAs, and the need for complementary management of key habitats of highly valued species that may also occur in adjacent planning regions.

The need for complementary management arrangements is most acute in relation to exploited species and species with highly dispersed populations which have individuals that may migrate over large distances, including beyond the planning region (such as some marine mammals, seabirds, large migratory fish species, etc that may occur in adjacent planning regions). While these latter species would not normally be the main focus of an individual MPA, a network of MPAs may be needed to provide protection for each of their important habitats and in this way individual MPAs may contribute to their conservation.

We do not apply this guidance in this project because the focus of the work here is on MPA zones of high protection and we have only been able to access limited data on other, possibly complementary, management systems that may relate to the MPA solutions. So for example, while there may be fisheries management arrangements that could provide for a significant off-MPA contribution to conservation of exploited fish species within the MPA solutions identified in this project, analysis of these is beyond the scope of this project.

2.3.2.3 Management Practicality

This section focuses on providing guidance on the scientific aspects of specific management arrangements, such as boundary locations and institutional arrangements that provide for efficient management systems to be implemented. These include selecting boundaries that are simple (i.e. not complex shapes or arrangements of small polygons) that enclose features of conservation interest and can be easily determined at sea using normal position-fixing equipment. This section also provides support for the establishment of partnerships between agencies that may have some jurisdictional responsibility for uses that may occur adjacent to an MPA (such as shipping, fishing etc.) to provide for efficient surveillance and compliance activities. Such partnerships contribute to institutional development and learning, as well as offer the prospect of enhanced efficiency and effectiveness. Examples of such relationships include building on existing MPAs where there is already an effective institutional and practical base for management, relationships that should be developed between terrestrial and marine conservation management systems (such as aligning MPA boundaries to be contiguous with National Park (terrestrial) boundaries), between conservation and resource management agencies (such as MPA and fish resource management agencies), and between state and national government agencies to provide for contiguous boundaries.

These aspects are mainly developed and implemented in later stages of the MPA design process, as candidate MPAs are identified and negotiated, and are beyond the scope of this project.

2.3.3. Multiple Objectives

MPAs in Australian waters are multiple-use systems, in accordance with the specifications of the NRSMPA. In some zones of the MPA network, uses are permitted that are consistent with achievement of nominated conservation objectives, recognising that not all forms of use are inconsistent with achieving some level of conservation outcomes. The intent of the NRSMPA is therefore to achieve conservation outcomes across the network by combining areas zoned for high protection with areas that are zoned for lower levels of protection. The areas of high protection are the core areas for conservation, where biodiversity is expected to exist and be conserved in a natural system unaffected by human activities, supported by other areas that are zoned for specific types of uses that have acceptably minor levels of impact. This Principle provides guidance about the scientific issues relating to the type and level of activities that could be expected to be permitted in the use zones of MPAs (not in the high protection zones). The focus in this guidance is about uses in MPA zones that can be conducted without detracting substantially from the achievement of conservation objectives in those zones.

The project conducted here is focused on MPA zones of high protection (marine sanctuary areas), and broadly speaking, much of this Principle is beyond the scope of the present project. There is however an important interaction between marine sanctuaries and the location of existing uses that may be having a significant impact on the biodiversity that we address in this project (section 3.2 of this Principle).

2.3.3.1 Use of Biodiversity

This section of the Principle establishes the need for all uses of any aspect of the biodiversity to be conducted in a systematic manner, with specific criteria that are used to control the level and location of exploitation and possibly access to the biodiversity. This applies to all forms of use, including active uses such as harvesting of fish resources, and passive uses such as eco-tourism. Criteria may also be required for activities that are conducted outside the MPA but have an impact on the biodiversity of the MPA. This may include watershed management affecting coastal waters MPAs, and oil/gas exploration activities within adjacent (non-MPA) waters. The establishment of criteria for uses provides for a systematic basis of assessment and approvals, and for monitoring and reporting of impacts.

2.3.3.2 Zoning

This section of the Principle gives guidance about how to choose types of uses that may permit significant conservation benefits to be retained within use zones of an MPA. This includes providing for the complementarity between different zones (in respect of achieving conservation outcomes) and minimising the extent of negative interaction between the competing objectives of conservation and specific types of use. Underpinning this section of the Principle is an inferred understanding of causes and effects—the effect of a use on achievement of conservation objectives. Such understanding is highly uncertain, and guidance is therefore provided to apply a precautionary approach to the designation of zones in the light of a limited knowledge about the impacts of different types of uses.

In this project we consider only the placement of marine sanctuaries—the other types of MPAs are beyond the scope of the project. To determine the preferred location of marine sanctuaries we apply the precautionary approach to the various activities that occur across the region (and surrogates for activities) by applying higher levels of 'costs' to those activities that are likely to have higher levels of impacts in relation to the biodiversity conservation objectives. Developing a detailed understanding of the actual impact of each existing use is beyond the scope of this project, and so the impact of each type of use activity was developed through a coarse analysis of the threats identified from the local and overseas literature. For fishing, we used data (where it was available) on the gross value of the products as a surrogate for the level and extent of impact. The ‘costs’ are therefore assigned at the activity level, using a broad classification of activity that could be determined from the data we were able to secure for the project.

The analysis identifies marine sanctuary areas that will achieve the conservation objectives and are also located away from the most costly of the existing activities. Where there is direct conflict between existing activities (such as locations where there are unique conservation values that have existing and impacting uses), then the marine sanctuaries take precedence and the relevant uses are displaced. The analysis in this way specifically seeks to find locations that do not displace the uses in favour of the marine sanctuaries until suitable alternative locations for sanctuaries cannot be found.

2.3.3.3 Support Traditional Owners

This section of the Principle provides guidance on scientific aspects of how to assist with the identification of MPAs that may support the goals and aspirations of Traditional Owners in conservation of resources and maintaining cultural respect for marine areas.

2.3.3.4 Support Low-impact Fisheries

Fishing is one of the few dominant activities in all of Australia’s marine jurisdictions, and has the potential for significant impacts on biodiversity depending on how it is managed and constrained. While fishing itself is generally regarded as inconsistent with conservation, there are forms of fishing that may be permitted in an MPA network, subject to careful management. Low-impact fishing may therefore be permissible in zones other than sanctuary zones, and this section of the Principle provides scientific guidance about specific aspects of fishing that may be used in determining what fisheries are actually low-impact, and hence may be permitted in use zones. This project is focused on marine sanctuaries, and other than minimising the extent of displacement involved in creating marine sanctuaries, the impacts of fishing are beyond the scope of this project.

2.3.3.5 Displaced Users

This section of the Principle identifies the need for scientific consideration for the management of any users that will be displaced from newly identified marine sanctuaries. The costs and impacts of such displacement should be carefully considered in developing a network of MPAs, including direct costs such as industry restructuring and compensation, and biodiversity impacts such as concentration of recreational fishing effort into fewer places where fishing is permitted.

2.3.4. Managing the Threats

This Principle addresses the scientific aspects of how to identify the relevant threats and how to respond to those within the MPA design. While there are many known threats, and to some extent these can be avoided or mitigated, this Principle is mainly focused on how to adopt a precautionary approach to MPA design so that both present and future potential threats can be reasonably managed to avoid major failure of the conservation objectives of an MPA network.

2.3.4.1 Avoid Known and Potential Threats

This section provides guidance about avoiding specific issues (such as proximity to high-use shipping areas), the development of risk assessment systems designed to inform MPA designs, and the use of simple models to underpin such threat assessments.

In this project, we assess threats based on activity type and included a surrogate for present and future threats based on proximity to population centres. Both were used to develop a unified cost index that is applied across the analysis. This cost index is applied as described above, and results in marine sanctuary areas that achieve the conservation objectives that have the lowest set of costs in terms of both notional impacts (activity type) and displacement cost.

2.3.4.2 Build Climate Change Resilience

This section provides guidance about how to plan for MPAs that can provide for resilience to the impacts of climate change. Given the broad range of species and habitats in most Australian ecosystems, this guidance is broad and generic, but is probably about as specific as it can be in the face of the current levels of knowledge. The main focus is on ensuring that highest level of natural ecosystem function is retained, together with taxonomic diversity including range of habitat types and ecosystems, to enable adaptation to develop naturally and maintain biodiversity *in situ*. This is expressed as maintaining the full natural range of structural and functional features, ensuring there is a southward migration pathway available for range extension for species that can occupy habitats that do occur to the south, and protecting any identified refugia or areas of unusual complexity where unusual local levels of diversity may exist.

In this project, in addition to the other approaches that will provide a form of climate-change resilience, to specifically represent an element of climate-change resilience we include a specific latitudinal gradient across the planning region to provide for southward migration to be represented in marine sanctuaries. Also, we nest conservation features within bioregions, which will provide for replication of features in sanctuaries within bioregions, allowing for the diversity of possible habitat range extensions to be retained across the SWMR.

2.3.4.3 Identify and Account for Uncertainty

This section of the Principle gives guidance about how to assess uncertainty in key assumptions and datasets. We assess uncertainty in this project by careful review of the datasets that we accept into the analysis, and by an assessment of the robustness of the Aquamaps modelled species distributions. A detailed treatment of uncertainty is beyond the scope of this project.

2.3.4.4 Spread the Risks

This section of the Principle gives guidance about adopting a precautionary approach to major risks that might underpin the decision problem. These risks could include bias incurred through inadequate knowledge of the conservation features or threats to their survival in the planning region, or an inability to systematically plan for the impacts of natural disasters. In this project we adopt several specific strategies to spread the risk of failing to include unknown elements of biodiversity within the sanctuary zone solutions. These include explicit inclusion of environmental and spatial gradients where data were available. A detailed treatment of risk-spreading is beyond the scope of this project.

2.3.5. Monitoring, Assessment and Reporting

The monitoring, assessment and reporting of MPA performance is a central requirement of good MPA management. This Principle provides guidance about the essential elements to provide the basic information for continuous improvement and adaptive management of MPA networks. The implementation of this Principle is primarily beyond the phase of initial MPA design, and we do not treat any aspect of this Principle explicitly in this project.

2.3.5.1 Performance Assessment

This section of the Principle provides guidance about the structure of an assessment and reporting process for MPAs.

2.3.5.2 Practical Monitoring

This section provides guidance about practical monitoring systems, and simple approaches for making monitoring a practical aspect of MPA management.

2.3.5.3 Scientific Reference Sites

This section provides guidance about the need for reference sites that are as least disturbed as possible, so that they may form benchmarks for assessments of biodiversity both inside and outside MPAs.

2.3.5.4 Fund Adaptive Management

This section provides some guidance about the need for adaptive management to be a funded mainstream activity in MPA management.

2.3.6. Stakeholder Engagement

Engagement with stakeholders is an important part of achieving a robust MPA design. This Principle provides guidance about which aspects of stakeholder engagement need the support of a scientific approach, and how local knowledge can be secured for the purposes of MPA design. These aspects are not relevant to the initial stages of MPA design at the scale of the SW region, and are not treated explicitly in this project.

2.3.6.1 Complementary Local Knowledge

This section provides guidance about the types of knowledge that is typically held by local communities, and could be very valuable for an MPA design. This includes habitats that may be highly valued for both conservation features and for uses such as recreational fishing.

2.3.6.2 Community Acceptance and 'Ownership'

This section provides guidance about the use of a scientific approach to consultation with stakeholders. This can be very valuable during broad objective setting phases of MPA design and can provide useful knowledge about compliance issues and possible agency partnerships that could be deployed during management of an MPA network. The adoption of a scientific approach to consultation also enhances the likelihood of maintaining stakeholder engagement and involvement with ongoing management of an MPA.

2.3.6.3 Community Engagement in Management

This section of the Principle provides guidance about securing ongoing engagement with stakeholders, specifically using various forms of incentive and the devolution of governance systems to the most practical level.

2.4 Maintenance of the Principles

The Principles presented above were developed over a short period with the assistance of the practitioners we consulted. Each Principle, and its structure, reflect a broad consensus of the opinions of the practitioners at the time, and relate specifically to their experience with the NRSMPA and the conditions and scientific knowledge prevailing at that time. This body of experience and knowledge, and the body of practitioners, continues to grow, and the guidance statement and the Principles contained therein should be considered to be a snapshot of the times.

We consider that the guidance statement needs to be kept under constant review, and to be updated on an annual basis as experience with the NRSMPA builds, and as new scientific knowledge expands. This is important at this time in the evolution of the NRSMPA because of the Commonwealth's major program of bioregional planning, which includes MPA planning, that is in the process of establishing regional marine plans for all of Australia's marine jurisdiction. We expect that there will be major incremental advances over the next few years derived from the successes and failures of this major program of investment into regional and MPA planning. It is therefore highly advisable that the guidance statement and the embedded Principles should be reviewed and updated annually for at least the next 5 years, and perhaps each 3 years thereafter.

There is no specific model that should necessarily be used for this process of updating, although there are five key requirements that will need to be applied if the guidance is to retain the very high standing and level of acceptance it has already secured within Australia. These requirements include:

1. a high level of independence from government and any research institution that may be compromised by high levels of funding from any major marine industry (such as the oil/gas industry, fishing industry, or shipping/transport industry).
2. an inclusive approach across the disciplines of biophysical science, social science, public policy and governance, and operations research.
3. a transparent and accountable approach that responds to the views of qualified and experienced scientists.
4. the process maintains a high level of scientific credibility amongst conservation science practitioners in Australia.
5. each finalised update is made freely available at a suitable website for use by any interested person, including for teaching, research or personal study within any public,

NGO or private sector entity subject only to normal Australian copyright law and source attribution in any use or adaptation of the guidance.

These requirements would be best achieved through a university-managed process, perhaps coupled with an annual workshop linked to a relevant scientific society and subsequent web-based calls for input/review.

3. DATA NEEDS FOR CONSERVATION PLANNING

The field of systematic conservation planning was born over two decades ago, as a departure from the *ad-hoc* manner in which protected areas had been established in the past. The term *ad-hoc* is typically used to describe protected area systems which have been pieced together based on a variety of criteria including scenic value and ease of acquisition, without broader consideration of the new sites' contribution to representing biodiversity features not currently represented in the reserve system (Pressey *et al*. 1994). Until recently the identification and establishment of protected areas had typically not been systematic in their approach to preserving biodiversity (Margules and Pressey 2000). Margules and Pressey identified six characteristics/stages that form the cornerstones of the systematic conservation planning approach. We summarise these as (from Margules and Pressey 2000):

1. clear definition of conservation features and surrogates
2. the setting of explicit goals
3. recognition of the contribution of existing protected areas
4. explicit methods for designing/locating reserves
5. explicit criteria for implementing conservation action
6. explicit mechanisms to ensure persistence of conservation features

Data gathering to support systematic conservation planning efforts is the first stage in the process, and is required prior to moving forward into the actual planning effort. We identify below three broad categories of data that are essential to spatial prioritisation, and discuss how each fits into the systematic conservation planning process.
These three broad data types are:

1. biological data
2. physical data
3. socio-economic data

Within the spatial conservation prioritisation process that is the primary focus of this work, it is essential that all the conservation features to be protected and the costs to be avoided are defined spatially. Because the prioritisation is spatially explicit, we cannot measure the benefit of, or account for the costs of, anything that is not delineated spatially.

For each of the data types we also recognise the need to identify the processes that affect the distribution and abundance of biodiversity within the region. Ecosystems are not static, and a prioritisation based only on existing patterns of biodiversity does not ensure that those patterns of biodiversity features will persist in the future. The persistence of biodiversity requires information about the physical, ecological and evolutionary processes that sustain and generate the biodiversity patterns that we observe today (Cowling *et al*. 1999). The failure to include such processes would result in temporal bias of any protected areas produced from a design process. Where these processes can be spatially mapped, they can be directly targeted for incorporation within protected areas (Klein *et al*. 2009; Rouget *et al*. 2006; Chan et al. 2006).

In addition to processes that maintain biodiversity pattern, it is also essential to gather information on processes that threaten or place pressure on the persistence of conservation features (Wilson *et al*. 2005). Information on threatening processes has been utilised in a number of different ways to inform conservation action. It can be used to inform overall conservation goals (Pressey *et al*. 2003); it can be incorporated into the scheduling framework by assigning higher priority to more vulnerable areas (Costello and Polasky 2004); or used to avoid those areas that are likely to be harmed (Game *et al*. 2008). Within the marine planning process the benefit of incorporating fine scale information on threatening processes has been demonstrated to lead to a better understanding of the current state or habitat quality of areas, and to aid in the identification of those areas most in need of protection (Eastwood *et al*. 2007). In this project, information on threats will also be used to inform the spatial prioritisation so that we can minimise user conflicts and simultaneously achieve conservation objectives.

3.1 Biological Data

The primary goal of conservation planning is the conservation of biodiversity. To support systematic conservation planning we need spatially explicit information on the suite of species that we hope to conserve through the establishment of a network of protected areas. Ideally our conservation planning effort would be supported by information on distribution of every species in the planning region. However, we do not live in an idealised world, and in reality we often have very little knowledge of biodiversity of even the best sampled regions (Pressey 2004). Our incomplete knowledge of the nature of biodiversity in any region has been described as based upon the two contributing causes, ‘Linnean’ and ‘Wallacean’ shortfalls (Whittaker *et al*. 2005). Linnean shortfall results from our incomplete knowledge of the complete suite of species in existence, while Wallacean shortfalls result from our incomplete knowledge about the distribution of species that we do know about (Whittaker *et al*. 2005). To compensate for the incomplete knowledge on the distribution species that all planning efforts encounter, surrogates are used, which are presumed to represent both the biodiversity that we know exist within our region but don’t have sufficient information about, and those features that we don’t yet know about.

Surrogates for biodiversity take two general forms: pattern surrogates and process surrogates (Pressey 2004). Surrogates for biodiversity pattern are probably the most commonly encountered, as this class includes information on distribution of species (either observed or predicted) and other common surrogates such as ecosystems and bioregionalisations. Surrogates for biodiversity processes include spatially explicit information about the processes that allow species to persist in a given region (Pressey 2004). This class includes information on currents, disturbance regimes, required spatial configurations, or other dynamics that drive the distribution of species that we observe (Pressey 2004). Surrogates that have a biological basis (such as some habitat types) may themselves be recognised as elements of the biodiversity of the planning region, and hence play two roles—representing other more poorly understood features of the biodiversity and their own role in the region's biodiversity.

When selecting species about which to gather information, it can be useful to differentiate species based on two general criteria that describe how they relate to the planning effort and the ecosystem. The first is those species that are not likely to persist without detailed consideration within the planning process, and the second are species whose protection is likely to confer protection to a broader number of species for which data might not be available (Groves 2003). Species in the first category are typically defined as those species that are listed either on a national or international threatened or endangered species list. The second category of species can be identified through the life history traits/characteristics of individual species and their relationships to other species in the planning region.

The concept of *complementarity* is central to the use of biological data within the systematic conservation planning framework. Complementarity is used to describe how well each area within a protected area represents features that are not represented within other parts of the network. Understanding the concept of complementarity is also essential for understanding the type of biological data needed for conservation planning. While data on species richness or other summary statistics can provide useful information for other aspects of management, when designing protected areas it is essential to use direct information on the biodiversity content of each area, so that we ensure that all biodiversity features are ultimately represented within the protected area (Wilson *et al*. 2009).

3.2 Physical Data

Physical data includes all data about the physical nature of the system. Within the marine context this includes but is not limited to depth, abiotic water column characteristics such as salinity and temperature, circulation regimes, and geomorphology. Physical data serves to define the planning region in space, and also serves as the context within which we spatially represent biodiversity and a number of surrogates.

3.3 Socio-Economic Data

Conservation planning does not occur inside a biological bubble, and the incorporation of information about the socio-economic environment in which the planning is taking place can increase the likelihood that a conservation plan becomes effective (Knight and Cowling 2007). While the goal of systematic conservation planning is the conservation of biodiversity, the means to achieving that goal often lie in understanding the socio-economic drivers that make conservation planning necessary (Polasky 2008). The incorporation of socio-economic data into the conservation prioritisation system recognises that while our success will always be measured in biological terms, the roots of our failures may lie elsewhere.

Collection of socio-economic data includes the development of an understanding of the context in which the planning process occurs. This includes the delineation of the planning region, identification of regional tenure, and information about existing protected areas or management institutions. It also includes gathering information on existing uses of the region, and the identification of potential stakeholders in the process. The process should also identify those processes and institutions which may influence the effectiveness of protected areas within the planning region, but which are beyond the influence of the planning process.

Gathering of information of socio-economic activities can result in many benefits, including reducing the cost of conservation and minimising impact on existing users (Stewart and Possingham 2005). Numerous studies have shown that including information about differing costs of conservation can both reduce the overall cost of conservation and change conservation priorities (Carwardine *et al.* 2008; Naidoo *et al*. 2006; Wilson *et al*. 2007). The inclusion of spatially explicit information on activities such as commercial fishing can minimise the impact that the establishment of protected areas has on existing uses (Klein *et al*. 2008). Understanding patterns of regional use can also be helpful in engaging stakeholders, and identifying barriers to implementation (Scholz *et al*. 2004).

3.4 Data Quality

Prior to utilising data in a systematic conservation planning process, the data should be assessed for its accuracy, coverage, and resolution. Every effort should be made to include only the most accurate and recent data available. The inclusion of datasets that offer only partial coverage of the planning region, or which are the product of uneven sampling effort that is not corrected for, can lead to bias in the selection of priority areas (Smith *et al*. 2009). In biological data, specific issues may also concern the taxonomic resolution or the reliability of identification of individual species, the selectivity of the tools used to sample species or habitats, and the extent and reliability of spatial modelling that may have been applied to convert point data into broader spatial data.

Once all available data have been identified for the planning region, it is important that planners acknowledge the limitations and uncertainties inherent in the datasets, and do so in a transparent way (Noss 2004). However, in assessing the quality or completeness of the available data, we should keep in mind that all efforts will rely on incomplete datasets, and that recent research has shown that even incomplete datasets can be used effectively to select priority areas for conservation (Grantham et al. 2008).

4. CONSERVATION PLANNING DATA FOR THE SOUTH-WEST

4.1 Sourcing the Data

This project is based on the identification and use of the publicly available biophysical datasets for the region, to lay the foundation for the application of systematic conservation planning for the region. However, the search for data was expanded to include not just publicly available biophysical data, but also other datasets that could be reasonably secured that were identified as crucial for effective conservation planning in this project.

The search began with the identification of information portals that were likely to hold information relevant to marine planning in the SWMR. After these portals were identified, each portal was searched either geographically or through the use of keywords relevant to the region. Information portals included in this search are summarised in Table 4.1.

After reviewing the data that was collected through the public portals outlined above, it became apparent that the resulting quality and scope of data would not be sufficient to meet the data needs described in the scientific consensus statement of marine planning principles presented in Chapter 2 of this document. Of particular concern was the paucity of socio-economic data that was publicly available. This result was not altogether unexpected as socio-economic data is frequently subject to access restrictions and confidentiality concerns and is often not made available directly to the public. In addition to concerns about the lack of the socio-economic data, UQ was also concerned that much of the publicly available biophysical data was collated to support the national marine bioregionalisation (NMB) effort in 2005. Because that data was compiled at least four years ago, and many of the datasets are older than that, it was determined that obtaining updated information from sources listed in the NMB bioregionalisation effort was a high priority for this project.

The expanded data search included contacting government and non-government institutions identified as experts or as the primary data custodians for relevant information. To identify such sources, UQ used publicly available reports and scientific papers to identify potential sources of additional information. We acknowledge here both Environmental Resources Information Network (ERIN) and DEWHA for their assistance in the search for data beyond that made readily available to the public. ERIN assisted in the identification of data custodians and DEWHA facilitated access to information developed as part of the Commonwealth bioregional planning effort that had previously not been made available to the public.

Table 4.1. Information portals utilised in the data search

Data Portals	location
AquaMaps	http://www.aquamaps.org/
Australian Spatial Data Directory (ASDD)	http://asdd.ga.gov.au/asdd/
Birdata	http://www.birdata.com.au/maps.vm#
Birdlife International	http://www.birdlife.org/datazone/index.html
Birds Australia	http://www.birdsaustralia.com.au/our-projects/iba-maps.html
BlueNet	http://bluenet.its.utas.edu.au/geonetwork/srv/en/main.home
Commonwealth Scientific and Industrial Research Organisation (CSIRO) Divisional Data Centre	http://www.marine.csiro.au/datacentre/
COSEMA	http://www.reefwatch.asn.au/cosema/cosema_databases.shtml
CSIRO data trawler	http://www.marine.csiro.au/warehouse/servlet/HTMLManager
Discover Information Geographically (DIG)	http://www.environment.gov.au/erin/dig/index.html
eMII	http://imos.org.au/emii.html
GA-MARS datasets	http://www.ga.gov.au/oceans/mc_smac_MARS.jsp
Geoscience Australia (GA)	http://www.ga.gov.au/map/national/
Global Biodiversity Information Facility (GBIF)	http://data.gbif.org/welcome.htm
MarLIN- the CSIRO Marine and Atmospheric Research Laboratories Information Network	http://www.cmar.csiro.au/marlin/
National Whale and Dolphin Sightings and Strandings Database	http://data.aad.gov.au/aadc/whales/
Ocean Biogeographic Information System Australia	http://www.obis.org.au/
Ocean Biogeographic Information System (OBIS)	http://www.iobis.org/
Seamounts Online	http://seamounts.sdsc.edu/
Species Profile and Threats Database (SPRAT)	http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl
Publicly available data products	**Copies available via**
Australian Bathymetry and Topography Grid DVDs	http://www.ga.gov.au
2005 National Marine Bioregionalisation of Australia DVD	http://www.environment.gov.au/, www.ga.gov.au, www.csiro.au

4.2 Datasets Identified

The intention of this section is to provide an overview of the types of data we identified, rather than report on each individual dataset, and provide additional information on some of the key datasets. Readers interested in a full inventory of datasets we collected will find the complete list in the First Progress Report of this project (April 2009), available from the Pew Environment Group, Wild Australia program, on request. A list of the datasets we used in the Marxan analysis is contained in Appendix 2.

4.2.1. Physical Data

Over 490 individual datasets were identified and collected during the search for physical data about the region. For reporting purposes we have broken down the physical data into two sub-categories: geophysical – information related to system characteristics that are static; and oceanographic – related to physical processes within the system. Each of these are discussed in brief below.

4.2.1.1 Geophysical

Bathymetry

A digital elevation model (DEM) for the region was available with the NMB Database and through Geoscience Australia. The DEM was developed by Geoscience Australia and the National Oceans Office, to support the bioregionalisation process, and provides ~250m resolution coverage for the entire region. A number of data products derived from the DEM were also available through the NMB, including potential error regions in the DEM and bathymetry contours. Two geomorphic characterisation layers were derived from the DEM by Geoscience Australia. The geomorphic unit layer delineated broad classes of geomorphic features, while the geomorphic features layer provided a more fine scale characterisation.

Sediment Composition

The National Marine Samples Database (MARS) is distributed by Geoscience Australia, and provides information about sediment sampling and grids with sediment characteristics. Grids delineating sediment composition with respect to following characteristics were available through the NMB: (1) % Carbonate, (2) % Gravel, % Mud, % Sand, and (3) sediment mobility layers. Individual MARS samples were not pursued, because processing was beyond the scope of this project. Based on the MARS data, Geoscience Australia developed a map of sedimentary basins to support petroleum and mineral prospectivity.

4.2.1.2 Oceanographic

CSIRO Atlas of Regional Seas

The CSIRO Atlas of Regional Seas (CARS) is a collection of ocean water property data that includes information for six water properties: temperature, salinity, oxygen, nitrate, silicate, phosphate (CSIRO 2006). Each water property is estimated at a variety of depth ranges and at different times of the year. A sub-sample of data available within the 2000 CARS data is provided on the NMB. The most recent version of the CARS dataset was compiled in 2006, and the full suite of CARS variables was accessed directly through CSIRO. Mean values for each property were downloaded for each depth zone available.

Leeuwin current and associated processes

The Leeuwin current is recognised as the 'signature current' in the region because of its significant likely impact on ecosystem structure and biodiversity (DEWHA 2007). Sea surface current data was also provided on the NMB. Both a point and a raster dataset were provided that mapped the direction of surface currents at four different times during the year. Both datasets were derived from the CARS 2000 dataset.

Because very little publicly available data was available for the Leeuwin current, Ming Feng of CSIRO was contracted to prepare and output datasets from their existing models, which mapped two different aspects of the influence of the Leeuwin current—the long term (1993-2007) mean eddy kinetic energy and vertical velocity.

Eddies and fields

Using Advanced Very High Resolution Radiometer (AVHRR) remotely sensed data and a pattern recognition method developed by Vincent Lyne, CSIRO mapped eddies and fields based on sea surface temperature. Four patterns were mapped: (1) core water masses, (2) eddy cores, (3) fronts, eddy edges, and (4) high gradient fronts. Each was mapped at four times in the year, January, April, July and October. Additional information on sea surface temperature (SST) and sea surface height (SSH) was also provided in the NMB. Mean SST and SSH were available for the months of January, April, July and October based on data collected in 2000. An additional grid containing the annual variance in sea surface height in 2000 was also available.

4.2.2. Biological Data

The biological data search focused on identifying the best possible datasets to represent the biodiversity of the South-west region. This included the EPBC listed species identified in the Bioregional Profile (DEWHA 2007) as well as publicly available information about species from each major taxonomic group. The data types and the uncertainty associated with the data varied greatly among the datasets found. Four major sources of biological data were identified: The Global Biodiversity Information Facility (GBIF) Data Portal, the Ocean Biogeographic Information System (OBIS), AquaMaps standardised range maps, and the Species of National Significance (SNES) database. In addition, we were provided access to data from two CSIRO Southern Surveyor Voyages that collected detailed species data at sampling points along the west coast, including approximately half of the study region.

Table 4.2. Example biological datasets for the south-west marine bioregion.

Name	Description	Category	Custodian
Online Zoological Collections of Australian Museums	Specimen records point occurrence database (lat/long)	biologic	OZCAM (GBIF)
OBIS_Species_OZ_EEZ.txt	Compiled point locations (lat/long) from numerous studies- includes all species	biologic	Individual dataset contributor (OBIS)
Arctocephalus_forsteri_aqua.shp	AquaMap- probability of occurrence for *Arctocephalus forsteri*	biologic	AquaMaps
814.shp	Distribution information for *Sterna anaethetus*	biologic	DEWHA

4.2.2.1 The Global Biodiversity Information Facility (GBIF) Data Portal

The GBIF Data Portal provides free and open access to species occurrence data records that are shared via the GBIF network. This means that it acts as a clearinghouse for point occurrence data from a variety of sources. The data are retained in their original dataset (with metadata) so the original study and source of data are clear. We requested occurrence data for all (non-invasive) species that occur in the Australian EEZ from GBIF. This request was forwarded to the Australian support centre for GBIF, and they provided us with data for all occurrences in the GBIF database for the study region. This included 12,899 point records for 2,294 species.

4.2.2.2 *Ocean Biogeographic Information System (OBIS)*

The OBIS website provides freely available marine biogeographic data from all over the world. OBIS obtains data from scientists within government agencies, museums, universities, commercial companies, and non-government organisations. The datasets are records of particular species in a particular location at a particular time, recorded as latitude and longitude. OBIS ensures that the datasets have high taxonomic quality by focusing on datasets where professional or trained biologists have identified the organisms. In addition, each dataset has to pass through the OBIS quality control protocol before it is added to the available datasets. We requested occurrence data for all (non-invasive) species for the Australian EEZ. The data provided includes 517,445 records for over 10,000 species.

4.2.2.3 AquaMaps

AquaMaps is a project that aims to create standardised range maps for all the species in the world's oceans. The maps are computer-generated predictions of the natural occurrence of marine species. These predictions are based on how a species is related to environmental factors, including depth, salinity, temperature, primary productivity, and the proximity of sea ice or the coast. The prediction model also includes information on an "environmental envelope" created using FAO areas, bounding boxes, depth ranges (from information in species databases such as FishBase) as well as incorporating occurrence point data from OBIS and GBIF (Kaschner et al. 2007). The output is in 0.5 degree "C-squares" with a probability of occurrence (range 0-1) for each species in each grid square. Outputs can be generated at finer scale (0.1 degree), but predictions at this spatial scale require further validation, and there are additional costs associated with both the validation and data extraction. These additional costs were considered beyond the scope of the present contract.

We requested AquaMaps modelled data for each (non-invasive) species in the study region. This data is freely available species by species, but due to the large number of species (and the processing necessary to extract the data) we requested the data for all species and paid a fee to AquaMaps to cover the bulk extraction costs. We obtained data at the 0.5 degree level of resolution on the 3013 species that have been modelled by AquaMaps that occur in the study region.

Listed Species in AquaMaps

Of the 106 species listed in the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 and identified in the South-western bioregional profile, all but two of the aquatic species (42) have modelled AquaMaps datasets. None of the 62 listed bird species are included because AquaMaps data are limited to aquatic species.

4.2.2.4 Species of National Significance (SNES)

The SNES database stores maps and point distribution information about species of national significance as listed in the EPBC Act. The database includes threatened species, migratory species, marine species and cetaceans. This is not a publicly available database, however The University of Queensland holds a licence to use the data internally and cannot share or distribute it to any other party.

The South-western bioregional profile identifies 106 EPBC-listed species that are known to occur in the region, and the SNES database contains information for 70 of those listed species. This data varies greatly in resolution. The database includes information for 53 of the 62 listed bird species.

4.2.2.5 Other Datasets

CSIRO - Southern Surveyor Cruise Data

2005 (SS200510)

This voyage collected Sherman sled and beam-trawl samples from 18 sites along the coast of Western Australia. Invertebrate catches were sorted and identified (to the species level) and catch weights or number of individuals were reported.

1991 (SS199101)

Southern Surveyor cruise SS 01/91 was undertaken to carry out a fish survey in the Western Deepwater Trawl Fishery (WDWTF) off the west coast of Western Australia between North West Cape and Cape Leeuwin and from the 200 m isobath out to the Australian fishing zone (AFZ) boundary. Cruise objectives included to identify the distributions of fish, squid and crustaceans by latitude and depth; map the distribution of fishing grounds; provide information on catch rates, abundance and catch composition of dominant fish species in relation to depth and locality; to provide a description of the WA slope fish community; and to obtain taxonomic specimens and photographic records of slope fish species.

From both CSIRO cruises, we requested the point data for species that were also included in the AquaMaps species information that we had secured, so that CSIRO data could be used as an empirical and independent validation of the AquaMaps predicted distributions for those species. There are 108 fish matches and 21 invertebrate species that occur in both data sources. CSIRO provided data for each of these matched species and included presence absence at each survey site and, in some cases, abundance data. More detail on the validation of the AquaMaps dataset is in Chapter 4.4.2.1 AquaMaps data.

4.2.3. Socio–Economic Data

Two reports were identified that documented socio-economic activity over the whole of the South-west bioregion—the Bioregional Profile (DEWHA 2007), and a Socio-economic Analysis and Description of the Marine Industries of Australia's South-west Marine Region (Gardner *et al*. 2006). These reports provided the socio-economic context within which the MPA planning is expected to occur, and identified activities that could impact the objectives of the planning process.

4.2.3.1 Tenure data

Tenure or jurisdictional data assists to define the planning framework within which the project analysis is focused. The datasets also identify existing management institutions that may influence the placement and effectiveness of the protected areas. The datasets identified here provide spatial limits to the decision space, and provide information necessary for target setting and stakeholder identification. Data on existing marine and terrestrial protected areas was made available from DEWHA.

Table 4.3 Example tenure datasets for the South-west Planning Region.

Name	Description	Category	Custodian
marine_region.shp	Commonwealth Marine Planning Regions	tenure	DEWHA
eez_poly.shp	Australian Maritime boundary	tenure	GA
NTDA_Register_SA.shp	Native title applications in SA, some overlap into the planning region	tenure	National Native Title Tribunal

4.2.3.2 Commercial Fisheries

Three agencies were identified as primary custodians for the commercial fisheries active within the region: the Australian Fisheries Management Authority (AFMA) for Commonwealth-managed fisheries, the South Australia Research and Development Institute (SARDI) for fisheries managed by South Australia, and the Western Australia Department of Fisheries (WADF) for fisheries managed by Western Australia. Each agency was approached independently, and asked for information with respect to the fisheries active within the region.
AFMA data

Access to log book-level data for all fisheries managed by AFMA was requested. UQ signed a deed of confidentiality with AFMA for transfer and use of any supplied data. AFMA supplied yearly data on catch (kg), GVP ($), and boats (#) for the eight year period beginning in 2000 and ending in 2007. The data provided was aggregated to 30 minute reporting blocks, and supplied at the fishery level for 15 fisheries. All data was subject to internal confidentiality requirements—no catch or GVP was reported when less than 5 boats were active in a block.

SARDI data

We requested access to log book-level data for all fisheries for which SARDI is the data custodian. SARDI provided data on the five South Australia managed fisheries that occur within the region. Fishery information is compiled by SARDI at the scale of fishery management block, which vary in size both within and between fisheries. UQ signed a confidentiality agreement with SARDI which specified that the data not be distributed to any third parties, and only be used within the context of marine planning. SARDI supplied yearly data on catch (kg), gvp ($), and effort (variable units) for the seven-year period beginning in 2000 and ending in 2006. The data was provided at the fishery block (or modified fishery block) level, which are spatial reporting units that are variable in size. All data was subject to internal confidentiality requirements—no catch, GVP or effort was reported when less than 5 boats were active in a block.

WA Department of Fisheries data

We requested access to log book-level data for all fisheries managed by WADF. UQ signed a deed of confidentiality and non-disclosure agreement prior to WADF releasing the data for use in this project. The agreement specified that the data would not be copied or released to a third party, and that the data will be used for *“the purpose of the organization undertaking a marine planning process which investigating options for establishing a system of marine protected areas in commonwealth waters.*”

WADF provided 54 different data layers for commercial fishery activities within the region. The datasets included raw data from the fisheries, BRS processed datasets, and ERIN processed datasets. The datasets covered the 2000-2006 reporting period, and included information on Species, Catch, Effort, Method and Gross Value of Product (GVP). All blocks with less than three boats active in the reporting year were reported as ‘no data’.

Supplemental data sources

In addition to information provided directly to the project through the data requests, additional information was sought from reports or other data sources to compensate for identified datasets that we were unable to obtain.

Bureau of Rural Sciences (BRS) is the primary custodian for the 2000-2002 national commercial fishing dataset. BRS provided us with total catch and gross value product information for each half-degree block. Additional information on species caught within each block was available from the OBIS database. The OBIS dataset listed only the range of species caught; it did not provide any information on the amount of each species caught.

Geoscience Australia maintains a database of Commonwealth fisheries. The data delineates the spatial extent of 13 fisheries whose activities extend into the planning region. No additional information about the fisheries is provided.

In addition to the data provided directly to the project by SARDI, additional information on the Northern Zone Rock Lobster fishery was also available in a report produced by SARDI on the impact of proposed MPAs on the fishery (McGarvey 2003). The report provided aggregated catch information by block between the years 1990/1991-2000/2001. The McGarvey report, which was primarily concerned with the establishment of MPAs in state waters, also included estimates for proportion of catch in state waters for fishery management blocks which overlapped state and Commonwealth waters. For management blocks that overlapped state and Commonwealth waters, we subtracted the estimates for catch within state waters from the overall estimates for the block to estimate catch within the Commonwealth waters of each block with overlapping jurisdictions.

4.2.3.3 Aquaculture

The Western Australia Department for Planning and Infrastructure provided information about aquaculture activities in the planning region. Only the spatial extent of the operations was provided to the project—information about the individual activities in each area was removed from the layer prior to delivery to UQ. Aquaculture activities off the coast of Southern Australia are only conducted in state waters (DEWHA 2007).

4.2.4. Defence Activities

The Australian Hydrographic Service (AHS) was identified as the primary custodian for information about the spatial extent Department of Defence activities within the region. When we inquired about the data, we were instructed that details of such activities were provided to the public in annual notice to mariners and that no GIS products were distributed publicly (Andrew 2009). Using heads-up digitising based on maps distributed by AHS, we created a spatial layer that defined the extent of defence activities within the region.

4.2.5. Recreational Use

4.2.5.1 Recreational Fisheries

In 2008, BRS compiled a report on available recreational fishing datasets at both the national and state level (Sahlqvist 2008). Three agencies were identified as the primary custodians for recreational fishing data collected by government agencies within the region.

At the national level the report identified the National Recreational Fishing Survey of 2000-2001 as the most recent nationwide assessment of recreational fishing. BRS is the primary custodian for this dataset, and we therefore requested all summarised spatial information on fishing intensity. BRS provided us with information on total number of individuals caught aggregated into seven groups of species: Baitfish, Cephalopods, Crabs/Lobsters, Finfish, Molluscs, Prawns, and Miscellaneous.

SARDI was identified as the custodian for two recreational datasets of interest: the South Australia Recreational Fishing Survey 2007-2008, and the South Australia Charter Boat Fishery Catch and Effort. SARDI indicated that the fishing survey was primarily aimed at estimating catch/effort for nine inshore species, and in any case, the data were still in analysis and not available for distribution (Jones 2009). SARDI responded to our inquiry for data related to the charter boat fishery by advising that they did not have time to process the request at this time (Knight 2009).

WADF was identified as the primary custodian for eight marine recreational fishery databases. Discussions with WADF revealed that many of the surveys conducted by the department could not be used within the systematic conservation planning effort because they did not identify areas of catch/effort in a spatially explicit manner (Baharthah 2009). The WA creel survey was the primary spatially explicit recreational fishery dataset held by WADF. The deed of confidentiality and non-disclosure agreement signed for release of the commercial fishery dataset was therefore extended to include use of the recreational fishing dataset.

WADF provided us with three different datasets on recreational activity in the region. All information was aggregated to five nautical mile recreational fishing blocks. The supplied datasets include information gathered during the 2005/2006 creel survey of recreational fishers, and information on charter fishing and diving activities in the region between 2002-2006. No information was reported in management blocks in which less than two boats were active during a year.

4.2.5.2 *Recreational Fishing Interest Groups*

Three organisations were identified as a primary advocates for recreational fishing interests within the region: RecFish Australia, South Australia Recreational Fishing Advisory Council, and RecFish West. Each group was contacted individually to solicit information on recreational activity within the region. RecFish Australia, a national sporting fishing association, instructed us that spatial data about recreational use would have to come from the regional organisations. No data was secured from any of the regional recreational fishing organisations.

4.2.5.3 Boating

Regional boat registration was identified as a surrogate for recreation use. Because the study region is restricted to Commonwealth waters, which are 3nm or more offshore, we restricted our inquiry to registration of boats greater than 6 metres in length. Two agencies are responsible for boat registrations within the region: the South Australia Department of Transport, Energy, and Infrastructure and the Western Australia Department of Planning and Infrastructure. Requests were submitted to each agency, requesting information about the size, and postal code of all registered boats within the agency's jurisdiction. The Western Australia Department of Planning and Infrastructure agreed to supply the requested data, but unfortunately the data could not be secured by UQ in time for use in this project.

4.2.5.4 Other recreation

Information on the location of wrecks, and dive sites was provided by DEWHA.

4.2.6. Petroleum

Three different types of data related to petroleum activities are available: Petroleum releases, Petroleum Permits, and Prospectivity. Geoscience Australia (GA) is the custodian for both the release and permit data. Release data delineates the areas opened each year for future bidding for the rights to exploration. Nation-wide petroleum release data was provided to us for both 2007 and 2008. The permit dataset delineates areas where permits for exploration have already been issued and the status of those permits. A potential prospectivity dataset was developed by ERIN and GA to support the Commonwealth's marine planning efforts of the southwest region. The layer delineated the relative prospectivity of different areas in the region for future petroleum development.

Table 4.5. Example petroleum datasets for the SWMR.

Name	Description	Category	Custodian
2008_release.shp	2008 acreage releases	socio-economic	GA
pet_permits.shp	Production/Retention/Exploration permit areas	socio-economic	GA
sw_prospectivity_sw_region.shp	Petroleum prospectivity for the SW marine region	socio-economic	DEWHA

4.2.7. Shipping

The Australian Maritime Safety Authority (AMSA) requires some commercial vessels in Australian territorial waters to report their position once every 24 hours, and many other vessels participate voluntarily. The Australian ship reporting records (AUSREP) dataset contains the point records for these reported ship locations. AUSREP data from 1999-2007 was made available to us through AMSA.

The spatial location of ports within the region was provided to us by DEWHA. The dataset also contained information relating to the size of the ship that each port could accommodate.

Table 4.6. Example shipping datasets for the SWMR.

Name	Description	Category	Custodian
ausrep_1999.shp	1999 point shapefile of ship positions	socio-economic	AMSA
ausrep_2000.shp	2000 point shapefile of ship positions	socio-economic	AMSA

4.2.8. Sea Dumping

Information on approved sea dumping operations within the region is compiled by the Australian Hydrographic Office (AHO). Four different kinds of dumping activities are tracked by the AHO: ammunitions dumping, boat dumping, chemical dumping, other/miscellaneous dumping. The datasets were made available directly from the AHO and also provided to us by DEWHA.

Table 4.7. Example sea dumping datasets for the SWMR.

Name	Description	Category	Custodian
ammodump.shp	Ammunitions dumping sites	Socio-economic	DEWHA
chemical_dump.shp	Chemical dumping sites	Socio-economic	DEWHA

4.2.9. Miscellaneous

The Perth canyon submarine cable runs through the planning area and is protected by a buffer zone. The Australian Communications and Media Authority (ACMA) provided us with a dataset that delineates the spatial extent of the exclusion zone for the submarine cable. The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) hydro-acoustic listening station west of Cape Leeuwin is located within the SWMR, although datasets delineating the listening station and the cable exclusion zones were not available.

4.3 Derived Datasets

A derived dataset contains data that are created from or composed of other data elements. This involves processing, refining, modelling, or interpreting the original data to produce a new data product, often an aggregated form of the original data. A number of derived datasets have been created as part of the NRSMPA process, including a bioregionalisation (benthic and pelagic) derived from biological and physical data, as well as a seascapes dataset that was derived from physical data. These derived datasets are freely and publicly available—from DEWHA for the bioregionalisation datasets and from GA for the seascapes.

Table 4.8. Example derived datasets for the SWMR.

Name	Description	Category	Custodian
primary_bathymetric_units.shp	4 classes (slope, rise, abyssal plain/deep ocean floor). Developed to support bioregionalisation	derived	GA
sed_facies_sw.shp	defined from a cluster analysis of geomorphic (bathymetry), sedimentary (mean grain size, %Gravel, %Mud, %CaCO3), and oceanographic (wave- and tide-exceedance, mean wave energy, maximum tidal current) data	derived	GA
imcra4_pb.shp	IMCRA 4.0 provincial bioregions	derived	DEWHA
lv_1b_surf	Oceanic Substructure – Water Masses: Surface -2D dataset from a 3D pelagic regionalisation using physical and chemical variables. temperature, salinity and oxygen	derived	CSIRO

4.3.1. Bioregionalisation

Bioregionalisations, or mapped classifications of patterns in biodiversity, are considered an essential tool for developing representative networks of marine reserves (Spalding *et al*. 2007). The NRSMPA process aims to represent the full range of biodiversity, and a bioregionalisation framework is considered necessary for performance reporting on the representativeness of the network (Olson and Dinerstein 1998).

4.3.1.1 Benthic bioregionalisation

The benthic regionalisation combines the Interim Marine and Coastal Regionalisation of Australia (inshore) and the National Marine Bioregionalisation (offshelf).

To inform and feed into the IMCRA, a number of datasets were derived using biological and physical datasets, including primary bathymetric units, sediment facies, demersal fish provinces, Provincial bioregions, mesoscale bioregions, and biomes.

Primary bathymetric units

This data layer defines the major morphological features of the seabed—the shelf, slop, rise, and abyssal plain/ deep ocean floor. Their purpose with respect to the IMCRA is to classify regional-scale differences in benthic communities (Heap et al. 2005).

Sediment facies

This data product aims to incorporate geomorphic, sedimentary and oceanographic data to define seabed areas that share the same characteristics, termed "Seabed Facies." The purpose of this dataset within the IMCRA is to define smaller-scale bioregions (Heap et al. 2005).

Demersal fish provinces

This dataset contains areas of endemism and transitions (areas of species overlap and faunal mixing). The boundaries were determined by Jaccard Analysis of the fish distributions. For the IMCRA, this was the primary biological dataset used in the process of defining the provincial bioregion boundaries (Heap et al. 2005).

Provincial bioregions

One of the main data products for the IMCRA, the provincial bioregions are large biogeographic regions defined from the regional structure of demersal fish off the shelf to 2000 metres depth. The demersal fish distributions are assumed to represent all marine faunal distributions. At depths greater than 2000 metres, the boundaries for the Provincial Bioregions were defined using geomorphic features, which are assumed to represent broad changes in benthic communities (Heap et al. 2005).

Mesoscale bioregions

The mesoscale bioregions were developed as part of the NRSMPA in an effort to summarise and integrate the regional scale classifications of near-shore ecosystem diversity that had been developed independently in each state. Different types of data and analyses inform the mesoscale bioregions (summarised in Table 4.9) (Heap et al. 2005).

Table 4.9. Meso-scale bioregion derived data sources and method

State	Primary data sources	Method
South Australia	Biological, physical, oceanographic, geomorphic, subtidal habitat, intertidal habitat, and mangrove data	Delphic approach to classification
Western Australia	Physical and biological data	Based on a geomorphic classification, derived by an expert panel

Biomes

In the context of the IMCRA, biomes are biogeographic regions that are nested within Provincial bioregions in order to capture a finer resolution of spatial distribution of benthic fauna. This data product is restricted to the slope, and is derived from the depth structure identified in a demersal fish dataset (Heap et al. 2005).

4.3.1.2 Pelagic Regionalisation

CSIRO has created a pelagic (water column) regionalisation that primarily utilises physical data and satellite-derived sea-surface plankton estimates. This regionalisation encompasses the water at the seafloor to the surface and is designed to illustrate the complexity of the structure of the marine water column (Lyne *et al.* 2005).

4.3.1.3 Seascapes

Geoscience Australia produced this dataset which consists of seabed habitat maps called ‘seascapes.’ Each seascape category corresponds to seabed areas with similar biophysical properties that have been shown to correlate with benthic biota in a number of studies (e.g. Post *et al*. 2006). GA asserts that these areas represent potential benthic habitats and communities, and that the seascape maps can act as a substitute for habitat type and biotic variability when comprehensive biological data are not available (Whiteway *et al*. 2007).

4.3.2. Key Ecological Features

Key Ecological Features have been determined for each of the marine planning regions as part of the Commonwealth's bioregional profile process. In the Southwest bioregional profile Key Ecological Features are defined as including "species and communities considered to play an important ecological role in the region and habitats or areas considered to be ecologically important at a regional scale." These features were identified by the Australian government after seeking advice from scientists via a commissioned report (South-west Marine Region Ecosystems and Key Species Groups Report) and a workshop of experts in 2006 (McClatchie *et al.* 2006).

4.3.3. Phytoplankton provinces

This dataset was provided by CSIRO for the IMCRA process and consists of phytoplankton provinces defined in 2004 by Dr. Gustaaf Hallegraeff of the University of Tasmania.

4.4 Treatment of datasets for Marxan Analysis

The acquisition and review of data for the SWMR presented a number of tenure, environmental and socio-economic datasets that were considered suitable for use in a conservation assessment. In some instances, pre-processing of data was required to prepare these datasets for use. Here, we discuss the treatment of datasets for the Marxan analysis.

4.4.1. Processing of Planning Units

Marxan requires the planning region to be divided into smaller "planning units." In the case of the SWMR, we created a 5 minute grid with 105, -40 as the lower lat/long boundary. The planning units were aligned along lines of latitude and longitude to comply with Principle 2.3.1, which suggests that boundaries need to be easily recognisable. Planning units were clipped to the extent of the planning region. After clipping, planning units smaller than 20% of the mean planning unit size were merged with the neighbouring planning unit with the longest boundary. After all processing, the mean size of a planning unit in the analysis was 70 km^2. The rest of the data (conservation features and cost) were summarised to this dataset for use within Marxan, and results are displayed based on the planning units.

4.4.2. Processing of Biological and Physical datasets

The delineation of conservation features was drawn from a range of environmental data and generally proceeded as follows:

1- Pre-processing (when necessary)
2- Select spatial representation of the activity within the planning region
3- Summarise the amount of the feature within each planning unit. All features were summarised using either the Zonal Statistics or Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

The methods involved in the pre-processing that was required for a number of datasets are discussed below.

4.4.2.1 AquaMaps data

AquaMaps is a project that aims to create standardised range maps for all the species in the oceans. The maps are computer-generated predictions of the natural occurrence of marine species. These predictions are based on how a species reacts to environmental factors - including depth, salinity, temperature, primary productivity, and the proximity of sea ice or the coast. The prediction model also includes information on an “environmental envelope” created using FAO areas, bounding boxes, depth ranges (from information in species databases like FishBase) as well as incorporating occurrence point data from OBIS and GBIF (Kaschner et al. 2007). The output is in 0.5 degree C-squares with a probability of occurrence (0-1) for each species in each grid square. We obtained data at the 0.5 degree level of resolution on the 3013 species that have been modelled by AquaMaps that occur in the study region.

AquaMaps Validation

The Aquamaps predicted distribution of species is the only accessible data that describes the distribution of a range of species, including the non-commercial and non-endangered species. It is therefore considered in this project as a vital dataset and provides for species-level knowledge to be used across the region for reserve design. This supplements, but does not replace, the data and knowledge of the various biodiversity surrogates (such as the bioregionalisations). Because of the importance of this data, and the influence it was expected to have on the reserve solutions, we conducted a form of independent validation of the modelled Aquamaps distributions. This validation used the two fine-scale CSIRO datasets from the Southern Surveyor cruises—one for invertebrates and one for fish species, to assess the robustness of the predictions.

We requested the CSIRO point sampling data for species that matched the AquaMaps species information we had secured, to conduct the validation. There are 108 fish matches and 21 invertebrate matches. CSIRO provided data for each of these matched species and included presence/absence at each survey site, and in some cases abundance data. The fish dataset included 505 records of matched species presence, and the invertebrate dataset included 55 records of matched species presence.

To determine how well the AquaMaps system predicted the occurrence of each of these species we considered each sampling location where the species was found by CSIRO, and identified the probability of occurrence predicted by AquaMaps for that species within the (0.5 degree) grid where the CSIRO station is located. While the prediction for the presence of each species varied, the average Aquamaps prediction of probability of occurrence for invertebrates was 0.23 and for fish was 0.73 (see Tables 4.10 and 4.11).

Table 4.10. Invertebrate species found in CSIRO SS200510 dataset and in AquaMaps, the number of records showing presence of that species in the CSIRO dataset, and the average prediction for those sites from AquaMaps.

Group	Number of presence records	Average AquaMaps prediction
All Invertebrates	55	0.23
Madrepora oculata	1	1.00
Arca ventricosa	1	0.00
Malleus albus	2	0.33
Hyotissa hyotis	4	0.23
Sepia cultrata	2	1.00
Sepia opipara	1	0.00
Euprymna tasmanica	2	0.00
Todaropsis eblanae	2	0.30
Syrinx aruanus	1	1.00
Melicertus marginatus	1	0.00
Aristeus virilis	3	0.44
Aristeus semidentatus	3	0.11
Benthesicymus investigatoris	2	0.35
Haliporoides sibogae	6	0.33
Metanephrops boschmai	7	0.21
Metanephrops velutinus	7	0.12
Puerulus angulatus	3	0.00
Ibacus peronii	1	0.00
Didemnum moseleyi	1	0.00
Cystodytes dellachiajei	4	0.00
Styela plicata	1	0.00

Table 4.11. Fish species found in CSIRO SS199101 dataset and in AquaMaps, the number of records showing presence of that species in the CSIRO dataset, and the average prediction for those sites from AquaMaps.

Group	Number of presence records	Average AquaMaps prediction
All Fish	505	0.73
Aldrovandia affinis	8	0.75
Aldrovandia phalacra	8	0.70
Alepocephalus australis	1	1.00
Allocyttus verrucosus	21	0.67
Antigonia rhomboidea	2	1.00
Antimora rostrata	13	0.96
Apogonops anomalus	11	0.63
Apristurus longicephalus	1	0.00
Bajacalifornia calcarata	4	0.59
Barbourisia rufa	4	0.50
Bathygadus cottoides	14	0.67
Bathypterois guentheri	6	0.50
Bathysaurus ferox	3	0.96
Bathyuroconger vicinus	1	0.00
Bembrops curvatura	1	0.00
Beryx splendens	8	0.87
Centriscops humerosus	3	0.22
Centroberyx australis	3	0.67
Centrophorus moluccensis	2	1.00
Centroscyllium kamoharai	6	0.79
Centroselachus crepidater	2	0.72
Coelorinchus charius	8	0.15
Coelorinchus matamua	1	0.48
Coelorinchus maurofasciatus	14	0.66
Coelorinchus mirus	9	0.88
Coryphaenoides rudis	5	0.90
Coryphaenoides striaturus	1	1.00
Cubiceps pauciradiatus	1	0.00
Cyttopsis rosea	3	0.67
Cyttus traversi	2	0.69
Dannevigia tusca	1	1.00
Deania calcea	5	0.77
Diastobranchus capensis	11	0.48
Dipturus gudgeri	3	0.97
Diretmichthys parini	18	0.89
Diretmus argenteus	3	0.00
Epigonus macrops	3	0.67
Etmopterus brachyurus	2	1.00
Etmopterus lucifer	2	0.87
Etmopterus pusillus	6	1.00
Euclichthys polynemus	12	0.87
Euprotomicrus bispinatus	1	0.00

Group	Number of presence records	Average AquaMaps prediction
Gephyroberyx darwinii	5	0.80
Grammicolepis brachiusculus	1	0.97
Helicolenus percoides	13	0.91
Heptranchias perlo	4	1.00
Hoplichthys citrinus	2	1.00
Hoplichthys haswelli	7	0.66
Hoplostethus atlanticus	1	0.72
Hydrolagus lemures	14	0.90
Iago garricki	1	1.00
Kathetostoma nigrofasciatum	2	0.50
Lepidoperca occidentalis	1	0.91
Lophiomus setigerus	8	0.80
Macroramphosus scolopax	1	1.00
Malacocephalus laevis	13	1.00
Maulisia microlepis	1	0.00
Mora moro	2	0.90
Nemadactylus macropterus	1	0.85
Nemadactylus valenciennesi	1	0.38
Neocyttus rhomboidalis	2	0.92
Neoscopelus macrolepidotus	13	0.46
Neosebastes nigropunctatus	1	1.00
Neosebastes thetidis	1	1.00
Nezumia kapala	3	1.00
Nezumia leucoura	9	0.87
Nezumia propinqua	7	0.50
Notacanthus sexspinis	2	0.85
Oplegnathus woodwardi	1	0.86
Oreosoma atlanticum	1	1.00
Polymetme corythaeola	11	0.89
Priacanthus macracanthus	2	0.00
Pristiophorus cirratus	2	0.16
Psychrolutes marcidus	5	0.98
Pterygotrigla hemisticta	2	0.50
Pterygotrigla polyommata	3	0.33
Ratabulus diversidens	1	0.00
Rexea solandri	12	0.73
Rhinochimaera pacifica	5	1.00
Rouleina attrita	2	0.50
Rouleina guentheri	13	0.85
Scombrolabrax heterolepis	12	0.27
Setarches guentheri	7	0.90
Squalus megalops	13	0.42
Synagrops japonicus	10	0.89
Synagrops philippinensis	4	0.57
Synaphobranchus affinis	11	0.91

Group	Number of presence records	Average AquaMaps prediction
Synaphobranchus kaupii	1	1.00
Talismania antillarum	5	0.60
Talismania longifilis	1	0.00
Torpedo macneilli	1	1.00
Trachonurus gagates	2	0.99
Tripterophycis gilchristi	6	0.63
Urolophus expansus	2	0.50
Urolophus viridis	3	0.21
Xenodermichthys copei	10	0.90
Xenolepidichthys dalgleishi	6	1.00
Zanclistius elevatus	1	0.92
Zeus faber	1	1.00

The level of robustness found for the invertebrate species is low (average of 0.23 across all species). This is probably related to some extent to the limited number of observations in the CSIRO data, and this in turn may be related to the natural rarity of individual species or possibly specific attributes of their distributions in the local environments where CSIRO sampled. The level of robustness of the fish data is much higher (0.73) and is of an acceptable standard for use in the Marxan analysis.

We chose to use the AquaMaps predictions for all the species based on the results of the validation, however, as a way to increase our confidence in the distributional data, we limited our use of the data for each species to areas where the species was predicted by Aquamaps to be present at a probability of 0.75 and above.

Applying this threshold resulted in selection of 1447 AquaMaps species for inclusion in our database for this project. The extent of the presence (probability of 0.75 or above) of each of these species within a planning unit was calculated using the Zonal Statistics function in ArcGIS 9.3 (ESRI 2009).

AquaMaps_endangered, AquaMaps_listed, AquaMaps_threatened

Of the 106 EPBC-listed species identified in the South-western bioregional profile, all but two of the aquatic (non-bird) species (42) have modelled AquaMaps datasets. However, after applying the 0.75 threshold to the AquaMaps datasets, we retained 22 datasets for listed aquatic species for use in the analysis. None of the 62 listed bird species are considered here because AquaMaps is limited to aquatic species. In order to have the flexibility to set different targets for endangered species, listed species, and threatened species, these AquaMaps species were placed in their own feature classes. All other processing for these feature classes was identical to the processing for the AquaMaps species overall.

AquaMaps_wide, AquaMapsListed_wide

A number of the AquaMaps species are wide-ranging or migratory species that are predicted to occur in all or most or the study region. We recognise that placing sanctuary zones in regions where such species are known to be present at some time of the year, without additional information on habitat utilisation, may contribute to their conservation needs but is unlikely to result in adequate protection for these species.

Preliminary analyses indicated that setting targets for all AquaMaps wide-ranging species resulted in a very high percentage of the planning region being selected in the network of marine sanctuaries, which could not defended given the nature of the input data. As a result of these exploratory analyses we defined a subset of AquaMaps species that we termed AquaMaps-wide species. AquaMaps-wide species were defined as species that occurred in 50% or more of the planning units in the analysis. We treat the AquaMaps-wide species as an independent feature class from the other AquaMaps species.

The recognition that sanctuaries may not be the main solution for conservation of these species led to the removal of direct targets for the Aquamaps-wide species from the analyses for this project. While targets for conservation of all Aquamaps-wide species were not applied, their representation in the solutions has been tracked and reported for each scenario.

4.4.2.2 Bioregions

For the bioregion features, we merged the provincial scale bioregions with the mesoscale bioregions in order to utilise the finer scale information that the mesoscale bioregions provide on the shelf. The extent of each bioregion within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.3 Demersal fish provinces

The demersal fish provinces are made up of two datasets—one from the shelf and one from the slope. The extent of each province within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.4 Depth by bioregion

We nested the depth zones (description below) within the bioregions using the Intersect tool in ArcGIS 9.3. The extent of each of the resulting features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.5 Depth zones

We established the depth zones in Table 5.5 to categorise major ecologically relevant breaks along the ocean floor, based on two DEWHA depth zone categorisations. The depth classes derived here provided for a systematic gradient of depth zones from the shallow shelf waters to the abyssal deep that was also consistent with an expected rate of species turnover in the benthic ecosystems. The extent of the features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

Table 4.12 Depth Zones

Depth Zones
0m plus
0m to -20m
-20m to -40m
-40m to -80m
-80m to -150m
-150m to -300m
-300m to -500m
-500m to -800m
-800m to -1100m
-1100m to -1500m
1500 to -3000m
-3000m plus

4.4.2.6 DEWHA AFAs

The Department of Environment, Water, Heritage, and the Arts Areas for Further Assessment (AFAs) shapefile was processed as a conservation feature to allow for scenarios that would attempt to confine the reserve solutions to areas contained by the AFAs. The extent of each AFA within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.7 Eddy Kinetic Energy by latitude

This dataset was created by Ming Feng of CSIRO as a product to map an aspect of the influence of the Leeuwin current, the long term (1993-2007) mean eddy kinetic energy.

The eddy kinetic energy (EKE) dataset was originally a continuous dataset. We categorised the dataset into low, medium, and high EKE based on the recommendations of Ming Feng. Then we nested the EKE dataset within latitudinal bands (details below) using the Intersect tool in ArcGIS 9.3. We then calculated the extent of each resulting feature within a planning unit using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.8 Pelagic Regionalisation – Energetics

CSIRO created a pelagic (water column) regionalisation that primarily utilises physical data and satellite plankton images. This regionalisation encompasses the water at the seafloor to the surface and is designed to illustrate the complexity of the structure of the marine water column (Lyne et al. 2005). One part of the pelagic regionalisation is the energetics dataset.

We discussed the use of the pelagic regionalisation with CSIRO, who offered advice on how to incorporate the data within the Marxan analysis. The energetics dataset was nested within circulation regimes, and then classified into high, medium, and low energetics within each circulation regime. The classification created three equally sized areas within each circulation regime; (1) the highest one-third energetics, (2) the middle one-third energetics, (3) the bottom one-third energetics. We then calculated the extent of each resulting feature within a planning unit using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.9 Geomorphic features by depth by Bioregion

We nested geomorphic features, depth, and bioregion using the Intersect tool in ArcGIS 9.3. The extent of each of the resulting features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.10 Geomorphic features

The geomorphic feature characterisation layer was derived from the DEM by Geoscience Australia. The geomorphic feature layer delineated a fine scale characterisation of geomorphic features.

We used the additional data on canyon type to add to the detail of the geomorphic features by incorporating this additional data (which was already in the shapefile). Then the extent of each of the geomorphic features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.11 Key Ecological Features

The Key Ecological Features dataset delineated the spatial extent of 15 of the Commonwealth's Key Ecological Features within the region. Spatially explicit maps of two Key Ecologic Features—Benthic invertebrate communities of the eastern Great Australian Bight and Small pelagic fish—were not included in the dataset provided by DEWHA. Two further Key Ecologic Features—Demersal slope fish communities and Western Rock Lobster—were not directly targeted by our analysis. The Western Rock Lobster was not included as a conservation feature within our analysis because the fishery itself was included as a cost component within the analysis. Within Marxan it is not logically consistent to be both targeting a feature for inclusion in a sanctuary zone, and trying to minimise inclusion of that feature in a sanctuary zone. Demersal slope fish communities were not targeted because equivalent data was not available for other provinces, and because the slope communities in all bioregions were directly targeted through the use of constructed surrogates. The extent of the features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.12 Latitudinal Bands

We created a shapefile that divided the study region into 3 degree latitudinal bands. The extent of the features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.13 Pelagic Regionalisation – level 1b

The CSIRO pelagic regionalisation includes the level 1b regionalisation, as well as the water masses datasets. For the pelagic regionalization dataset (level 1b) we used the following depths 0, 100, 250, 500, 1000, 2000, 3000, 4000, and the 25 water masses class structure for each depth. Then the extent of each of the resulting features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.14 Phytoplankton Provinces

There was no pre-processing for the Phytoplankton Provinces dataset. The extent of the features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.15 Primary Productivity

The mean annual primary productivity dataset was created by CSIRO for the National Marine Bioregionalisation project. The Primary Productivity dataset was originally a continuous dataset. We classified the dataset using Natural Breaks (Jenks) in ArcGIS 9.3, resulting in 5 classes. Then the extent of each of the resulting features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.16 Seabird Foraging

The Species of National Significance database (SNES) stores maps and point distribution information about species of national significance as listed in the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999. Species include threatened species, migratory species, marine species and cetaceans. The SNES dataset covers 53 of the 62 listed bird species in the SWMR and reports on species occurrences in state waters adjacent to the

SWMR for several of the listed birds. To evaluate the relative importance of areas within the planning region to these species, information about foraging ranges was obtained from the Handbook of Australian, New Zealand, and Antarctic Birds (Marchant & Higgins, 1991) and through solicitation of expert opinion (Dunlop, 2009). Foraging range information is not available for many species, however, through the combination of literature estimates of foraging ranges and the expert opinion we were able to obtain foraging ranges for 18 of the listed birds. When the Marchant and Higgins foraging distance did not match the expert opinion, we applied the following decision rules: If the expert provided an estimate of a specific distance, it was used; if the expert opinion provided a range and it corresponded to the Marchant and Higgins distances or there are no Marchant and Higgins distances, the longest end of the range was used; if there was no overlap in ranges, and the Marchant and Higgins estimate was less than expert range, the midpoint of the expert range was used; if there is no range estimate elicited through expert consultation, information and a range was provided in Marchant and Higgins, the longest end of range was used. The foraging distances used are summarised in Table 4.13.

We used these foraging distances with the spatial data from the SNES database for these 18 species to create foraging distance datasets, using the buffer tool in ArcGIS 9.3. When the foraging distance information was detailed, additional clipping (i.e. clipping to limit the foraging distance to the shelf) was performed. We then calculated the extent of each resulting feature within a planning unit using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

Seabird foraging wide

Two of the seabird foraging species (*Pterodroma macroptera* and *Sterna fuscata*) are wide-ranging species, and their foraging areas include all or most of the SWMR. As a result, we built in the flexibility to set different targets for these species by placing them in their own feature class (like the wide ranging AquaMaps species). The threshold for inclusion in this feature class was that the species needed to occur in 50% or more of the planning units in the study region. The processing for this feature class was identical to the processing for the other seabird foraging species. As with the wide-ranging species in AquaMaps, in a preliminary analysis, these seabird foraging areas were exerting a disproportionate impact on the Marxan solutions. As a result, they were removed from the analysis (targets were not applied), but we report on them in the scenario results in Chapter 6.

Table 4.13 Listed bird species and the corresponding foraging distance information applied in the Marxan analysis.

Common name	Species name	Foraging distance used
Australian lesser noddy	Anous tenirostris melanops	50 km shelf edge or slope
Black-faced cormorant	Phalacrocorax fuscescens	10 km
Bridled tern	Sterna anaethetus	80 km central and outer shelf
Caspian tern	Sterna caspia	10 km inshore
Common noddy	Anous stolidus	125 km seaward of shelf break
Crested tern	Sterna bergii	20 km inner shelf or along coastline
Flesh-footed shearwater	Puffinus carneipes	400 km along shelf
Great-winged petrel*	Pterodroma macroptera	not on shelf 600 km offshelf
Hutton's shearwater	Puffinus huttoni	70 km
Kelp gull	Larus dominicanus	30 km
Little penguin	Eudyptula minor	20 km along the coast
Pacific gull	Larus pacificus	39 km
Roseate tern	Sterna dougalli	50 km on shelf
Short-tailed shearwater	Puffinus tenuirostris	200 km
Sooty tern*	Sterna fuscata	350 km off shelf
Wedge-tailed shearwater	Puffinus pacificus	120 km on shelf
White bellied sea eagle	Haliaeetus leucogaster	10 km
White-faced storm petrel	Pelagodroma marina	370 on shelf

* Wide range species- not targeted in Marxan analysis

4.4.2.17 Seascapes

There was no pre-processing for the seascapes dataset. The extent of the features within a planning unit was calculated using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.2.18 Vertical velocity by latitude

This dataset was created by Ming Feng of CSIRO as a product to map an aspect of the influence of the Leeuwin current, the vertical velocity. The vertical velocity dataset was originally a continuous dataset. We categorised the dataset based on the recommendations of Ming Feng. The categories were: strong downwelling, moderate downwelling, no significant vertical motion, moderate upwelling, and strong upwelling. Then we nested the vertical velocity dataset within latitudinal bands dataset using the Intersect tool in ArcGIS 9.3 (ESRI 2009). We then calculated the extent of each resulting feature within a planning unit using the Tabulate Area function in ArcGIS 9.3 (ESRI 2009).

4.4.3. Processing Cost surface Datasets

The Marxan software package utilises a single cost surface for optimisation. It is the cost surface that the algorithm seeks to minimise while still meeting the representation targets. The development of a single cost surface for this project required the aggregation of the selected individual cost surfaces. The following section describes the technical processing required to aggregate individual costs with different units of measurement, into a single cost surface. Forty-six individual layers were incorporated into the final cost surface (Table 4.14).

Table 4.14 Spatial data layers used to develop Marxan cost surface.

Id	Name	Units
1	Area	Area
2	Defence	Area
3	Petroleum Exploration	Area
4	Petroleum Prospectivity High	Area
5	Petroleum Prospectivity Low	Area
6	Petroleum Prospectivity Low/Medium	Area
7	Petroleum Prospectivity Medium	Area
8	Petroleum Prospectivity Medium/High	Area
9	Petroleum Production Leases	Area
10	Petroleum Release 2008	Area
11	Population Pressure	Index
12	Recreational catch	Catch
13	Recreational effort	Hours
14	Charter fishing	Effort
15	Shipping	Reported boat density
16	Eastern Tuna and Billfish	Effort
17	Great Austrian Bight Trawl	GVP
18	Gillnet, hook and trap	GVP
19	High Seas Tuna	Effort
20	Southern Bluefin Tuna	GVP
21	Southeast Nontrawl	Effort
22	Southeast Trawl	Effort
23	Southern Shark	GVP
24	Small Pelagics	Effort
25	Western Deepwater Trawl	GVP
26	Western Tuna and billfish	GVP
27	Skipjack Tuna	Effort
28	Abalone	GVP
29	Marine Scalefish	Effort
30	Rock Lobster	GVP
31	Sardine	Catch
32	Abalone	GVP
33	Abrolhos Island Trawl	GVP
34	Esperance Southern Rock Lobster	GVP

35	Open Access Crabpot	GVP
36	Open Access Dropline/Handline	GVP
37	Open Access Dropline/Trolling	GVP
38	Shark Bay Snapper	GVP
39	South Coast Purse Seine	GVP
40	South Coast Trawl	Effort
41	Southern Demersal Gillnet/Longline	GVP
42	Southern Rock Lobster	GVP
43	South West Inshore Trawl	GVP
44	West Coast Gillnet and Longline	GVP
45	West Coast Rock Lobster	GVP
46	West Coast Purse Seine	GVP

After identifying cost layers for inclusion, the general process for processing individual cost layer involved three steps:

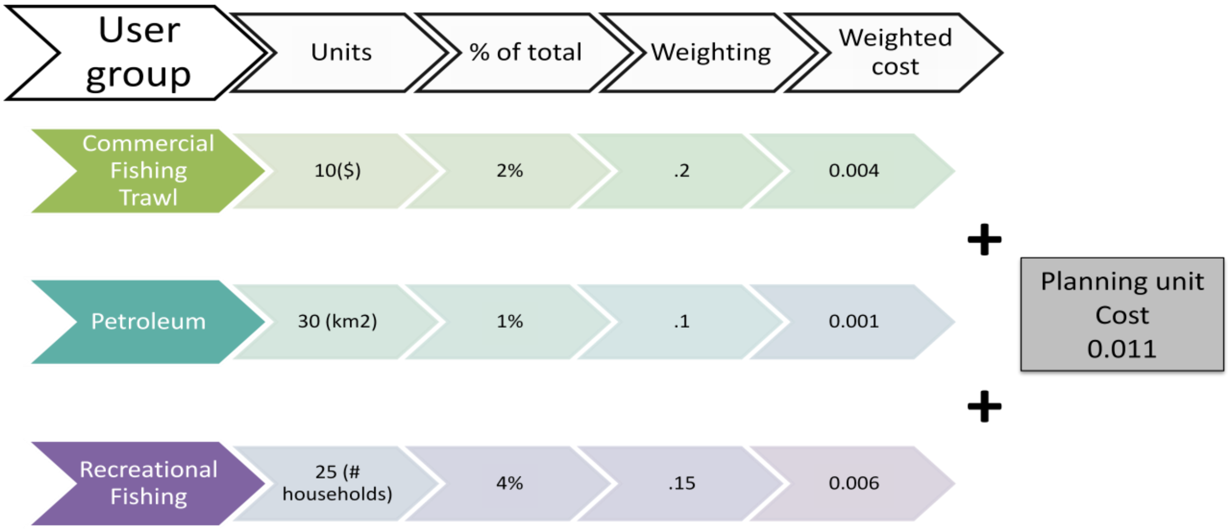
1- Select spatial representation of the activity within the planning region.
2- Summarise the amount of the activity within each planning unit. All activities were summarised using either the Zonal Statistics or Tabulate Area function in ArcGIS 9.3(ESRI 2009).
3- Transform the value of the activity in planning unit for inclusion in the cost database. Normalised value was set equal to the percentage of the overall activity that occurred within the planning unit: $Vij = Aij / \sum_i^n Aji$

Where V_{ij} is the normalised value of activity j in planning unit i, A_i is raw value of activity i in planning unit j.

The transformation allows for an intuitive interpretation of the amount of the impact to each activity of proposed network of marine sanctuaries. This transformation (unlike others such as a min/max transformation) maintains the distribution of costs within the feature, and the relative differences between planning units. It also allows for the flexibility of combining the individual costs into a single cost surface, because the total value of each cost (activity) is one. Because the summed value of each activity is one, the weighting applied at the cost activity level also has an intuitive interpretation—a cost with a weighting of two contributes twice as much as a cost with a weighting of one.

After calculating the percentage of each activity in a planning unit, the individual values of all activities within the planning unit were summed to derive the final cost for the planning unit (Figure 4.1). Prior to summing the individual costs, a cost specific multiplier was applied to each activity based on the desired contribution to the final cost surface. The multiplier serves to mitigate the importance of number of measures available for each activity, and ensures that the contribution of each activity to the final cost layer was consistent with the principles (The Ecology Centre 2009).

Figure 4.1 Conceptual model for aggregation of costs at the planning unit level.



4.4.3.1 Area

Area is the area in square kilometres for each planning unit. Area is included purely as a control measure to ensure that each planning unit has a "cost" within Marxan. It is important that each planning unit have a cost within Marxan, to prevent areas being added to solution sets because it is incorrectly assumed that the cost of the protection is zero.

4.4.3.2 Commercial Fishing

Data was available for twenty different commercial fisheries active within the region, and each fishery was represented by an individual cost surface within the analysis. Activities relating to commercial fishing within the region accounted for 31 of the 46 cost surfaces. The number of different cost surfaces reflects the number of different fisheries active within the region. The value of each individual fishery was used as a surrogate to estimate the extent of activity of each fishery, and to provide the basis for the analysis to find solutions that minimise impact to each fishery. Fishery value data have substantial limitations, but were the only data on fisheries that were available to us for this project. We have assumed that the value of each fishery expressed within the data that we have been provided from the various agencies provides a reasonable estimate of the extent of fishery interests throughout the SWMR. We therefore have used these data to maximise retention of fisheries activity in the SWMR through avoidance of inclusion of the extent of their value within sanctuary solutions. We recognise that finer scale data on fisheries value may provide better estimates of the importance of different areas within the SWMR for fishing, and that there are other ways of estimating value to fishing beyond Gross Value Product. However, we appreciate the effort required by data providers to produce reliable estimates, and that such matters are all well beyond the scope of this project.

Table 4.15 Commercial fisheries in the SWMR. Individual fisheries grouped by reporting agency.

Commonwealth	South Australia	Western Australia
Great Austrian Bight Trawl	Abalone	Abalone
Gillnet hook and trap	Marine ScaleFish	Abrolhos Island Trawl
High Seas Tuna	Rock Lobster	Esperance Southern Rock Lobster
Southern Bluefin Tuna	Sardine	Open Access Crabpot
Southeast Nontrawl		Open Access Dropline/Trolling
Southeast Trawl		Open Access Dropline/Handline
Small Pelagics		Shark Bay Snapper
Southern Shark		South Coast Purse Seine
		South Coast Trawl
		Southern Demersal Gillnet/Longline
		Southern Rock Lobster
		South West Inshore Trawl
		West Coast Gillnet and Longline
		West Coast Rock Lobster
		West Coast Purse Seine

We defined value of each fishery as the total Gross Value Product (GVP) of the fishery over the entire reporting period. The choice of GVP as the metric for fishery value comes with some shortfalls, for instance GVP is subject to market fluctuations in the price of the product. However it has the benefit of identifying areas that are the most valuable from a monetary standpoint for individual fisheries. The difference between total catch and GVP is more pronounced in mixed species fisheries in which some species are more valuable than others—here total number of individuals caught or kilograms caught do not correlate well with GVP. The use of GVP assumes that individual fisheries would prefer to retain revenue rather than catch. Prior to any additional processing all reported GVP values were converted to 2006 dollars using the estimates of inflation provided by the Reserve Bank of Australia (RBA 2009). Because of confidentiality concerns, some fisheries had little or no reported GVP. When no GVP was reported, or when GVP was reported in fewer than 40% of total blocks, we used the number of boats active in the block as a proxy for the fisheries GVP. The implicit assumption here is that fishery management blocks with more boats are more valuable than blocks with fewer boats. We acknowledge the imperfect nature of this surrogate, and understand that boat size, block location, and many other factors can influence block value, but a further investigation of such factors was beyond the scope of this project.

Within the commercial fishing datasets, non-reported values are a frequent problem. Non-reported values occur in the data because of confidentiality concerns, when the number of boats active in a block during the reporting period is fewer than the managing agency's specified minimum.

Total block value was estimated using the following decision rules:

1- If the number of years with GVP reported = Number of years fished, sum the time adjusted value of all years reported.
2- If the number of years with GVP report is >=1, but < the number of years fished. Sum the total reported value, then calculate the mean reported value for boats in the block, and multiple by the number of boats for which no GVP was reported.
3- If GVP reported = 0, and number of years fished >=1, value equals the number of boats active in the block * the median value of all boats in partial reporting blocks. Here we defined partial reporting blocks, as blocks for which not all years with effort contained reported GVP.
4- If no values were reported – value of block equals 0.

After calculating the value of the block for the fishery, the planning unit value was calculated using the Zonal statistics function in ArcGIS 9.3 (ESRI 2009). The implicit assumption in this calculation is that fishery harvest is homogenous within fishery reporting blocks. While we know this assumption to be false, it was beyond the scope of the project to take the necessary steps to move beyond it.

4.4.3.3 Defence

Extent of the presence of defence activities within each planning unit was calculated using the Zonal Statistics function in ArcGIS 9.3.

4.4.3.4 Petroleum

Two different classes of petroleum related activities are recognised within the cost layer, leased areas, and areas with prospective future value. The difference between the two is described in greater detail within the data description of this report. However, without additional information with which we could ascribe relative values to the different types, we treated all petroleum related activities as a single class. The extent of the presence of all petroleum related activities within a planning unit was calculated using the Zonal Statistics function in ArcGIS 9.3.

4.4.3.5 Population Pressure

To estimate the relative influence of populations on the marine environment, population centres were first related to ports and marinas, based on the distance from the population centre to the marine port. Influence or weighting of the population on the port was assigned using a linear decay function for distance from the port:

$$Port\ population = \sum \frac{1}{Dc} * Pc$$

Where D_c is distance to the port, and P_c is the population of the area. All population within 1,000 kilometres of the port were summed to give the total weighted population value of that port.

Population pressure on each planning unit was calculated based on the distance of the planning unit from all ports, using a similar approach to the above:

$$PU\ Population = \sum \frac{1}{Dp} * Pp$$

Where D_p is distance to the port from the planning unit, and Pp is the population pressure from that port. The impact of all ports within 100 kilometres was summed to reach the total weighted population pressure on that planning unit.

4.4.3.6 Recreational Fishing

Three layers were used to represent recreational fishing within the region. Two layers provided by BRS, with spatial coverage that included the entire planning region, represented effort and catch. Effort and catch were also available at a finer scale for areas off the coast of Western Australia (WA). Catch and effort for the WA region were processed and incorporated independently.

Reporting on recreational fishing is subject to the same confidentiality concerns that are associated with data on commercial fishing. These confidentiality concerns required us to estimate catch and effort in blocks where the reported values were withheld. Unreported values for WA charter fishing catch were filled in using the estimation procedure as outlined in the commercial fishing section. Estimation of unreported values within the BRS dataset followed a different method because only a single year of data was available. The following steps were used to estimate non-reported values for BRS Catch, and BRS Effort:

1- Calculated rate (catch per unit effort, or effort per house) for all blocks
2- Used a Modified z-score calculation to identify outliers
3- Used linear regression to fit relationship for catch per unit effort.

4- Predict catch for all unreported values
5- Summed catch for full reporting period
6- Calculate catch per unit area of reporting block

Charter fishing effort in WA was reported both by number of boats engaged in a specific charter method, with three methods listed—diving, fishing, and snorkelling. If a boat engaged in more than one of the three activities it would be reported multiple times within this dataset. To prevent counting a single boat multiple times, the maximum number of boats across all activities was used as the measure of effort per block. Effort was then summed over the entire reporting period, and divided by block area. Effort (number of boats active) was not subject to confidentially concerns, thus no estimation of unreported effort was necessary.

4.4.3.7 Shipping

Presence of shipping intensity was calculated using AMSA reported shipping records from the most recent five-year period (2003-2007). Density of shipping activities within each planning unit was then calculated using Hawth's Tools for ArcGIS (Beyer 2004).

5. APPLYING THE DESIGN PRINCIPLES

This chapter describes how we operationalise the scientific principles within the specific design context of the SWMR, what we refer to as 'principles mapping'. This is an important first step in framing the conservation planning problem for the SWMR to the standard of scientific best practice. In this chapter we summarise how datasets captured for the SWMR have been applied to fulfil the intent of the principles document.

The intention of the guidance statement is to identify a set of science based principles that set out design criteria for MPAs within the NRSMPA. While the principles strive to provide robust guidance at the operational science level, they are limited in the extent to which they can assume/anticipate specific MPA design contexts, and this limits the extent to which any generic statement can provide detailed guidance. This section summarises how the datasets that have been captured for the SWMR have been regarded to fulfil the intent of the principles document (The Ecology Centre, 2009).

The success of the prioritisation problem of defining a network of marine sanctuaries for the SWMR depends on the extent to which regional patterns of diversity have been captured within the data and surrogates. The outcomes also depend heavily on how the datasets are used within the Marxan process. The principles play a crucial role in informing the assessment—they provide framing for the problem, guiding the way in which the available datasets have been dealt with within the Marxan process, and assisting with the context for target setting. Table 5.1 summarises the physical and biological datasets that were used as conservation features within the Marxan analysis, and the socio-economic datasets are summarised in Table 5.2. The datasets have been grouped into categories for more convenient presentation—a full list of the datasets used in the analysis is presented in Appendix 2. Our analysis focuses on defining marine sanctuary areas within the SWMR within a broader MPA framework, and therefore we focus on the principles that apply to marine sanctuaries in the principle mapping. A summary of the datasets and their relationship to the principles is presented in Appendix 3.

The principles were designed to guide actual marine planning efforts through the full management lifecycle of MPAs design and implementation. The scope of this present project does not encompass the full range of management activities that are required for implementation of protected areas, which would be a next logical process of assessment (when the actual MPA boundaries have been chosen). Because the present project does not include all of these activities, many of the principles relate to activities that were beyond the scope of the project. Where such gaps exist we explicitly identify them, and recognise the limited scope of the present analysis. We have noted this limited scope by identifying principles that were not addressed within the project, with the text "Beyond project scope"***.***

5.1 Principle 1 Biodiversity Primacy

The headings and numbering in the following sub-sections are drawn directly from the Principles.

In the Scientific Principles, biodiversity primacy is defined as: *Nature conservation and maintenance of the ecological integrity are the primary objectives and outcomes to be achieved by the MPA or network.* The following sections consider the sub-sections of the biodiversity primacy principle and explain some of the choices that were made in terms of datasets to be used or actions to be applied for Marxan based on this principle.

5.1.1. Planning Framework

5.1.1.1 Planning Boundaries

The South-west Marine planning region has previously been defined by the Commonwealth, and the NRSMPA clearly indicates that the IMCRA bioregionalisation framework should be used as the primary benchmark for target setting and decision making.

5.1.1.2 Bioregions

The meso-scale and Provincial bioregions form the primary sub-regions for the Marxan analysis, and a number of the conservation features are nested within the bioregions.

5.1.2. Biodiversity Data

5.1.2.1 Scope of Information

In order to represent the full range of biodiversity present in the region, we included individual species level biodiversity data, special features defined by the Commonwealth, physical features of the seafloor, as well as derived datasets designed to predict patterns of biodiversity. The individual species level data we collected consists of presence-only point data (primarily OBIS and GBIF datasets) from museum, herbarium, and other opportunistically collected samples, as well as modelled species distribution data (the AquaMaps dataset).

The South-west region does not have complete presence/absence point data (like most such regions) because of the immense resources that would be required to have such complete surveys. As a result, incomplete point data introduces bias that can misdirect conservation effort towards the areas that have been surveyed. Predicted distribution data like the AquaMaps modelled species distribution data are able to overcome these types of point data problems, to some extent (Rondinini et al. 2006). While there are new modelling methods that may create more accurate predictions of species distributions (Elith et al. 2006), the AquaMaps data is the only freely available species-level dataset with at least moderate reliability that we found for this region.

The AquaMaps distribution data incorporate many of the OBIS and GBIF data records, so this important species-level data can be included in the analysis as modelled distributions without the bias associated with including the actual point data. As a result, we decided to use the AquaMaps data to represent the range of species from several major taxonomic groups (invertebrates, fish, and marine mammals). Birds are included in the threatened species dataset (SNES). A data gap exists for a few major taxa, including higher plants (notably seagrasses) and benthic algae, although these taxa are primarily associated with coastal and shallow-waters, and in the SWMR will be of limited occurrence. We recognise that there will be some occurrences of these taxa in waters to 100 m depth, and acknowledge that the distributions of these flora taxa will not be specifically included in the Marxan analysis. The species-specific planktonic algae data gap may be partly addressed by using the mean annual primary production dataset and the phytoplankton provinces dataset.

5.1.2.2 Scope of Intervention

The options for networks of marine sanctuaries that will be identified through this process will have both scale and management-related limitations. Processes (such as climate change) that are difficult to predict and migratory species such as seabirds or whales that are not contained wholly within the individual sanctuaries, the sanctuary network or the region will not be completely accounted for within the scope of this planning process. In some cases, these processes or species may be partially accounted for (e.g. foraging grounds for threatened seabirds will be included as conservation features). However, we recognise that MPA-complementary management arrangements are necessary outside the MPAs to enable conservation features within the MPAs to be maintained, and to control impacts on the MPAs such as the management of water quality coming from land and the management of fisheries harvest outside the MPA network. The Marxan analysis in this project is highly data-limited in this respect, and there are only limited tools available to enable us to incorporate such issues into the design of the sanctuary network.

5.1.2.3 Best available data

When multiple datasets were available for single species or features, each dataset was considered and the best available data was selected for use within the analysis. In addition, we selected derived datasets (when available) to act as surrogates to supplement direct biodiversity data.

5.1.2.4 Special features

Special features are represented with the Commonwealth-defined Key Ecological Features datasets.

5.1.2.5 Threatened species

For our analysis, we have defined “listed” species as the species that are defined in Appendix C of DEWHA 2007 as listed in the EPBC Act. The AquaMaps dataset covers 42 of the 44 aquatic listed species (reduced to 22 species after applying the 0.75 threshold), but does not include any of the 62 bird species. We identified the best available dataset for listed birds as the SNES dataset, which covers 53 of these species, and we were able to obtain foraging distance data for 18 of these species. This dataset includes nesting areas in state waters adjacent to the South-west Planning Region for several of the listed birds. To evaluate the relative importance of areas within the planning region to these bird species, information about foraging ranges was obtained through a literature search and through solicitation of expert opinion.

5.1.2.6 Transboundary issues

Within the scope of this project we have been unable to address the transboundary issues because of a lack of relevant datasets. We considered the following approaches:

- using datasets locating existing marine protected areas, or expected protected areas, to implement adjacency preference to these pre-existing protected areas;
- allocating higher targets to shelf biodiversity Conservation Features adjacent to the boundary with the South East Region;
- implementing higher targets for Conservation Features overlapping with, or having key dependencies on, unmanaged/weakly managed state waters/islands; and
- explicitly identifying issues of complementary management within other zones of MPAs, and identifying external issues that cannot be effectively dealt with by either MPAs in general or this project in particular.

5.1.2.7 Incomplete knowledge

The problem raised by incomplete knowledge of the full range of biodiversity in the South-west planning region is addressed by including derived datasets that are designed to represent patterns of biodiversity and by setting higher targets. Some of these "surrogate" datasets are nested within the depth classes or the bioregions to further account for incomplete knowledge in a precautionary manner. The derived datasets identified for use are described below, along with information about the type of biodiversity they represent.

Bioregion: The bioregions were created specifically for the NRSMPA process and are designed to represent different demersal/ benthic communities in the region. They attempt to capture broad scale differences in the regional composition of species, and reflect both cross-shelf and depth gradients. Within this project they have also been used as the primary unit for nesting of other conservation features. We use the term nesting to describe the process by which we further classify a feature based on a characteristic of that feature that is independent of the feature itself. For example, we have nested geomorphic features within the bioregions datasets. This means that a geomorphic feature that occurs in two or more bioregions will have targets set so that each feature is represented in each of the bioregions in which it occurs. Through setting targets for nested features we hope to capture some of the false homogeneity (or incomplete knowledge) that would pervade the process if, for example, we treated all seamounts across the region as the same feature.

Seascape: Seascapes were developed based on the premise that physical characteristics can be used as a surrogate for the underlying biota, using variables that have been shown in various studies to be potential surrogates. We accept that this has a limited taxonomic applicability, but at broad spatial and taxonomic scales, is a reasonable surrogate for biodiversity pattern. The variables used to develop the seascape classes include water depth, seafloor temperature, mud content, gravel content, and sediment mobility (Post 2008; Post et al. 2006) as well as primary productivity (as a measure of turbidity), and slope (Beaman and Harris).

Depth: A number of studies have identified depth as a potential surrogate for identifying different marine biotic communities (Blaber et al. 1994; Konar et al. 2009; Rosa et al. 2008; Sousa et al. 2006). DEWHA has identified two different potential depth zone categorisations for the SWMR, from which we derived our depth categorisation.

Geomorphic features: Geomorphic features (such as canyons, seamounts) are associated with different infaunal diversity and biomass and have been shown to have distinct infaunal and epifaunal assemblages (Vetter and Dayton 1998). This allows for their use as surrogates in representing different assemblages in the absence of more detailed faunal datasets.

Pelagic bioregionalisation datasets (Pelagic 1b and Energetics): These datasets were designed for use within the NRSMPA process to represent classes of pelagic biologic communities. In the water column, bioregions are likely to be influenced by water properties and ocean circulatory regimes that influence the way in which biological organisms utilise the pelagic environment. This led to the use of abiotic characteristics (such as temperature, salinity, currents) along with biological information such as pelagic fish and phytoplankton zones datasets to derive a classification of the pelagic environment (Lyne et al. 2005).

Primary productivity: Primary productivity has been shown to explain over 40% of the variance in species richness (Rosa et al. 2008). The mean annual primary productivity dataset was created by CSIRO for the National Marine Bioregionalisation project.

Nested datasets derived and directly targeted within this analysis are:

- Depth class by bioregion
- Geomorphic features by bioregion by depth class - several geomorphic features have been shown to have potential as physical surrogates for biodiversity distribution, particularly seamounts (pinnacles) and canyons (Williams et al. 2008). However, simply including these features without further differentiation results in "false homogeneity" meaning that canyons that are not similar are not differentiated in the dataset. Nesting the geomorphic features in bioregions begins this process of differentiation, and we further differentiate by also nesting by depth class. Williams *et al* (2008) suggest that it is critical to nest geomorphic features within depth classes because the biodiversity associated with a feature depends greatly on the depth of the feature. In addition, Williams *et al* recommend further differentiating geomorphic features with respect to size and anthropomorphic disturbance history, but we lacked the data to include those refinements.

5.1.3. Maintaining Biodiversity

5.1.3.1 Ecosystem processes

The major ecosystem process identified in for the region (DEWHA 2007) is the Leeuwin current and associated eddies. We represent these processes in our analyses using information developed by CSIRO (Ming Feng) on vertical velocity and mean eddy kinetic energy (Feng et al. 2005; Schiller et al. 2008). Together, these datasets describe different characteristics of the

Leeuwin Current and associated eddies to allow for targeting of each type. We nest them within latitudinal bands to capture the gradient of pattern along the entire extent of the linear range of influence of the current.

5.1.3.2 Socio-economic impacts and drivers

Identified socio-economic activity within the South-west region includes commercial fishing, recreational fishing, petroleum industry activities, defence activities, port activities, and recreational activities linked to population areas. In explicitly recognising the different activities that occur in the region, we hope to efficiently achieve biodiversity conservation with a minimal level of corresponding disruption to the socio-economic values through careful consideration of the placement of the sanctuaries in relation to these activities. Prior work has shown that by carefully considering the spatial configuration of socio-economic activities, both gains are possible (Polasky et al. 2008; Polasky et al. 2005). We aim to achieve this within our Marxan analysis by using defined relationships amongst a set of selected activities (the ‘costs’) to produce a single weighted cost layer for input to the Marxan optimisation. The selected costs and their weightings are defined explicitly in the model used to develop the combined cost surface.

5.1.3.3 Incomplete knowledge

Incomplete knowledge about processes and linkages has been addressed through the use of the BLM parameter in Marxan (to create compact and connected networks of reserves), and through the replication of some features in multiple bioregions and at multiple depth zones.

5.1.4. Levels of Representation

5.1.4.1 Minimum levels of representation

This has been addressed through the target setting process for the Marxan analysis with conservation feature targets set at a minimum of 30% in sanctuary as a proportion of their distribution within each bioregion, as shown in Table 5.1below. Targets for listed species were incremented by 20% above the base level of 30%, consistent with the principles relating to features with special protection needs.

Table 5.1 Feature classes included in Marxan analysis, with number in class and target indicated. EPBC Act Listed species indicated in *italics*.

Feature Class	Number in class	Target
AquaMaps-general species	1188	30%
AquaMaps endangered	2	50%
AquaMaps listed	12	50%
AquaMaps vulnerable	8	50%
AquaMaps Wide*	220	-
*AquaMapsListed Wide**	17	-
Bioregions	10	30%
Demersal Fish Provinces	9	30%
Depth by bioregion	72	30%
Depth zones	12	30%
Eddy Kinetic Energy by Latitudinal Bands	15	30%
Geomorphic Feature by Depth by Bioregion	233	30%
Geomorphic features	20	30%
Key Ecological Features	14	30%
Latitudinal Bands	5	30%
Pelagic Regionalisation- Energetics	21	30%
Pelagic Regionalisation 1b	23	30%
Phytoplankton Provinces	3	30%
Primary Productivity	5	30%
Listed Seabird Foraging	16	50%
*Listed Seabird Foraging Wide**	2	-
Seascape	19	30%
Vertical Velocity by Latitudinal Bands	25	30%
Total Conservation Features	1951	

* Targets were not set for wide range species.

5.1.4.2 Quality of conservation features

This has been addressed through assessment of the input data, and where there is a reasonable knowledge base indicating that features are of reduced quality, we have processed the data to increase our confidence or to reduce the risk that might arise from inclusion of the dataset. Details of this processing are contained in Chapter 4.4.2 Processing of Physical and Biological datasets.

5.1.4.3 Important features

We used a higher target (50% of the extent of the feature in the region) for endangered, vulnerable, and other EPBC Act listed AquaMaps species, as well as for listed seabirds foraging areas (all listed species as defined in Appendix C of DEWHA 2007). See Table 5.1 above for details.

5.1.4.4 Additional representation

Beyond project scope.

5.1.4.5 Whole structural features

This principle is best addressed as part of a post-Marxan analysis, as Marxan is not needed to simply include an entire structural feature. In some cases, it may not be possible to include whole structural features into solutions, and a Marxan analysis that is not constrained to include whole features can help to identify what portion of a large structural feature might be best to include within a marine sanctuary. In this project we used the latter approach, setting a target of 30% for each important structural feature so that solutions would identify the most important parts of any such features that could not included in full in the final arrangement of MPAs.

5.1.4.6 Output area achievement

In the post-Marxan analysis, we report the solutions that result in a reserve network covering at least 30% of each bioregion.

5.2 Principle 2 Management Constraints

5.2.1. Business Management

Beyond project scope.

5.2.2. Complementary Management

This is mostly beyond the scope of this project. However, with respect to endangered species and highly migratory species, we specifically recognise that many of these species occur both inside and outside our planning region. Where marine sanctuaries are likely to assist with conservation outcomes (such as protecting breeding or feeding areas) higher targets should be used for these features to account for the risk posed to them in areas outside the planning area. Also, although we did not actually implement this, where conservation features within a bioregion overlap with the previously zoned Southeast marine bioregion, the level of representation of the conservation features within protected areas in the SE region can be taken into account and targets adjusted for the SW region where necessary. Beyond this approach, we assume that areas that have yet to be subject to MPA planning (both in Commonwealth and state waters) would protect shared conservation features in the same proportion as their representation and protection within the SW region.

5.2.3. Management Practicality

Easily identified boundaries: Planning units are the spatial blocks that decision support tools such as Marxan use to divide a region in order to make decisions about where conservation treatments should be located. Because these building blocks form the basis for the boundary of the sanctuary areas, we have aligned them along lines of latitude and longitude in order to ease implementation and make on-water identification relatively easy. When sanctuaries are finally determined, they can closely follow the boundaries of the solutions we identify in this report.

Fewer/larger high protection zones: More spatially compact solutions can be achieved within Marxan by adjusting the boundary length modifier (BLM). Increasing the weighting given to this parameter will result in fewer protected areas, each with larger spatial coverage (Game and Grantham 2008). The trade-off involved within increasing the importance of spatial compactness is that spatially compact solutions are less cost-efficient than less spatially compact solutions (Stewart and Possingham 2005). Within the course of the analysis in this project we consider a range of BLM values, and assess the trade-offs between boundary length and cost-effectiveness to provide a range of solutions.

Align with existing protected areas: The Great Australian Bight protected area is the only gazetted marine protected area within the planning region, and, a number of state marine parks are planned for declaration. Unfortunately, resources have not been available to enable us to explore the effect of including either the gazetted or planned protected areas, or any of the various forms of fishery closure, on the Marxan solutions in this project.

The remaining aspects of this Principle are beyond the scope of this project.

5.3 Principle 3 Multiple Objectives

5.3.1. Use of Biodiversity

Minimise conflict with users: Our assessment seeks to minimise the extent to which conservation feature targets are achieved at the expense of socio-economic activities. The primary mechanism for minimising these conflicts is the incorporation of socio-economic data within the planning process through the use of cost surfaces that represent the socio-economic activities within the region. Marxan allows designers to specify target levels for biodiversity, and then attempt to achieve these targets at a minimum possible cost (Ball and Possingham 2000). ‘Cost’ surfaces within Marxan are the spatially explicit delineation of activities within the planning region - higher costs are more likely to be avoided, while lower cost regions are preferred in the solutions. Individual cost surfaces have been developed for each of the selected socio-economic activities within the region for which we could secure an acceptable level of data. By using the socio-economic activities as a cost surface within Marxan, we have attempted to minimise the overall impact that the establishment of MPAs have on existing socio-economic activities within the region. For the purpose of this analysis we assume that conflict with users is minimised when displacement of existing activities in minimised.

In addition to the cost surfaces developed for individual socio-economic activities, we also developed a general surface for distance to populations. This surface takes into account both the population size, and straight-line distance of that population to each area in the planning region. This surface is incorporated into the 'cost' surface, in an attempt to favour regions farther away from population centres when equivalent biodiversity options are available.

Cost Surface

It is important to note here that the number of features or cost surfaces associated with an activity is not a reflection of the relative weight of those interests within the analysis. Rather the number of features is a reflection on the complexity of interests within an activity, and the data available to the project team.

In a Marxan analysis, cost is usually framed as the financial cost or financial implications of including a spatial unit within a protected area. These costs may include the price to purchase property, ongoing cost of management, or the opportunity cost of displacement of an existing use from the area to be protected. In this project, we broaden the concept of cost to mean 'constraint', which allows us to also consider the cost to include the impact of a use on the achievement of conservation objectives for an area. So, for example, inclusion of an area that currently contains an activity that is highly inconsistent with conservation objectives would be framed as having a high cost, compared to other areas that may have activities that have lesser forms of impact on conservation objectives.

The challenge in developing a single cost layer to reflect the variety of activities and interests (Chapter 4) identified in the region is obvious and any amalgamation is by definition a subjective balancing of various considerations. The data on uses that we collected was measured in a variety of differing units, and this posed a further problem for aggregation. For example, commercial fisheries were measured in Gross Value Product ($), petroleum prospectively measured in km^2, and recreational fishing in number of households that engaged in the activity. Ideally, we would have developed a single metric to combine all of these activities, such as a dollar value of the opportunity cost, and then simply summed the total opportunity cost for all activities in a planning unit. Given that the time and resources for an economic valuation of the identified activities were beyond the scope of the project we adopted a different approach. We also recognise that even a full economic valuation of all activities would not necessarily have resulted in cost outcomes that would be deemed more appropriate by all stakeholder groups. Maximising the aggregated economic value may not be the only socio-economic objective, and issues of equity with respect to the distribution of impacts (both costs and benefits) are a key consideration.

Within the Marxan analysis all costs are treated in a linear fashion. A planning unit with a cost of two is half as desirable as a planning unit with a cost of one that contains the same biodiversity features. This does not mean the selection frequency of the planning unit will be twice as high, but rather that its contribution to overall cost is twice as much. It also means that after aggregating individual costs into a cost surface, the impact to the individual underlying costs is no longer tracked. It is the amount of the overall cost surface that Marxan attempts to minimise during the optimisation procedure.

To develop our single cost layer, we developed a conceptual model for the weighting of activities. The model itself is a mixed model, considering both the impact of the activity on biodiversity, potential displacement of the activity, and the economic value of the activity:

Weighting = (impact = likelihood+consequence) + spatial extent/intensity + value

The model was first applied to group the activities into higher level classes, then to assign weightings to each class of activity. First pass application of the model resulted in a seven-class grouping of the spatial layers (Table 5.2).

Table 5.2 Higher-level cost classes identified in the first pass of the conceptual cost model.

Id	Class
1	Area
2	Commercial fisheries
3	Defence
4	Petroleum
5	Population Pressure
6	Recreational Fishing
7	Shipping

The seven classes were then further refined with the model, and the commercial fishing class was subdivided into three additional classes, which were included at the class level in the hierarchy. The three classes identified were the Trawl fisheries, Non-trawl fisheries, and the Western Rock Lobster fishery.

Within the SWMR the Western Rock Lobster fishery is the largest fishery based on spatial scale and GVP, and depending on the source of the estimate and seasonal fluctuations in catch/sale price, is worth more than 64% of the total GVP generated by commercial fishing in the region. To prevent this single fishery from exerting excessive influence of GVP weighted fishery cost surfaces, the fishery was set aside and treated at the class level. This segmentation was consistent with Principles 1.3.2 which suggests consideration of socio-economic drivers (not specifically restricting consideration to economic value), 3.4 which suggests consideration for low impact fisheries, and 5.1 which offers guidance on displacement of existing users.

The second set of fisheries defined as a class are those fisheries that utilise trawl as the primary fishing method. The impact of trawl fisheries on the seabed and biodiversity has been well documented in the past, and we felt the severity of the impact necessitated treatment as a separate class (Watling and Norse 1998). The establishment of an independent trawl class was guided by Principle 1.4.2, which suggests that conservation features in high protection zones should be high quality examples, and principles 3.2.1/3.2.3 which suggest that there needs to be specific consideration of threats posed by individual activities. We estimated that the seven trawl fisheries contributed ~6% of regional commercial fishing GVP. Within the trawl fishery class, sub-class weightings were assigned based on the contribution of the fishery to the overall class GVP (Table 5.3). Thus the weighting at the sub-class level is a pure economic weighting, with the explicit objective of maximising class level GVP. We contrast this aim with other aims that were considered, such as maximise the retention of individual fisheries, or maximising total area available for trawling.

Table 5.3 Subclass weightings within Commercial fishery-Trawl class

Sub-class: Commercial fishery -Trawl	Weighting
Great Australian Bight Trawl	0.554
Southeast Trawl	0.023
Abrolhos Island Trawl	0.359
South Coast Trawl	0.005
South West Inshore Trawl	0.024
Western Deepwater Trawl	0.035

The third set of fisheries included all fisheries not mentioned in the above two classes (classed as Non-trawl). This accounted for 24 of the 31 fisheries active within the region. By our estimates, these 24 fisheries accounted for ~28% of regional GVP. Following the GVP retention model applied to derive sub-class weightings for the trawl fisheries, sub-class weightings for the fisheries-non trawl class were assigned based on the estimated GVP from the fishery (Table 5.4). This model aims to maximise overall GVP retention from all fisheries within the class.

Table 5.4 Subclass weightings within Commercial fishery- non trawl class

Sub-class: Commercial fishery-Non trawl	Weighting
Southern Bluefin Tuna	0.411
Abalone – West	0.155
Dropline and Trolling	0.080
Southern Rock Lobster (SA)	0.042
South Demersal Gillnet and Longline	0.036
Crab (WA)	0.034
Western Tuna and Billfish	0.034
Shark bay snapper	0.033
Dropline and Handline	0.026
Sardine	0.021
Gillnet Hook and Trap	0.019
South Coast Purse Seine	0.015
Abalone – East	0.014
Gillnet longline	0.013
Esperance Southern Rock Lobster	0.012
Southern Rock Lobster (WA)	0.012
Skipjack Tuna	0.009
Marine Scale Fish	0.007
West Coast Purse Seine	0.006
Eastern Tuna and Billfish	0.005
High Seas Tuna	0.005
Southeast Nontrawl	0.005
Small pelagic	0.005
Southern Shark	0.005

Class level weighting

After the secondary subdivision of the commercial fishing class, there were nine higher level cost classes. The mixed model was applied to these nine classes to derive a class level weighting within the cost surface (Table 5.5). The weighting of this class represents our broader interpretation of the principles guidance on minimising impact to existing users.

Table 5.5 Classes of socio-economic features used in the Marxan analysis, and the corresponding weightings applied within the analysis.

Class	Weighting
Commercial fisheries –Non trawl	0.2
Commercial fisheries –Trawl	0.2
Commercial fishery-Western Rock Lobster	0.15
Recreational Fishing	0.15
Petroleum	0.1
Population Pressure	0.1
Defence	0.025
Shipping	0.025
Area	0.001

Commercial fisheries-Non trawl

The Principles stress the minimisation of impact or efficiency both in framework for understanding the Principles and directly again in principle 3.2.3. A narrow interpretation of minimising impact could have restricted our analysis to only considering GVP during the assigning of values. We opted for a wider interpretation of "*minimise conflict with users*" with the understanding that all conflict cannot be minimised simply by maximizing GVP across the region. Other considerations, such as number of people employed, and equity of impact on different types of activities also contribute to the potential for conflict within the planning process. This broader interpretation allowed for broader consideration of individuals engaging in the activities. The sheer number of fisheries (24) aggregated into this class was a significant consideration in the allocation its final class weighting.

Commercial fisheries-Trawl

The trawl activities were given a relatively high weighting within the cost class because of their inconsistency within biodiversity values. The same principles that suggest trawl fisheries should be treated as higher level class also suggested that the class should be given a relatively high weighting. The higher class weighting means that when non-trawled alternatives are available they will be selected because they include better quality representations of biodiversity values (Principle 1.4.2).

Commercial fisheries-Western Rock Lobster

The Western Rock Lobster fishery was given a relatively high weighting mainly because of its spatial dominance in the region. Also taken into account was the effect of this fishery on the shelf ecosystems, where the population of lobsters has been reduced to less than 20% because of the effects of the fishery, and this will have ecological consequences for both predators and prey of the lobster. These factors were substantially offset because the gear type deployed in this fishery (potting) is a relatively low-impact type of gear, and being a large and widely distributed fishery, it creates a strong local employment base across many of the WA coastal communities.

Recreational Fishing

Weighting of the cost class considered the number of recreational users and the employment related to recreational activities. The class weighting also reflects that most recreational effort occurs within state waters, rather than within the Commonwealth waters that are the focus of this analysis. Nonetheless, the impacts of a focused recreational fishery can be severe, especially since recreational fishing throughout the SWMR is only managed in a limited way. The final weighting also took into consideration the relatively poor nature of the spatial data, which was aggregated to reporting blocks with a mean size of ~14,000km^2.

Defence

The lack of emphasis on defence use is related to two main factors. First the activities undertaken are of limited ecological impact, and typically are infrequent. Second, the main types of activities are restricted to a small proportion of the SWMR.

Shipping

The cost weighting for shipping is based on the use of shipping lanes and are transiting by vessels in general. Ports and harbours have significant impacts on coastal ecosystems, particularly through dredging activities, but there are no such activities within the SWMR. The cost weighting of shipping is therefore more related to the potential for impacts from introduced marine pests and negative interactions with marine mammals. While both of these are relatively substantial risks, they represent risks to only a small element of the conservation values of the SWMR, and neither is likely to be the focus of a marine sanctuary network.

Population Pressure

Population pressure was included as a surrogate for a number of uses that are likely to be related to population density and recreational use of nearshore ecosystems. These include the consequences of foreshore development, catchment impacts, and recreational fishing impacts related to coastal access points. The relative weighting of this cost reflects the numbers of people accessing the SWMR, even though individually they may have a limited set of impacts.

Area

Although not an explicit cost, within the cost layer area acts as a surrogate for any number of costs that are not explicitly accounted for in the above cost layers such as management costs or previously unidentified opportunity costs. Here we follow the model of Stewart and Possingham (2005), where socio-economic values and area were combined to derive the final cost surface. Within Marxan the inclusion of area ensures that each planning unit has a cost greater than zero. A cost greater than zero is required to prevent planning units from being added to the solution simply because they have no associated costs.

The other aspects of this principle are beyond the scope of this project.

5.4 Principle 4 Managing the Threats

5.4.1. Avoid Known Threats

5.4.1.1 Threat data

By using data on significant potential threats (such as the different types of fishing grounds, high prospectivity oil and gas areas) within the costs surface, we avoid such locations if the conservation targets can be achieved in other places. We have been unable to access any reliable threat models (for these or any other potential threats) to use in this project, and so rely on broad judgements based on data and knowledge from the literature and other Australian examples about what activities have impacts on marine biodiversity.

5.4.1.2 Defensive locations

By using distance to population centres within the cost layer, we have encouraged the software to locate the reserve solutions further away from high-density developments. By locating protected areas farther away from development we assume that likely pressures from human populations will be reduced, although not eliminated, and any remaining pressures will be easier to manage. There may be some exceptions to this, such as near islands that have strong management regimes in place where the MPA solutions might be easier to manage and have better compliance. Also, this remoteness factor may be eventually able to be traded-off against adjacency to state-managed MPAs, although we have not been able to explore this option in this project.

5.4.2. Climate-change Resilience

A CSIRO report on the potential impact of climate change in the marine environment listed the Southwest and west-central marine domains as the two domains in which biodiversity was the least vulnerable to the impacts of climate change (Hobday et al. 2006a,b). The Southwest marine bioregion roughly corresponds to the southwest domain used in the report, but it also extends into the west central domain. While the region was identified as one of the least vulnerable, it should be recognised that the vulnerability index was relative to other regions, and the overall impact of climate change could still be significant at local scales. Indeed, the climate-driven variability in ocean currents is considered to be the major factor responsible for a highly damaging series of recruitment failures in Australia's most valuable fishery, based wholly within the SW region—the fishery for the endemic Western Rock Lobster.

Sample the gradients: A range of physical and recognised biological gradients (discussed above) are targeted within the Marxan analysis, including gradients in depth classes, latitudinal profile, sediment composition, Leeuwin current patterns, seabed topography, and species-derived bioregions.

Include naturally resilient areas: At present we do not have any information about which areas might be naturally resilient. However, we target topographic features such as canyons for reservation, which may be naturally resilient to change because of their structural complexity across the range of natural gradients cited above.

Include sources and refugia: At present we do not have any specific information about which areas might function as sources or refugia. However, the region features extensive shelf-edge canyons, and they may play a refugia role for shelf species, and could conceivably provide for a gradual southward progression of shelf and slope faunal assemblages.

5.4.3. Account for Uncertainty

Propagate uncertainty through the design process: We address uncertainty in a number of ways including careful assessment of which datasets to use, the utilisation of multiple scenarios in the Marxan analysis, and through a systematic sensitivity analysis of cost-effectiveness as a part of the Marxan analysis. Weak or biased datasets are not included when a more robust dataset is available, and we track the decisions made about the inclusion of each dataset. Where there is a high level of uncertainty in a conservation feature dataset, we have responded by additional processing of the dataset to decrease uncertainty or by setting more conservative targets during the target setting process (for listed species). We assessed the robustness of the Aquamaps dataset through the independent datasets obtained from the CSIRO cruises to make an independent estimate of the species-level uncertainty in the Aquamaps dataset. We then applied a threshold of 0.75 for an acceptable level of probability of occurrence to account for the uncertainty in this data. Details of this assessment are in Chapter 4.4.2 above.

5.4.4. Risk Spreading

Apply risk spreading strategies: We applied two specific forms of risk-spreading strategies. First, we apply an explicit form of replication at the bioregion level. Several conservation features have been represented in multiple areas, through the nesting of conservation features within gradients or within coarse scale conservation features represented by the bioregion classification. Second, we use several derived datasets (as above) and ecological gradients (as above) to represent "unknown" biodiversity (Pressey 2004).

5.5 Principle 5 Monitoring, Assessment & Reporting

The elements of this principle are all beyond the scope of this project.

5.6 Principle 6 Stakeholder Engagement

The elements of this principle are all beyond the scope of this project.

6. IDENTIFYING A NETWORK OF MARINE SANCTUARIES FOR SWMR

Marine Bioregional Planning for the South-west Marine Region is currently underway. Through this process, the Australian Government will identify areas within Commonwealth waters for inclusion in the National Representative System of Marine Protected Areas (NRSMPA). In this chapter we perform a spatial conservation prioritisation to support the Marine Bioregional Planning process by identifying priority conservation areas for protection. Our focus in this project is on delineating a network of marine sanctuaries within the SWMR. This type of analysis is typical of conservation prioritisation problems and is underpinned by a well-established scientific theory and techniques. Quantitative techniques bring a powerful set of tools to bear on conservation problems (Moilanen 2009a). When incorporated within a planning framework, these tools are regarded as more systematic, rigorous, and accountable than the opportunistic allocation of conservation funds (Margules and Pressey 2000, Wilson et al 2009).

This chapter begins by outlining the goals and objectives of the assessment and briefly summarises the key attributes of the planning problem. We introduce the Marxan software that is used to conduct the spatial prioritisation, and briefly discuss the key data and input parameters. We then describe the planning scenarios, which define the specific conservation problems that this conservation assessment will address. This is followed by the results of the analysis and a discussion of the significance of this work for the SWMR bioregional planning. In closing, we highlight some of the implementation issues for ongoing work in this process.

6.1 Introduction to Analysis

The approach taken in performing the conservation assessment has been to:

1. conduct a biophysical resource assessment that summarises the available spatial information for the region (Chapter 4);
2. develop a scientific set of principles that serves to identify design criteria for implementation of the NRSMPA (Chapter 2); and
3. use the principles to provide explicit guidance for a conservation assessment for the SWMR (Chapter 5).

In general terms, the purpose of this conservation assessment it is to identify a cost-efficient network of marine sanctuaries for the protection of the SWMR's biodiversity. Definition of the specific design criteria and targets required to achieve protection of the SWMR's biodiversity is largely a technical-scientific process. We acknowledge the contribution of over 50 professional scientists active in MPA planning who provided clear science based guidance on design principles and criteria. The consideration of spatial data relevant to the SWMR, together with the application of these scientific principles to the design context of the SWMR are critical in providing a robust framework for performing this work. Further information on these aspects of the assessment is documented in full in Chapter 5 Applying the Design Principles to the SWMR. A summary of the general attributes of the conservation assessment of the SWMR is presented in Table 6.1.

Table 6.1 Attributes of the Conservation Prioritisation Problem for the SWMR

Planning region (area)	1,292,014 km^2
Planning Units (number)	18377
Planning Units (average size- km^2)	70
Conservation Features (total number)	1951
Listed (EPBC) species targeted (number)	38
Non-listed species targeted (number)	1188
Surrogates (e.g. bioregions, depth zones) (number)	486
Targets for listed features (percent of extent in region)	50%
Targets for other features (percent of extent in region)	30%
Cost surface layers (number)	46

Within this general framework, we explore a variety of scenarios for the efficient allocation of areas to sanctuary zones in the South West Marine Region. The development of alternative planning scenarios provides the flexibility to explore different assumptions underpinning the conservation planning problem and examines the sensitivity of the outputs to different treatments of uncertainty. Scenario development and definition is fully described in Chapter 6.4.

6.2 Marxan Software

Marxan is a decision support tool designed to solve reserve design problems where the goal is to achieve a user-specified level of representation (or target) of conservation features for the least cost (Possingham et al 2000). It employs simulated annealing as the optimisation algorithm to find multiple good solutions to the minimum representation problem.

In simulated annealing, candidate reserve networks (solutions) are generated iteratively, with the performance of each feasible configuration of sites evaluated against an objective function. Many iterations are performed, with planning units either excluded or included in the reserve network, depending in part upon what is already contained within the reserve network (complementarity), the gaps in the network and how expensive individual planning units are (if a cheaper parcel can be identified then an exchange will be made). Changes that improve the solution are always accepted, but also some changes that do not improve the solution may be accepted, giving the algorithm the ability to escape local optima. Satisfying targets are not guaranteed however and penalties exist within the process for not achieving targets.

Cost efficiency is an important consideration in conservation as resources must be allocated prudently. Costs of conservation, like the distribution of biodiversity, are not homogenously distributed, so formally incorporating information on costs into the analysis can result in efficiency gains where there is the flexibility to do so. While spatially explicit cost data may not be available at the desired resolution, cost surrogates can be used to represent the cost of conservation. Yet cost data must be captured prudently, for if we are to achieve efficiency gains it is important to reflect the actual resource constraints limiting conservation effort. The actual cost of reserve acquisition, compensation costs, management costs or opportunity costs are all examples of cost surrogates. Chapter 6.3 discusses the cost surrogates applied to this analysis. Marxan input files are generated for individual scenarios and generally incorporate the scenario definition file and basic information on the distribution of conservation features across individual planning units (the conservation feature matrix) and the distribution of cost features across individual planning units (the cost feature matrix). The targets and design criteria are typically defined in the scenario definition file and the conservation feature matrix.

Marxan generates two standard outputs. First, the 'best' solution file lists the reserve network with the lowest score from all the good reserve networks generated. This is the solution that performs best against the objective function. Second, the summed solution file records the selection frequency for planning units across all the good reserve networks generated. The selection frequency for a planning unit is a measure of how important the planning unit is to achievement of the planning objectives. Planning units are selected infrequently when there are a range of equally good alternatives. Planning units that are truly irreplaceable will appear in every solution and must be included to achieve the planning objectives. Of special note are those planning units which are frequently included in the reserve network, yet have a high cost associated with them. These areas are often the focus of negotiations as they may have particular significance for multiple objectives (e.g. high conservation value and high socio-economic value). It is important to note that selection frequency maps do not represent solutions; rather they indicate the relative importance of planning units.

The Marxan software used in this project is version 2.2, downloadable from www.uq.edu.au/marxan.

6.3 Data Summary

For this conservation assessment the conservation feature data, the conservation feature targets, and the cost data decisions are all informed by the principles document developed as part of this project (The Ecology Centre, 2009). A brief overview of the conservation features and socio-economic costs follows.

6.3.1. Conservation Features

Conservation feature data that are used for a conservation assessment often aims to represent the biodiversity of a region, and can include coarse surrogate data as well as fine-scale species level data. When data are available, ecological processes and environmental condition information may also be included. We selected 1,951 conservation features which were classified into 23 broad feature classes (see Table 6.2) for inclusion in the Marxan analysis. Of these, targets were set for 1,712 features from 20 of the classes. These features were chosen from the available data to represent the biodiversity present in the study region, guided by the principles document developed for this project (The Ecology Centre, 2009). One principle in particular guided the feature selection—Principle 1- Biodiversity primacy (see Chapter 5). The feature classes include coarse and fine-scale datasets, incorporate data from benthic and pelagic ecosystems, ecosystem processes, various taxa (at the individual species level), and a range of depth classes and physical environmental types. These features, and the targets set for them, remain the same throughout our analysis and all of the scenarios presented below. The full list of conservation features used in the analysis is reported at Appendix 4.

Table 6.2 Features included in the Marxan analysis, grouped by feature class, with EPBC Act listed species shown in italics.

Feature Class	Number in class
AquaMaps-general species	1188
AquaMaps endangered	2
AquaMaps listed	12
AquaMaps vulnerable	8
AquaMaps Wide*	220
*AquaMapsListed Wide**	17
Bioregions	10
Demersal Fish Provinces	9
Depth by bioregion	72
Depth zones	12
Eddy Kinetic Energy by Latitudinal Bands	15
Geomorphic Feature by Depth by Bioregion	233
Geomorphic features	20
Key Ecological Features	14
Latitudinal Bands	5
Pelagic Regionalisation- Energetics	21
Pelagic regionalisation 1b	23
Phytoplankton Provinces	3
Primary Productivity	5
Listed Seabird Foraging	16
*Listed Seabird Foraging Wide**	2
Seascape	19
Vertical Velocity by Latitudinal Bands	25
Total Conservation Features	1712 (excludes wide-range species)

* Targets were not set for wide-range species.

6.3.2. Summary of Cost Data/Resource Constraints

6.3.2.1 Principle Mapping and Selection of Cost Surfaces

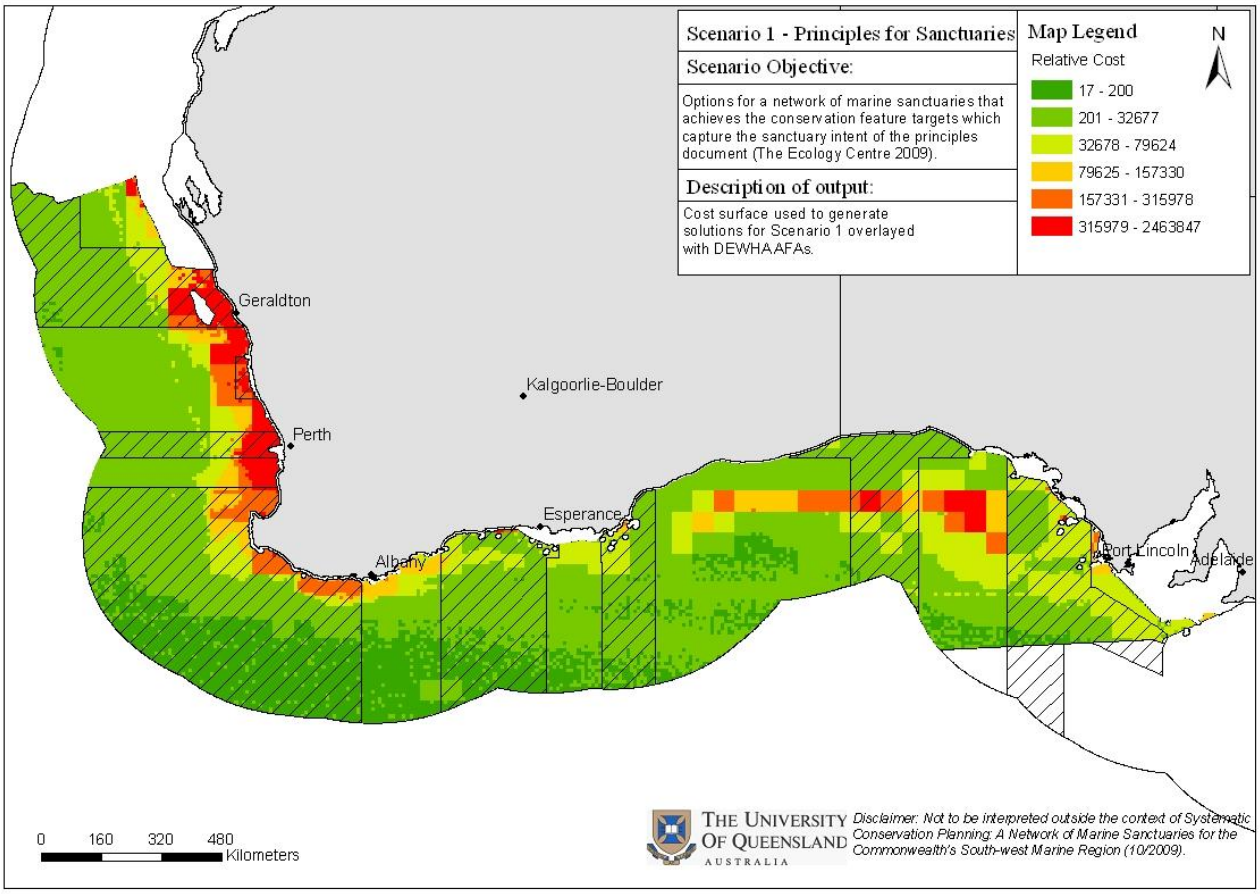
Marxan solves the minimum set problem, which is to achieve a set of representation targets at minimum cost. In Marxan, the constraints are typically referred to as 'costs' and captured in a cost layer that is used to discourage the selection of areas with higher 'cost' when cheaper alternatives exist. The objective within Marxan is to minimise the total cost of achieving all conservation objectives.

Cost data may represent the impact to socio-economic activities from MPA establishment (i.e. the opportunity cost), such as the GVP of an impacted fishery in the marine environment, or the cost of surveillance of a sanctuary network. Multiple costs can be incorporated in Marxan by combining normalised costs using a weighting system that defines the relationships between the cost datasets (Stewart & Possingham 2005, Richardson 2006, Klein et al, 2008). We selected 46 individual costs types for inclusion in the cost layer (Table 6.3), guided by the Principles developed as part of this project (The Ecology Centre 2009) (Chapter 5). These features represent the range of socio-economic activities identified as active within the region (DEWHA 2007) and for which data were available. The full list of cost types we used in the analysis is reported at Appendix 5.

Table 6.3. Primary cost classes included in the Marxan analysis.

Cost Surface Class	Number of cost types
Area	1
Defence	1
Commercial Fishing	31
Petroleum	8
Population Pressure	1
Recreational Fishing	3
Shipping	1
Total cost surface classes	46

Figure 6.1. Map of Cost surface used to generate solutions for Scenario 1- Principles



6.4 Scenario Development

One of the key benefits of systematic conservation planning tools is the flexibility they provide to explore alternative planning scenarios. Scenario planning is a strategic planning method that can strengthen the robustness of any analysis by facilitating a clear understanding of the sensitivity of the output (i.e. the solution) to different assumptions. This is important when dealing with complex problems in which many factors combine to produce a wide range of possible solutions. Any particular scenario is unlikely to be implemented within an MPA solution in the exact form that a Marxan analysis will produce; therefore the aim is to focus discussions on a limited number of the most important issues. In this assessment we have endeavoured to target those factors that we perceive to be most critical to further negotiations.

A total of six scenarios have been formulated. The objective for all scenarios is to configure a network of marine sanctuaries that achieves the conservation feature targets that are consistent with the intent of the sanctuary component of the MPA Principles document.

All scenarios share the same conservation objectives which are an expression of the design principles and criteria documented in the MPA Guidance Statement. As a result, conservation features and conservation feature targets are constant for all scenarios. Scenarios are similarly constrained in that they can only achieve these conservation objectives by selecting sites (planning units) as marine sanctuaries. Thus the primary objective is to identify networks of marine sanctuaries that satisfy conservation feature targets. No other form of protection or zoning is considered. We recognise that the sanctuary scenarios will not provide full conservation for a number of the biodiversity aspects of the region, and that there will need to be complementary management arrangements (which may include other forms of zoning within MPAs) established outside any intended sanctuaries to enable overall conservation goals to be achieved for the many species that occupy the region. Design for the complementary management outside the sanctuaries is beyond the scope of this project.

All the scenarios considered and reported here have the same features and targets, but they differ in their treatment of solution constraints, which we consider to be the driving forces that are critical to the outcomes and about which there is considerable uncertainty. We encounter these constraints in two forms. The first are the costs—the economic imperatives that are of a variable nature (a range of socio-economic activities across the SWMR all of which interact differently with the conservation objectives), which are critical to the outcome. The second constraint is of a spatial nature—the Commonwealth Government's Areas of Further

Assessment (AFAs) that have been established across the SWMR. The probable scenario is that marine sanctuaries are more likely to be designated within the AFAs than outside.

The scenarios forming this conservation assessment are summarised in Table 6.4 and discussed in detail below. For each scenario, 100 Marxan solutions were generated. All solutions were required to meet all targets.

Table 6.4 Description of Planning Scenarios considered in the Marxan Analysis

Scenario Number	Scenario name	Defining features of scenario
1	Principles for Sanctuaries	Guided by MPA Principles document
2	AFAs	As Scenario 1 but with spatial constraints that favour sanctuary solutions within the AFAs
3	Area	As for Scenario 1 but adopts Area as the only cost constraint, selecting sanctuaries without recognising costs to any activity
4	Petroleum	As for Scenario 1 but adopts Petroleum as the priority cost constraint and favours sanctuary solutions that avoid areas of high petroleum industry interest
5	Recreational Fishing	As for Scenario 1 but adopts Recreational Fishing as the priority cost constraint and favours sanctuary solutions that avoid areas of high recreational fishery activity
6	Fisheries by GVP	As for Scenario 1 but adopts Fisheries GVP as the priority cost constraint and favours sanctuary solutions that avoid areas of high fishery GVP

6.4.1. Scenario 1 Principles for Sanctuaries

The objective for all scenarios is to configure a network of marine sanctuaries that achieves the conservation feature targets. This scenario includes an examination of the levels of compactness of reserve solutions, and the trade-offs that should be expected when attempting to create a compact network of sanctuary zones. It should be noted that while only Scenario 1 includes an explicit discussion of the cost:compactness trade-off, the same calibration routine was used for all scenarios, to select an efficient level of compactness.

6.4.2. Scenario 2 AFAs

Conservation features and targets are constant. This scenario varies from Scenario 1 in that it examines the effect of spatially favouring sanctuary solutions to be within the AFAs. This is performed by discounting the cost of planning units within the AFAs relative to planning units outside the AFA. We considered a range of discounting rates from 10%-90%: the 10% discount provides a slight preference for the solutions to be within AFAs, while the 90% discount highly prefers the solutions to be within AFAs. Costs weightings of all activities were kept constant and the same as in Scenario 1.

6.4.3. Scenario 3 Area

Conservation features and targets are constant. Cost in this scenario is represented only by the area of each planning unit. Solutions produced by Marxan will represent areas that contain the conservation features that meet (or approach) the targets and occupy the smallest easily achievable areal extent. The areas chosen by Marxan represent the most efficient arrangement of the features to meet the targets irrespective of other uses that may currently occur in those areas.

The inclusion of this scenario is to establish a reference point for estimating the extent to which targets can be met in solutions free of any other costs so that, in later scenarios, the improvement in efficiency of the solutions generated can be estimated, and so that the extent to which other uses can be avoided through the inclusion of specific types of costs. Marxan scenarios based on area cost alone do not normally generate good MPA solutions, as they do not minimise impacts on other users, and in this project, would not be consistent with Principle 3 of the Scientific Principles in respect of minimising impacts on users. This scenario is therefore included here only for the purposes of establishing a technical reference point and is not intended to produce useful solutions to the Southwest decision problem of where to locate sanctuaries.

6.4.4. Scenario 4 Petroleum

Conservation features and targets are constant. Cost weightings are applied to discourage the selection of planning units where petroleum exploration or production occurs, where there is the flexibility to do so. We expect this scenario will result in a network of marine sanctuaries configured to minimise the economic impact to the petroleum industry.

6.4.5. Scenario 5 Recreational Fishing

Conservation features and targets are constant. Cost weightings are applied to discourage the selection of planning units where recreational fishing occurs, where there is the flexibility to do so. We expect this scenario will result in a network of marine sanctuaries configured to minimise the economic impact to the recreational fishing.

6.4.6. Scenario 6 Fisheries GVP

Conservation features and targets are constant. Cost weightings are applied to discourage the selection of planning units containing high levels of commercial fishing GVP, where there is flexibility to do so. This is a departure from the previous scenarios—they used cost layers that considered both the value and impact of the fishery in developing the cost weightings. This scenario keeps the overall weight of commercial fishing activities (with respect to other uses) constant, but reallocates weightings within the commercial fishing classes, based solely on the GVP derived from the activity of each individual fishery. This scenario tests the sensitivity of selected outcomes to both the delineation of three commercial fishing cost classes, and the broader interpretation of impact minimised beyond simply retention of GVP. We expect that this scenario will minimise the economic impact on total GVP of all fisheries.

6.5 Results

6.5.1. Summary of Marxan Pre-processing and Relevant Data Constraints

The Marxan analysis of the Southwest Marine Region commenced by pre-processing the scenarios, generating some basic results that provide a useful context for further analyses. In the first instance, we reviewed the distribution of conservation features across the DEWHA AFA areas to identify data constraints that are relevant to achieving conservation objectives. We noted that for 88 conservation features that occur in the SWMR, their range is entirely separate to the AFAs, such that even with all of every AFA protected, targets for these conservation features would not be met, even partially. Table 6.5 reports the distribution of these features across the feature classes. In addition, a further 51 features, five of which are Listed species, were found to have less than their feature target within the AFAs. The corollary of this is that these conservation feature targets cannot be met by the AFAs alone, even if all of every AFA were designated as sanctuaries. However, for the five Listed species, the AFAs come close to their targets, with more than 45% of their SWMR distribution captured in the AFAs. The extent of the SWMR distribution of each of the conservation features contained within the AFAs is reported in Appendix 6.

In the possible event that all of the AFAs were to be designated as marine sanctuaries, to assess if missing targets would be a problem from an ecological viewpoint, we randomly selected for assessment several of 139 conservation features that would not be represented up to target level within the AFAs. A small number of the missed targets comprise highly nested features, for which missing a target by even a substantive margin may not be an issue. However, there were some nested features that did not meet their target but would be considered an ecological issue. For example, there is only one reef in the 40-80m depth zone in the Murat bioregion. For all of the AquaMap species that we reviewed here that would miss their target in the AFAs, each species had large areas of high probability of occurrence elsewhere in the Australian EEZ, and lower than 0.75 probability of occurrence in much of the SWMR. This resulted in the species having a high probability of occurrence in only a few planning units in the SWMR, despite being a wide-spread species. Many of these species have broad distributions in more tropical areas, and some may be considered as stragglers in the SWMR that would not normally be expected to be protected to any significant extent by marine sanctuaries. Both of the above examples highlight the need to review conservation features that are unable to meet their targets to assess the ecological significance of such failures.

Table 6.5 The number of conservation features that occur entirely outside the AFAs, reported by Feature Class

Feature Class	Number of Features
Aquamaps species	56
Demersal fish provinces	1
Depth by bioregion	3
Energetics	1
Stratified geomorphic features	26
Seascapes	1
Total	88

With the cost types, we report on the percentage of their distribution within the SWMR that is in the AFAs, by cost type class (Table 6.6). These values equate to the amount that each cost type class would lose if all of every AFA was designated as marine sanctuary. For the purpose of this analysis we assume that the impact from sanctuaries is minimised when displacement of existing activities is minimised. Finer scale reporting (e.g. by individual fisheries) was restricted to comply with the relevant data confidentiality agreements.

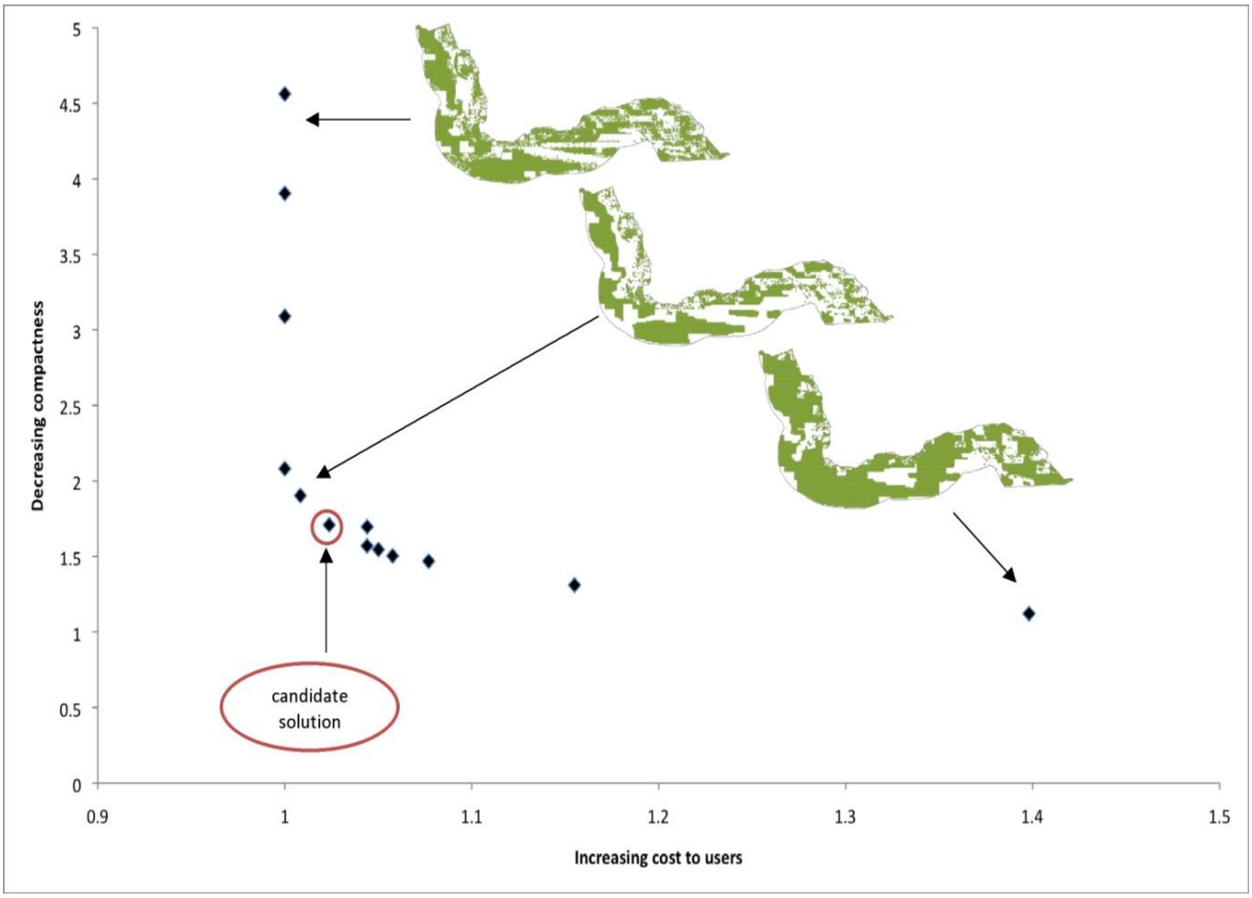
Table 6.6 The distribution of cost types within the AFAs, reported by as % Cost class in the SWMR

Region	Shipping	Population Pressure	Defence	Trawl fishery	Non-trawl Fishery	Rec fishery	Petroleum	WRL
AFAs	55%	55%	34%	55%	40%	67%	54%	52%

6.5.2. Scenario 1 Principles for Sanctuaries

A series of calibrations were performed to derive the appropriate settings for the Marxan software. One parameter of interest is the BLM, which can be weighted to improve the compactness (clumping) of the solutions. In doing so, there is a cost to the efficiency of the solution and so an important first step is to determine the trade-off between the cost of the marine sanctuaries network and its compactness. We performed this calibration by iteratively increasing the importance of compactness (BLM) and plotting the cost of the solution against the boundary length. A BLM of 10.3 was selected as the BLM for the analysis. The BLM of 10.3 occurred at the inflection point in the cost/boundary length trade-off curve (Figure 6.2). Increasing the BLM higher than 10.3 resulted in steep increases in solution cost, relative to the marginal reduction in boundary length.

Figure 6.2 Boundary length:cost trade-off curve. Maps of indicative solution candidates are shown for three levels of emphasis on compactness.



Scenario 1 Principles for Sanctuaries examines the problem of designing a network of marine sanctuaries for the SWMR that captures the intent of the sanctuaries component of the Scientific MPA Principles. This is represented by one of many good candidate solutions (Candidate A) in Figure 6.3. All 100 solutions successfully met conservation feature targets, with the levels of representation actually achieved reported in Table 6.7 by feature classes. Even the wide ranging features defined as AquaMaps-wide, AquaMaps – Listed wide and Seabird foraging-wide achieved a minimum level of representation of 49% across all solutions, despite no targets being set for these features. Ensuring that minimum targets for all individual features were achieved clearly resulted in representation levels above target for some species, as indicated by Median and Mean Class Representation that are sometimes well above the Minimum Class Representation (Table 6.7).

In Table 6.8 we report on the performance of the Scenario 1 solutions against some key indicators. The *Candidate Solution* refers to the solution presented in Figure 6.3, while *All Solutions* reports the average of all 100 solutions generated. Approximately half of the SWMR planning region is required to efficiently achieve the targets captured by the Scientific MPA Principles, with the solutions fairly equally distributed above and below the 1500m depth. However, on average, 40% of the marine sanctuaries network falls outside the AFAs, with just over half of the AFAs themselves selected in the Candidate A Solution network of marine sanctuaries (54%) as illustrated in Figure 6.4. One of the strengths of using Marxan is the ability to have many good spatially different solutions to a given problem. The solution presented in Figure 6.5 (Candidate B) is an example of another, spatially different, solution for Scenario 1.

Figure 6.6 presents the selection frequency of planning units across all the solutions generated. It is a common misconception that this type of output represents a solution. What it does reveal is which sites are essential to solve the problem framed by Scenario 1. These sites are represented in Figure 6.6 as '*Always Selected'.* Practically, they serve to highlight where key focal areas are located and to suggest where a subsequent prioritisation process could be started if required. Planning units that are *Always Selected* and located in the AFAs are an obvious place to commence negotiations for marine sanctuaries, however these sites alone will not achieve the conservation feature targets. Many more planning units are required to solve the conservation planning problem and meet all the targets and some degree of flexibility is afforded in selecting these. Planning units which are '*Regularly Selected'* are likely to contain common features that are also found elsewhere, at a reasonable cost, while those that are '*Frequently Selected'* most likely contribute to efficient representation of targets. Planning units identified as '*Never Selected'* or *'Seldom Selected'* may be regarded as offering a poor return on investment, in that they are possibly too expensive given that the conservation features they contain can be found elsewhere and so alternative sites would be preferred.

The DEWHA AFAs appear to be reasonably efficient at capturing planning units (Figure 6.6) that are *Always Selected, with some notable exceptions along the mid-west coast and the Great Australian Bight.* Because selection frequency maps are not solutions in themselves, we reviewed individual AFAs to determine what percentage of each AFA was represented in Candidate Solution A as marine sanctuaries. While the contributions made by each AFA are to be considered equally important, results in Table 6.9 demonstrate that 85% of the Jurien Bay AFA was identified in marine sanctuaries, followed by the South-west Corner AFA (62%) and the Houtman Abrolhos AFA (59%). More than 24% of every AFA was selected as marine sanctuary in Candidate Solution A.

Figure 6.3 – A candidate solution for Scenario 1: Principles for Sanctuaries proposing a network of marine sanctuaries in the SWMR

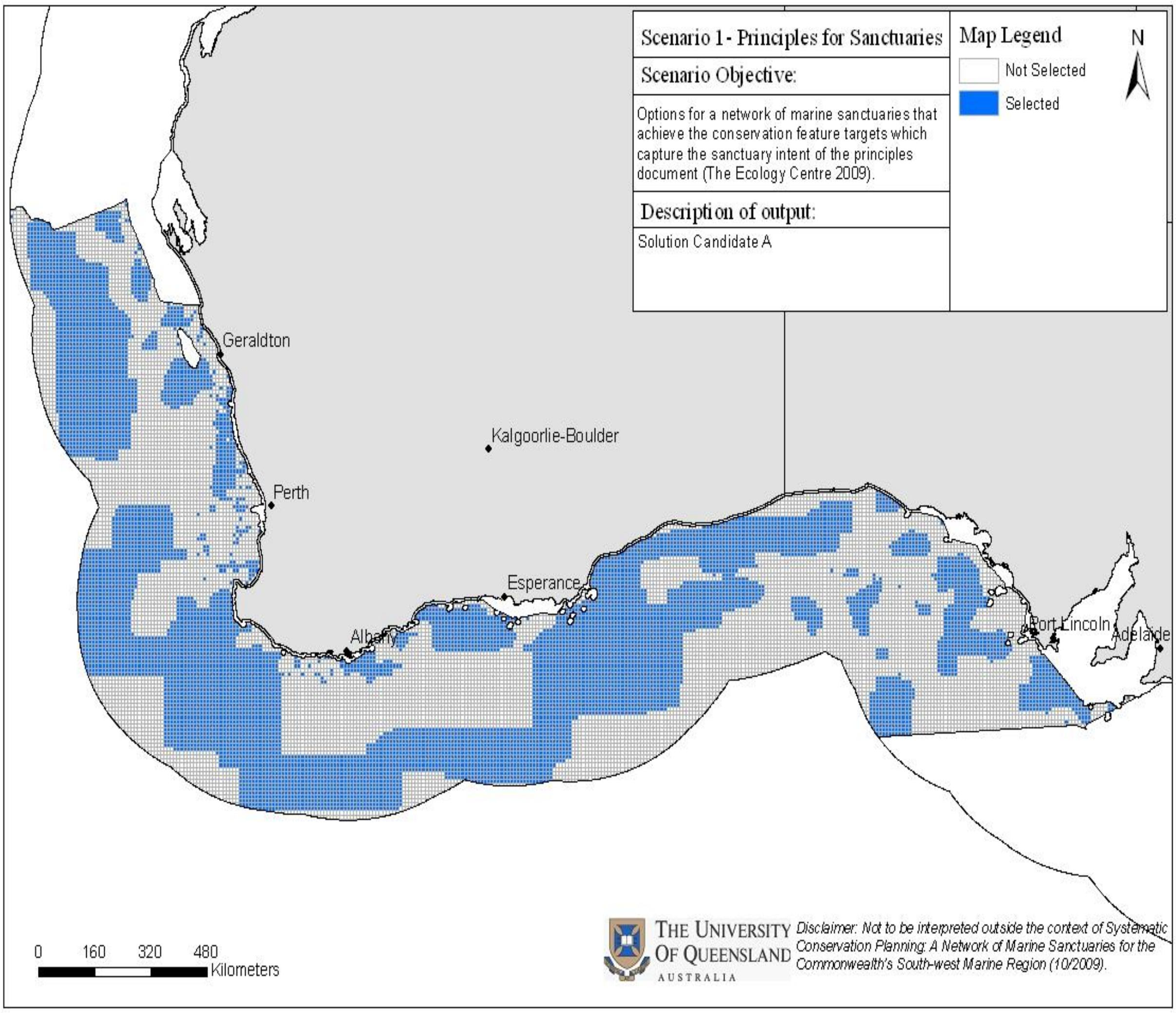


Figure 6.4 – Candidate A solution for Scenario 1: Principles for Sanctuaries showing the relationship of the marine sanctuaries to the AFAs

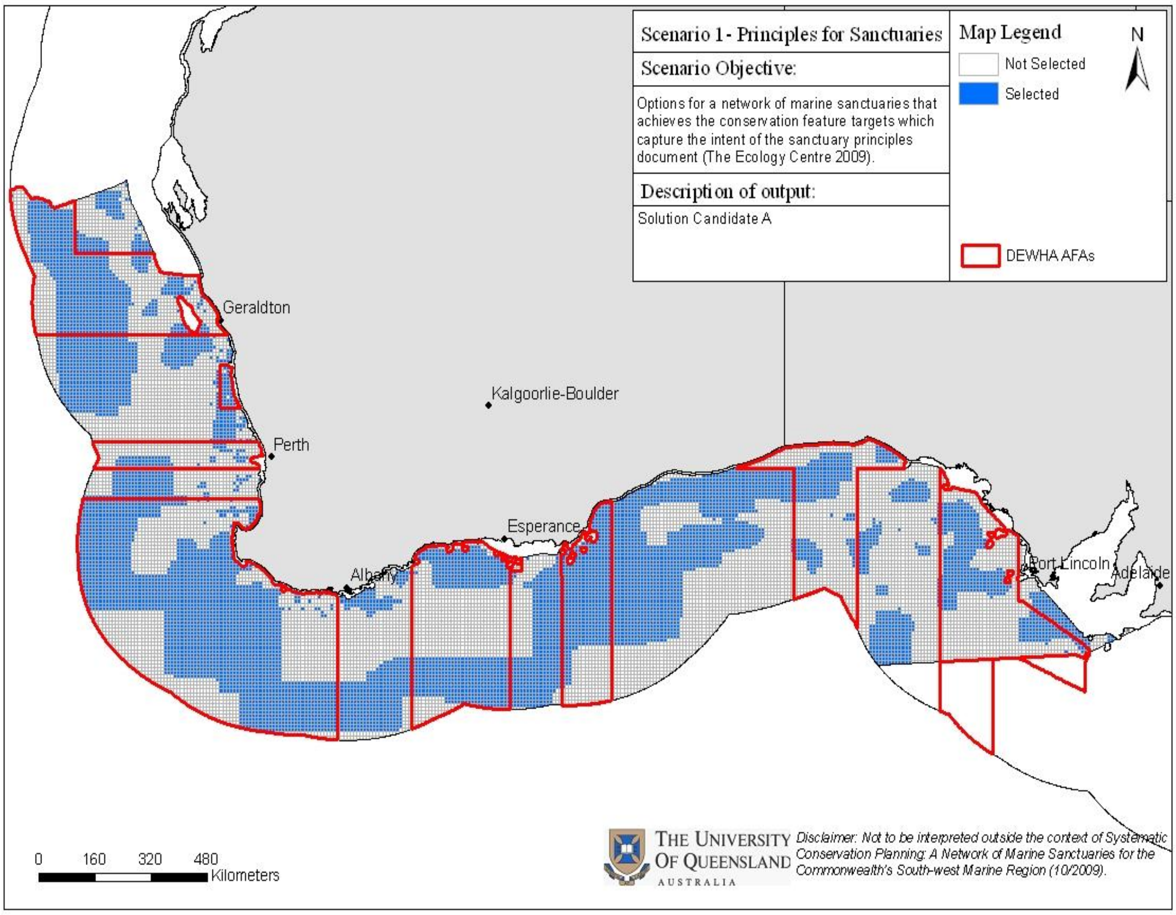
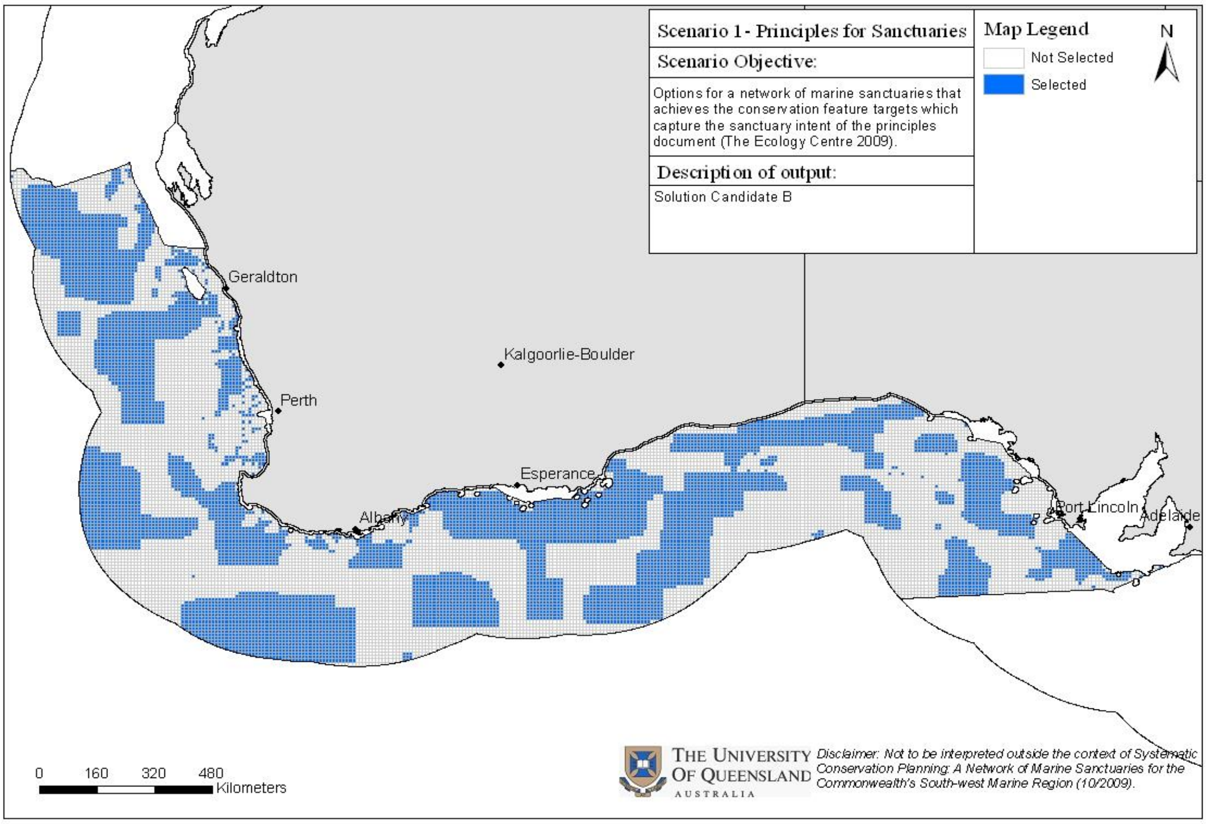


Table 6.7 Level of representation achieved for conservation features in Scenario 1: Principles, reported as a percentage of the total conservation feature in the SWMR. Results are reported by conservation feature class.

	Candidate Solution A			All Solutions*		
Feature Class	Median Class Representn	Mean Class Representn	Minimum Class Representn	Median Class Representn	Mean Class Representn	Minimum Class Representn
AquaMaps endangered	52%	52%	51%	57%	57%	53%
AquaMaps general species	51%	50%	30%	51%	50%	30%
AquaMaps listed	50%	52%	50%	50%	52%	50%
AquaMaps listed wide	51%	52%	50%	51%	51%	49%
AquaMaps vulnerable	50%	53%	50%	52%	53%	50%
AquaMaps wide	51%	51%	48%	51%	51%	49%
Bioregions	49%	50%	30%	49%	50%	30%
Demersal fish provinces	49%	49%	30%	48%	47%	31%
Depth by bioregion	54%	57%	30%	49%	57%	30%
Depth zones	48%	49%	36%	49%	49%	34%
Eddy kinetic energy	54%	56%	30%	50%	54%	30%
Energetics	44%	47%	30%	47%	50%	30%
Geomorphic Features	60%	59%	34%	57%	58%	36%
Key ecologic features	44%	48%	30%	43%	50%	31%
Latitudinal Bands	54%	54%	45%	54%	53%	44%
Pelagic regionalisation (1b)	51%	51%	32%	51%	51%	34%
Phytoplankton Provinces	55%	50%	40%	55%	52%	41%
Primary productivity	50%	51%	43%	49%	49%	39%
Seabird foraging	51%	53%	50%	51%	53%	50%
Seabird foraging - wide	52%	52%	52%	52%	52%	51%
Seascape	51%	56%	30%	48%	51%	35%
Stratified geomorphic features	60%	63%	29%	58%	63%	30%
Vertical Velocity	50%	51%	36%	52%	52%	37%

*All Solutions reports the result of 100 runs, which generate 100 different options for a set of sanctuaries in the region. When reporting results for class level representation, the mean representation of the individual feature in all 100 runs is calculated first, then we report the median, mean, and minimum of these means for individual features.

Figure 6.5 A spatially different candidate solution (Candidate B) for Scenario 1: Principles for Sanctuaries proposing a network of marine sanctuaries in the SWMR



Selection Frequency

In displaying the selection frequency from scenarios (Figure 6.6) we delineate five different categories of selection frequency; 1- Always selected, 2-Frequently selected, 3-Regulary selected, 4-Seldom selected, 5-Never selected. 'Always selected' are those planning units included in every solution of the 100 options generated in each scenario. 'Never selected' has a similar definition, and includes only those sites that were never selected. The middle three categories were defined using the binomial distribution. The binomial distribution is a probability distribution of success for a series of independent trials. To generate the binomial distribution we defined the probability of success as being 50%, which was the percentage of all planning units included in the average solution in the calibrated principles for sanctuaries scenario. The Frequently selected class was defined as those planning units that were selected greater than the 90% confidence level (selection frequency higher than 58), the Regularly selected range as those in the 10-90% confidence interval, and the Seldom selected as those with a selection frequency below the 10% level (selection frequency below 41). Another way of phrasing the interpretation of these range categories is that for the "frequently selected" planning units, there is a greater than or equal to 90% chance that the planning unit was not included in the solution set solely based on chance. The distribution was estimated using the *Hmisc* package in R statistical computing software.

Table 6.8 Performance of solutions generated for Scenario 1: Principles for Sanctuaries

	Total area of sanctuaries in SWMR (km^2)	% AFA area in sanctuaries	Boundary length (km)	Above 1500m (km^2)	Below 1500m (km^2)	% sanctuaries outside AFAs
Candidate Solution	50.2%	53.3%	20,791	48.4%	51.1%	42%
All Solutions	49.9%	54.0%	21,950	48.1%	50.8%	40%

Figure 6.6 Selection Frequency of planning units across all the solutions generated in Scenario 1: Principles for Sanctuaries

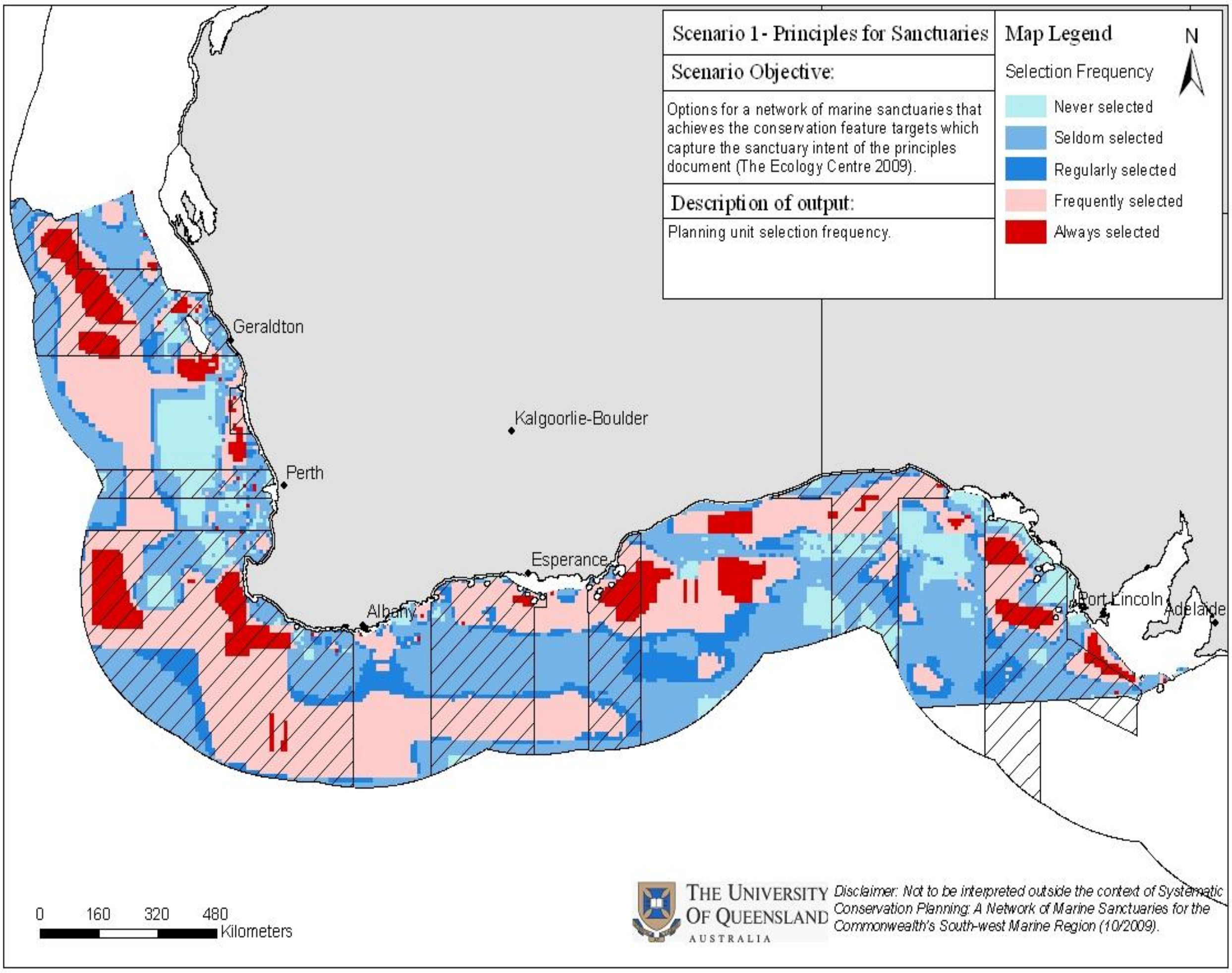


Table 6.9 The mean percentage of the AFAs identified in the network of marine sanctuaries for Scenario 1: Principles for Sanctuaries

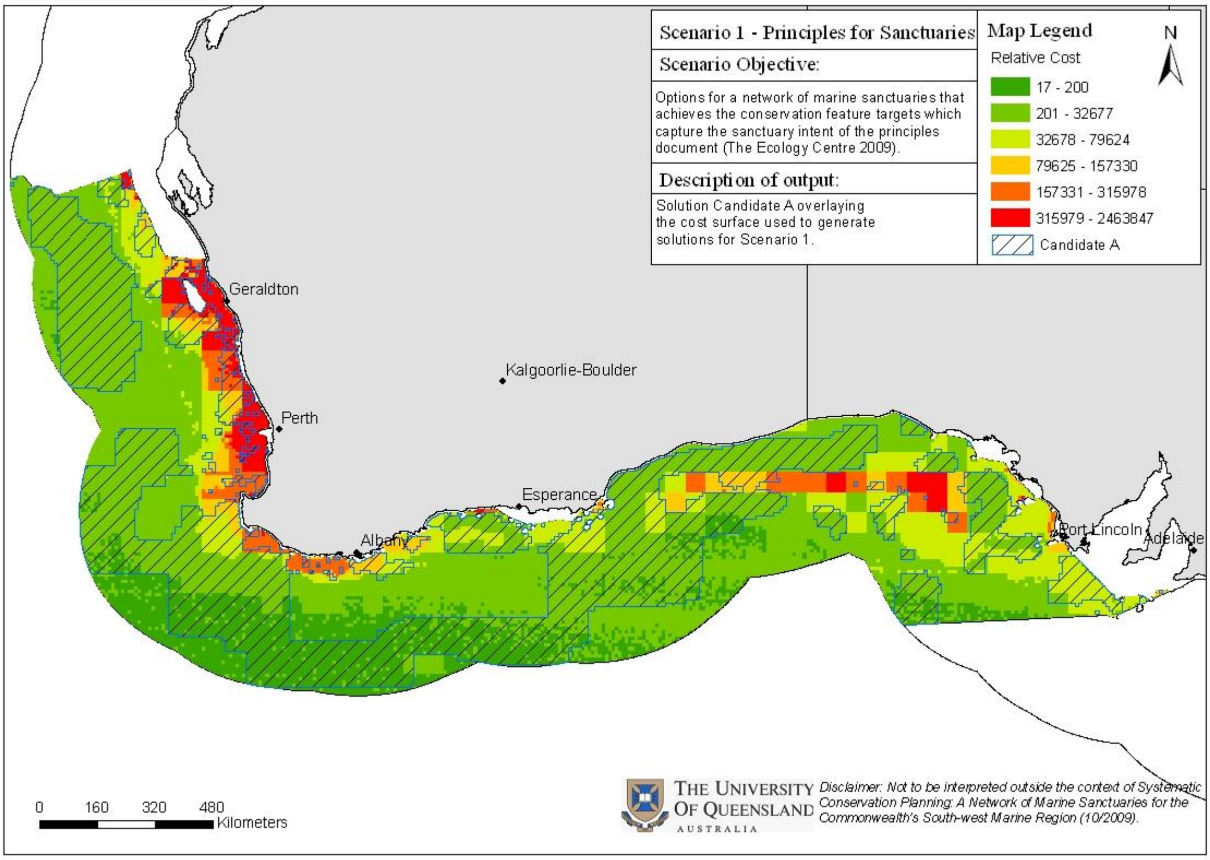
DEWHA AFA	Candidate Solution A	All Solutions Mean
Great Australian Bight	33%	40%
Houtman Abrolhos	59%	59%
Jurien Bay	85%	80%
Perth Canyon	24%	27%
Recherche	55%	49%
South-west Corner	62%	63%
Western Eyre	39%	47%
All	53%	54%

Minimising cost is a key objective of the Marxan optimisation problem. In Scenario 1 Principles for Sanctuaries we report on the extent to which costs are minimised across the different cost classes. These results are specific to the cost surface described in 6.3.2, which applies a greater cost weighting on planning units that contain more intensive activities such as the commercial and recreational fisheries. Under this framework, we would expect the selection of marine sanctuaries to minimise the impacts to these cost features in particular. Figure 6.7 shows the candidate solution (Candidate A) overlaying the cost surface described in 6.3.2. Table 6.10 reports on the percentage of each cost feature class that is contained in the proposed network of marine sanctuaries. It points to the highly efficient results achieved by the solutions overall, given that the spatial extent of the marine sanctuary network is approximately 50% of the SWMR and yet no individual cost feature class is displaced more than 37%, and most cost features do much better. Of course, cost efficiencies can only be achieved where there is the flexibility to select alternative sites, as conservation feature targets must be met. For example, despite equal weighting given to both types of commercial fisheries, the Commercial Trawl Fisheries is minimised to a greater extent than Non-trawl commercial fisheries. Scenario planning affords considerable flexibility to explore the sensitivity of outputs to different cost weightings, as we will examine further in Scenarios 3 to 6.

Table 6.10 Scenario 1: Principles for Sanctuaries reports on the estimate of impact to cost classes as a percentage of their total distribution in the SWMR

	Shipping	Population Pressure	Defence	Trawl Fisheries	Non trawl fisheries	Recreational Fishing	Petroleum	Western Rock Lobster
Candidate Solution	37%	23%	19%	19%	24%	31%	33%	28%
All Solutions	37%	23%	19%	18%	25%	32%	33%	28%

Figure 6.7 Candidate Solution A for Scenario 1: Principles for Sanctuaries overlaying the cost surface for Scenario 1



6.5.3. Scenario 2 AFAs

Scenario 2 AFAs addresses the problem of achieving conservation feature targets as defined in Scenario 1 while exploring the options for achieving these targets within the AFAs, where possible. The analysis is performed by discounting the cost of planning units within the AFA's relative to planning units outside the AFA. We considered a range of discounting rates from 10%-90%, however cost weightings of all activities were kept constant. Conservation feature targets were met for all solutions across every level of discounting. We limit the following analysis to two discounting rates within this range: 30% and 80%. Candidate Solutions are presented for both these levels in Figure 6.8 and Figure 6.9 to illustrate the shift of the solution towards increased inclusion within the AFAs as the level of discounting is increased. The increasing concentration of solutions into the AFAs is also clear in the two selection frequency maps for these levels (Figure 6.10, 6.11). The levels of representation actually achieved at these discounted rates reported in Table 6.11 by feature classes and compared with results for Scenario 1. For the most part, Scenarios 1 and 2 achieve comparable levels of representation of conservation features when reported at either the minimum or mean level of representation.

Table 6.12 reports on the performance of the Scenario 2 solutions against a selection of indicators and demonstrates that the two discounting rates result in solutions that are very similar in terms of the size of the network and its distribution above and below 1500m. As the discounting rate increases, so too does the percentage of the solution that occurs in the AFAs, such that at a discount of 80% as much as 70% of the AFAs are marine sanctuaries, which is equal to approximately 77% of the solution. We know from pre-processing results that the AFAs fail to deliver on 139 conservation feature targets so areas outside the AFAs will always be required if all targets are to be met. However, the total areal extent of the network does not change due to the decreasing amount of the solution that falls outside the AFAs, demonstrating the effectiveness of the discounting method as a tool for favouring the selection of sites within the AFAs without incurring a penalty to the overall size of the solution.

At the level of individual AFAs, the higher discount rates result in an increased percentage of the AFA identified as marine sanctuaries. As much as 94% of the Jurien Bay AFA would be required in marine sanctuaries to achieve conservation feature targets at a discount rate of 80% (Table 6.14). Indeed at least 64% of all individual AFAs except the Perth Canyon are required at this discount rate. Hence, favouring solutions in AFAs has the advantage of minimising the extent of the solution outside the DEWHA AFAs but it does result in very high proportions of each individual AFA being identified as a marine sanctuary (and increases costs overall—see below).

Constraining the solution to the AFAs incurs a cost penalty as evidenced in Figure 6.12 and Table 6.13. We noted a general trend where individual cost features were increasingly displaced as more areas within the AFAs were selected, with higher costs to Recreational fisheries, Petroleum, Shipping and Commercial Fishing-Nontrawl, in particular. For Commercial Trawl and the Western Rock Lobster, the low discount rates (e.g. 30% discount) result in an overall reduction to the cost of these features, yet as the percentage of the solution in the AFAs increases to around 80%, these cost features too experience a penalty, resulting in a network of marine sanctuaries that achieve the same conservation targets yet at a much higher cost to all cost feature classes. With the marine sanctuary networks configured in Scenarios 1 and 2 both using about 50% of the SWMR, it highlights that the areal extent of the marine sanctuaries network is not a very informative measure when the impacts across different users are to be considered.

Figure 6.8 A candidate solution for Scenario 2 AFAs presents the proposed network of marine sanctuaries in the SWMR using 30% AFA discounting rate

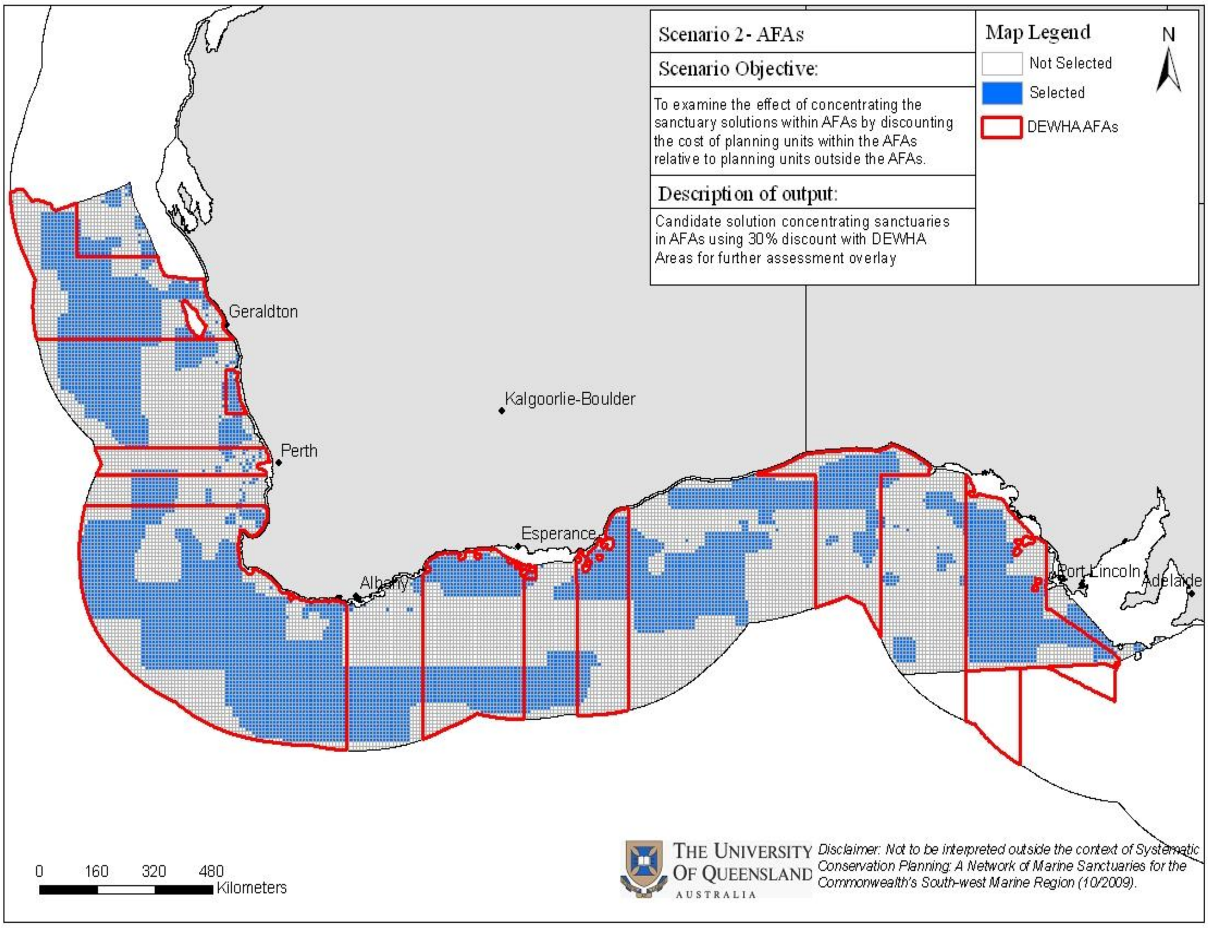


Figure 6.9 A candidate solution for Scenario 2 AFAs presents the proposed network of marine sanctuaries in the SWMR using 80% AFA discounting rate

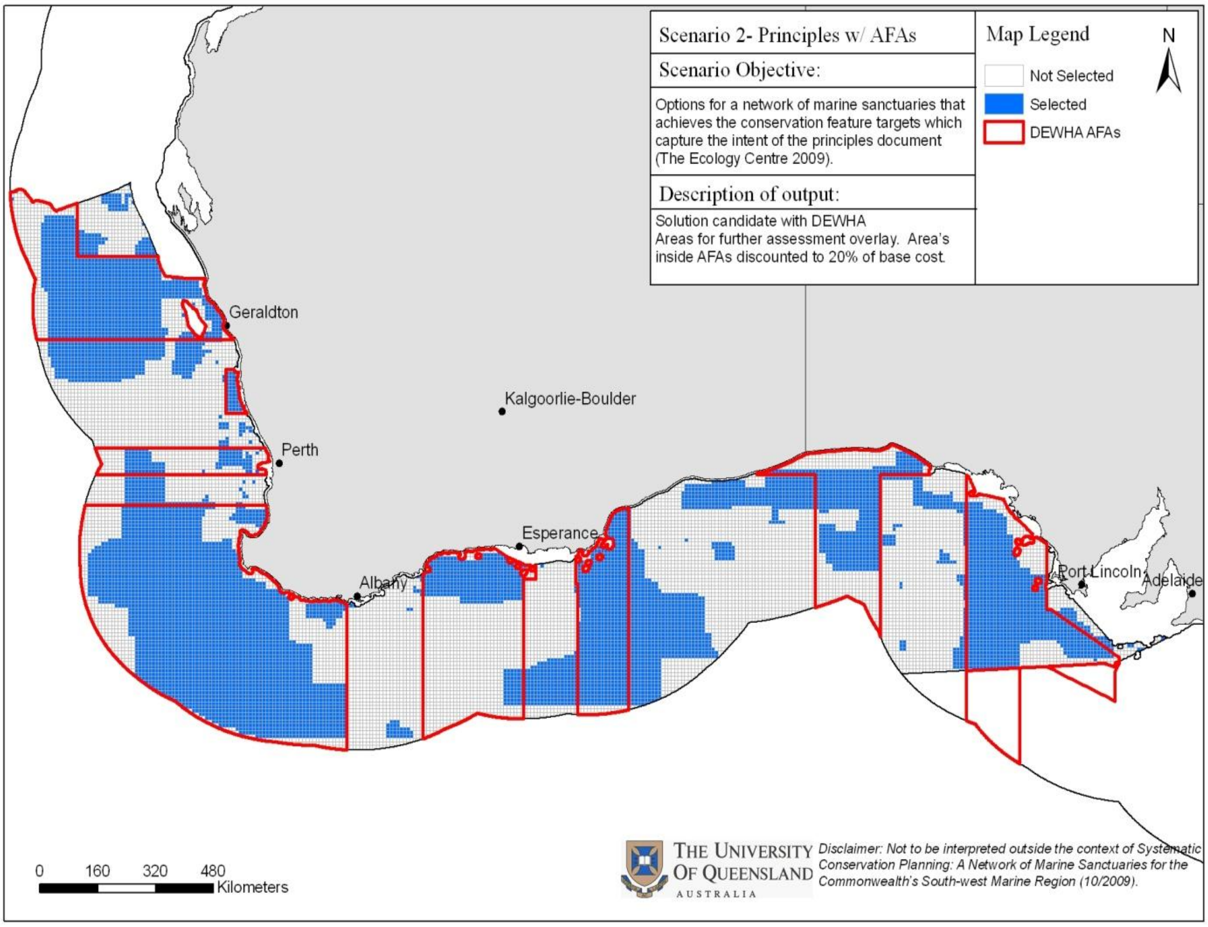


Table 6.11 Level of representation achieved for conservation features as a percentage of the total conservation feature in the SWMR. Results are based on all solutions and reported by conservation feature class for Scenario 1 Principles and Scenario 2 AFAs at the 30% and 80% discount rates.

	Scenario 1:Principles		Scenario 2:AFA 30% Discount		Scenario 2:AFA 80% Discount	
Feature Class	Median Class Representn	Minimum Class Representn	Median Class Representn	Minimum Class Representn	Median Class Representn	Minimum Class Representn
AquaMaps endangered	57%	53%	57%	52%	56%	52%
AquaMaps general species	51%	30%	51%	30%	51%	30%
AquaMaps listed	50%	50%	51%	50%	54%	50%
AquaMaps listed wide	51%	49%	51%	49%	51%	48%
AquaMaps vulnerable	52%	50%	51%	50%	51%	50%
AquaMaps wide	51%	49%	50%	48%	50%	48%
Bioregions	49%	30%	49%	30%	52%	31%
Demersal fish provinces	48%	31%	52%	32%	50%	42%
Depth by bioregion	49%	30%	49%	30%	52%	30%
Depth zones	49%	34%	49%	35%	47%	40%
Eddy kenetic energy	50%	30%	52%	30%	49%	32%
Energetics	47%	30%	49%	30%	50%	30%
Geomorphic Features	57%	36%	59%	36%	65%	34%
Key ecologic features	43%	31%	48%	31%	53%	31%
Latitudinal Bands	54%	44%	54%	42%	51%	41%
Pelagic regionalisation (1b)	51%	34%	51%	33%	50%	31%
Phytoplankton Provinces	55%	41%	55%	39%	54%	41%
Primary productivity	49%	39%	49%	38%	48%	34%
Seabird foraging	51%	50%	51%	50%	52%	50%
Seabird foraging - wide	52%	51%	51%	50%	52%	50%
Seascape	48%	35%	51%	34%	50%	33%
Stratified geomorphic feat.	58%	30%	59%	30%	63%	30%
Vertical Velocity	52%	37%	53%	38%	53%	39%

Figure 6.10 Selection frequencies for Scenario 2 AFAs using 30% AFA discounting rate

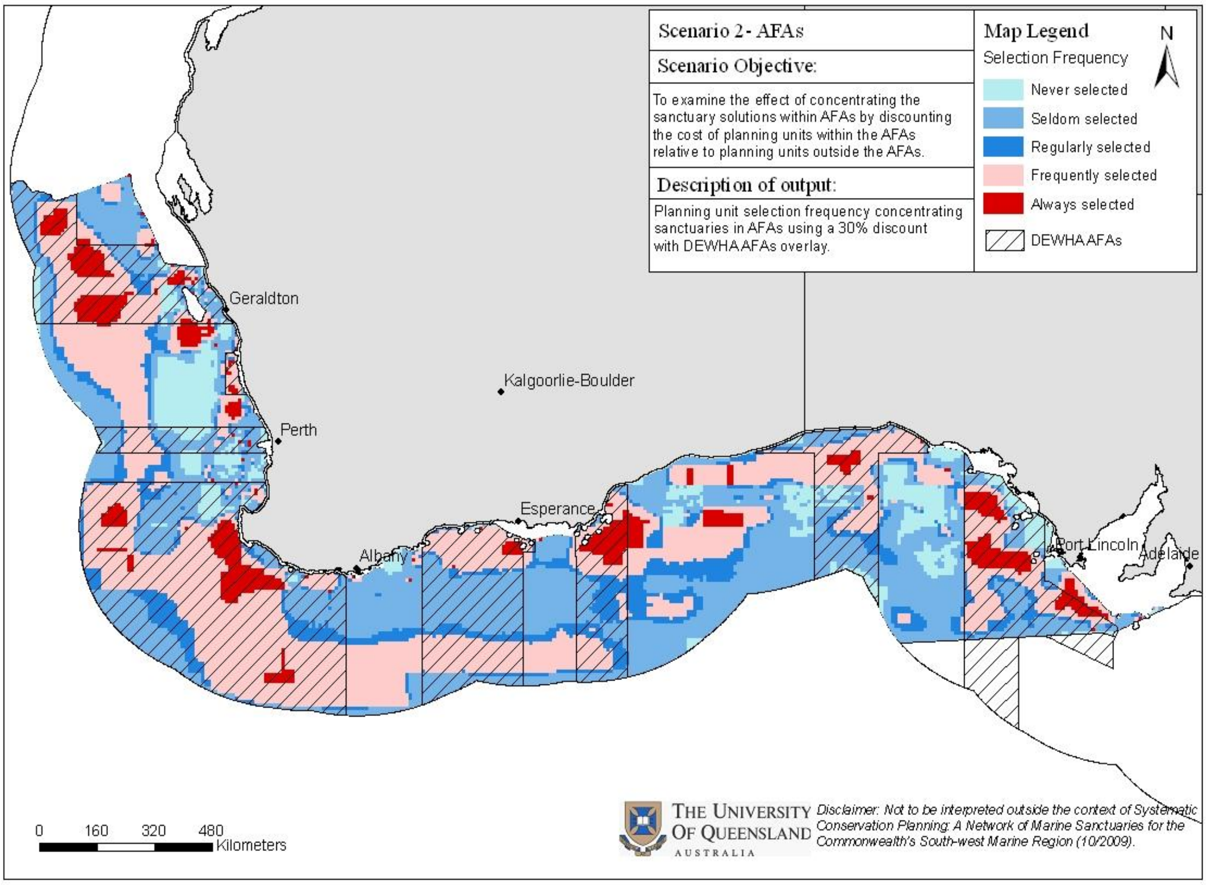


Figure 6.11 Selection frequencies for Scenario 2 AFAs using 80% AFA discounting rate

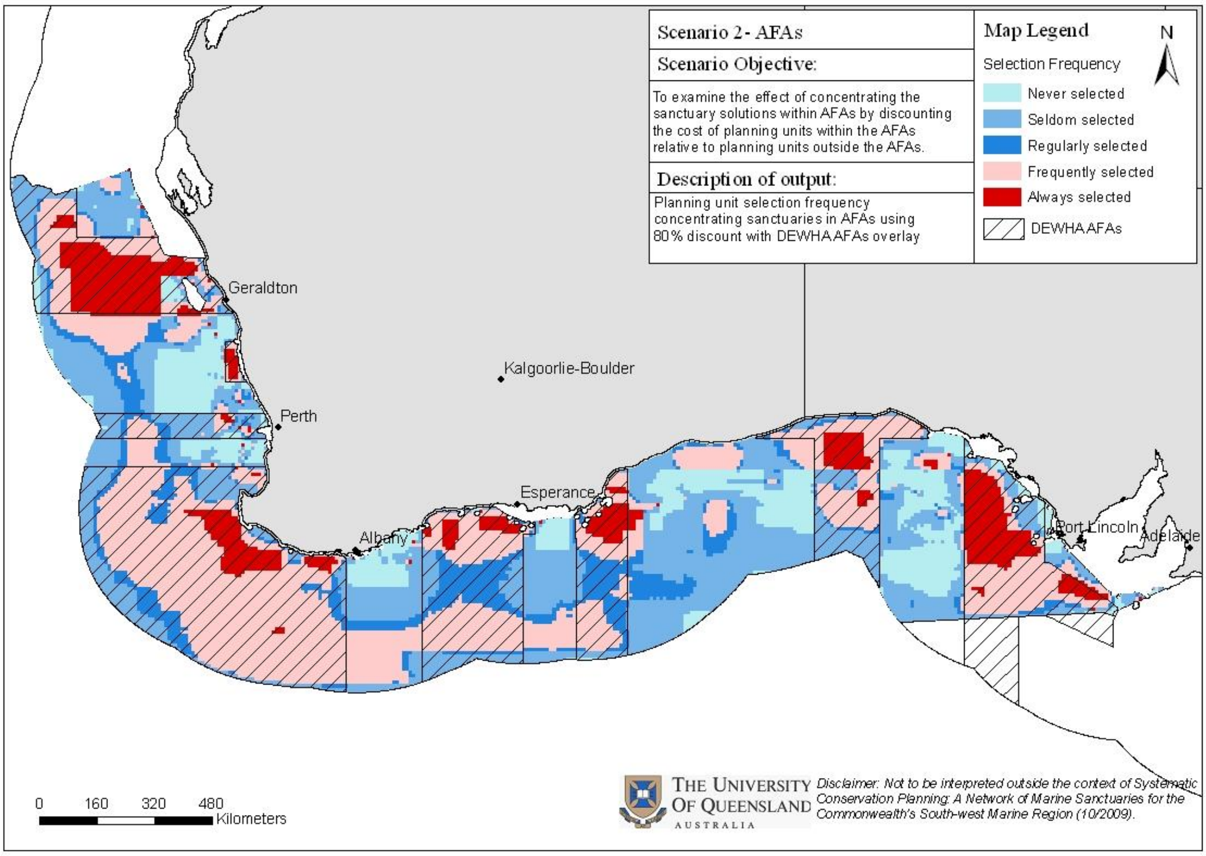


Table 6.12 Performance of solutions generated for Scenario 2 AFAs

	Total Area (km^2)	% of AFAs in Sanctuaries	Boundary Length (km)	Above 1500m (km^2)	Below 1500m (km^2)	% Solution Outside AFAs
AFAs	56%	N/A	13,389	51%	57%	N/A
AFA 30% Discount	50%	60%	20,821	49%	50%	34%
AFA 80% Discount	50%	69%	17,852	50%	50%	23%

Table 6.13 Cost surface impact trade-offs as a result of different levels of spatially concentrating sanctuaries inside the AFAs.

AFA Discount Amount	Area	Shipping	Population Pressure	Defence	Trawl Fisheries	Non trawl fisheries	Recreational Fishing	Petroleum	Western Rock Lobster
0%	50%	37%	23%	19%	18%	25%	32%	33%	28%
10%	50%	37%	23%	19%	17%	25%	33%	34%	28%
20%	50%	37%	23%	19%	17%	26%	34%	35%	27%
30%	50%	38%	24%	18%	16%	27%	35%	36%	27%
40%	49%	39%	24%	19%	16%	27%	36%	38%	27%
50%	50%	40%	24%	18%	16%	28%	37%	40%	27%
60%	49%	41%	24%	18%	16%	29%	38%	42%	27%
70%	50%	42%	24%	18%	17%	30%	40%	44%	28%
80%	50%	44%	26%	19%	20%	31%	43%	47%	30%
90%	51%	45%	29%	25%	31%	31%	50%	49%	35%

Table 6.14 The mean percentage of the AFAs identified in the network of marine sanctuaries for Scenario 1 and 2

DEWHA AFA	Scenario 1: Principles	Scenario 2: AFA 30% Discount	Scenario 2: AFA 80% Discount
Great Australian Bight	40%	48%	64%
Houtman Abrolhos	59%	64%	76%
Jurien Bay	80%	87%	94%
Perth Canyon	27%	29%	37%
Recherche	49%	53%	65%
South-west Corner	63%	66%	71%
Western Eyre	47%	61%	79%
All	54%	60%	70%

Figure 6.12 Trade-off to cost classes as the solution is increasingly concentrated within the AFAs.

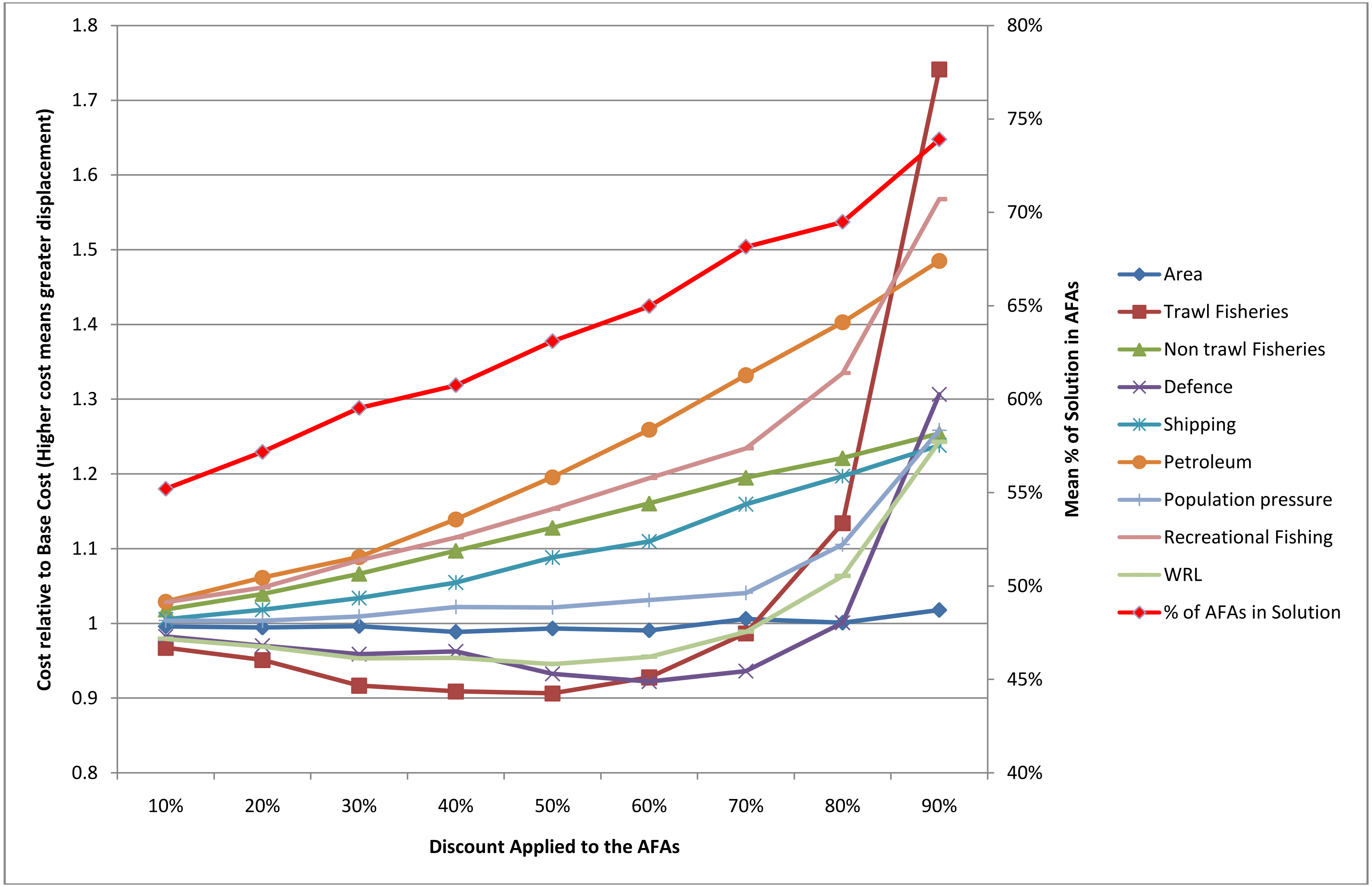
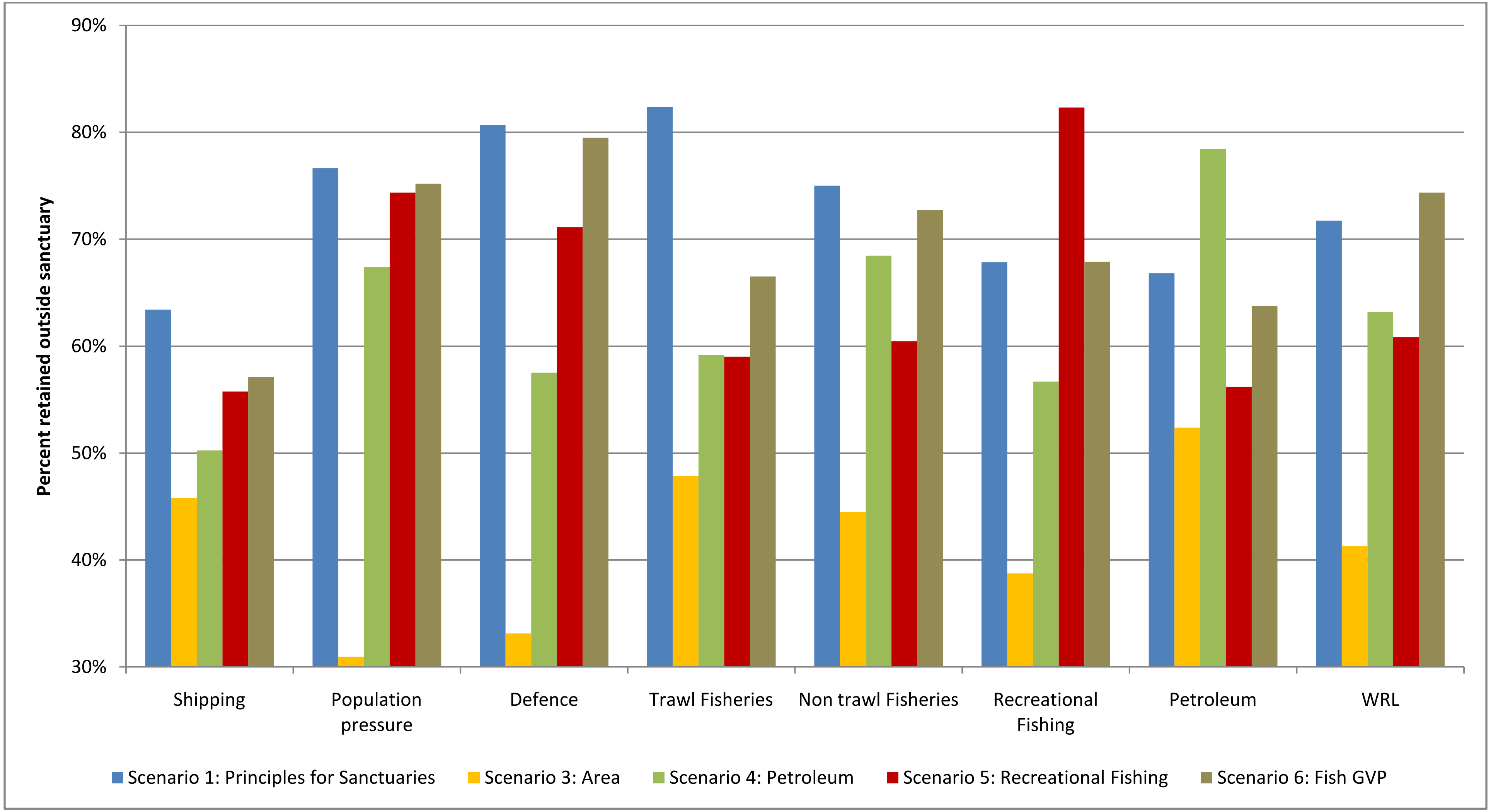


Figure 6.13 Effect of alternative cost weightings on activities across the SWMR. Higher levels of activity retained outside the sanctuaries infer reduced level of effect of the solutions on an activity.



6.5.4. Alternative Cost Surface Scenarios

Given the likely importance of alternative costs in establishing the sanctuaries in the SWMR, we sought to examine the sensitivity of Marxan outputs to different cost surfaces. Scenarios 3 to 6 examine this issue to determine how the range of cost classes respond to different cost weightings. The four different cost surfaces from these scenarios are presented in Table 6.4 and defined in Chapter 6.4. Each scenario applies a different cost surface to the Marxan analysis. For example, Scenario 3, which uses Area as the cost surface, is concerned with the problem of satisfying feature targets whilst minimising the size of the marine sanctuaries network without taking account of socio-economic activities. All conservation features and feature targets remain constant and were successfully met across the four scenarios.

In Figure 6.13 we consider how the different cost feature classes respond to each of the four scenarios. The percentage of each of the cost classes that would be retained outside the network of marine sanctuaries under each scenario is reported. To benchmark these results, we include results for Scenario 1 Principles for Sanctuaries. A selection of summary performance indicators comparing scenario performance is presented in Table 6.15.

Table 6.15 Comparison of solution performance for scenarios comparing different cost weightings.

Scenario	Total Area (km2)	Boundary Length (km)	Above 1500m (km2)	Below 1500m (km2)	% Outside AFAs
Scenario 1: Principles for Sanctuaries	50%	21,950	48%	51%	60%
Scenario 3: Area	43%	21,199	48%	40%	55%
Scenario 4: Petroleum	53%	22,246	48%	62%	64%
Scenario 5: Recreational Fishing	57%	23,392	48%	55%	49%
Scenario 6: Fish GVP	53%	17,859	50%	51%	54%

The analysis was designed to explore some of the flexibility in areas available to achieve biodiversity objectives within the Southwest Marine bioregion. The scenarios presented here were selected to demonstrate the broad range in potential different impacts to different activities, and the ability to mitigate those impacts with preferential sanctuary designs.

Scenario 3 is a departure from other scenarios in that it seeks only to minimise the total extent of the sanctuary zones. The result is a network of sanctuary zones that occupies 43% of the region, or 7% less compared to Scenario 1. However, the 7% reduction in overall extent comes at a high price to all other costs classes considered, with displacement of six cost classes estimated at about two-fold higher than Scenario 1. The percent of the total region included in protected areas is often cited in other analyses as an objective, however Scenario 3 demonstrates that simply focusing on minimising the total area in sanctuary zones can result in outcomes that are unfavourable to many existing users. Figures 6.14 and 6.15 present a candidate solution and selection frequency map for Scenario 3.

Scenarios 4 and 5 were specifically designed to minimise impact to individual activities; Scenario 4: Petroleum, and Scenario 5: Recreational Fishing. The selection of these two activities as examples for scenarios here should not be interpreted as any form of preference of these activities over any other activities in the region. Rather, the two were selected because of their divergent spatial patterns, which mean that they were reasonably appropriate for further investigation of the impact of preferential weighting. In both of these scenarios we observe a dramatic reduction in the expected displacement of the targeted activity. When compared with the baseline of Scenario 1, Scenario 4 delivered 35% more areas that were prospective for petroleum outside of sanctuary zones, and Scenario 5 secured 45% better value for recreational fishing.

However, such trade-offs are not without costs to other activities. To deliver the 35% additional areas open to petroleum exploration, all other cost classes are adversely affected. These consequent costs range from an additional 25% impact to the non-trawl commercial fisheries, to as much as a two-fold increase in the impact on trawl fisheries and defence activities. The additional benefit to recreational fishing comes at similar costs to other activities, with increases in expected displacement ranging from 20% increase in shipping traffic to a two-fold increase in the impact to trawl fisheries.

Figures 6.16 and 6.17 present a candidate solution and selection frequency map for Scenario 4, and Figures 6.18 and 6.19 present a candidate solution and selection frequency map for Scenario 5.

Scenario 6 explored a slightly different aspect of cost surface manipulation. Rather than exploring preferential treatment across a single industry group, Scenario 6 explores what happens if the approach to assessing costs of sanctuary displacement of commercial fisheries is different. Instead of subdividing the commercial fisheries into three distinct types of fisheries, Scenario 6 effectively treats them as a single activity, and seeks to maximise overall retention of GVP across the entire commercial fishing sector. Thus the results from Scenario 6 should be interpreted very differently from Scenarios 4 or 5. In comparing the output of Scenario 6 we notice a more subtle trend in the results. A slight reduction in the displacement of the Western Rock Lobster fishery is observed, relative to Scenario 1. The improvement in retention of the rock lobster fishery was expected because of the large contribution of this fishery to regional commercial fishing GVP. The decreases in the performance of the other two commercial fishing cost classes is a direct result of the redistribution of weight of commercial fishing activities within the cost surface used in this scenario. The decrease could have been mitigated by increasing the overall importance of all commercial fisheries in the region, but this was not the primary aim of Scenario 6. Figures 6.20 and 6.21 present a candidate solution and selection frequency map for Scenario 6.

Table 6.16 Comparison of the estimated of impact to cost classes as a percentage of their total distribution in the SWMR

Scenario	Area	Shipping	Population Pressure	Defence	Trawl Fisheries	Non trawl fisheries	Recreational Fishing	Petroleum	Western Rock Lobster
1- Principles for Sanctuaries	50%	37%	23%	19%	18%	25%	32%	33%	28%
3-Area	43%	54%	69%	67%	52%	56%	61%	48%	59%
4-Petroleum	57%	50%	33%	42%	41%	32%	43%	22%	37%
5-Recreational Fishing	53%	44%	26%	29%	41%	40%	18%	44%	39%
6- Fish GVP	51%	43%	25%	21%	33%	27%	32%	36%	26%

Table 6.16 summarises the range of impacts to the individual cost classes associated with the different costs weightings explored in Scenarios 1, and 3 to 6. The levels of are shown to provide a general idea of range of impacts that could be expected in meeting the sanctuary zone objectives. While the range could be indicative of the likely impacts, it should not be interpreted as the absolute range or inclusive of all possible zoning scenario options.

We also note that much of the data used to estimate potential impact to the cost classes was coarse in nature. Within the optimisation framework used for this problem, coarse cost data can often lead to overestimates of the cost burden, because it is likely to mask ‘hotspots’ in regional and local activity. This is most likely to occur in the commercial and recreational fishing datasets which are aggregated to large reporting blocks, which mask the spatial heterogeneity of the underlying activity. We also note that with many activities the closure of an area is more likely to lead to displacement of those activities, rather than total loss of all value derived from the activities.

Scenario 1 had the lowest overall expected level of impact of six of the nine cost classes, and had the second lowest level of impact to the three classes which had individual cost surface tailored to minimise impact.

Table 6.17 summarises the range of impacts across all the cost classes for all the scenarios other than Scenario 2 Area.

Table 6.17 Range of impacts to different cost classes for Scenarios 1-6 (Scenario 2 analysis is not included in this table).

Cost Class	Minimum Explored Impact	Maximum Explored Impact
Shipping	37%	54%
Population pressure	23%	69%
Defence	19%	67%
Trawl Fisheries	18%	52%
Non trawl fisheries	25%	56%
Recreational Fishing	18%	61%
Petroleum	22%	48%
Western Rock Lobster	26%	59%

Figure 6.14 A candidate solution for Scenario 3 Area sanctuaries, ignoring all socio-economic uses and costs other than area.

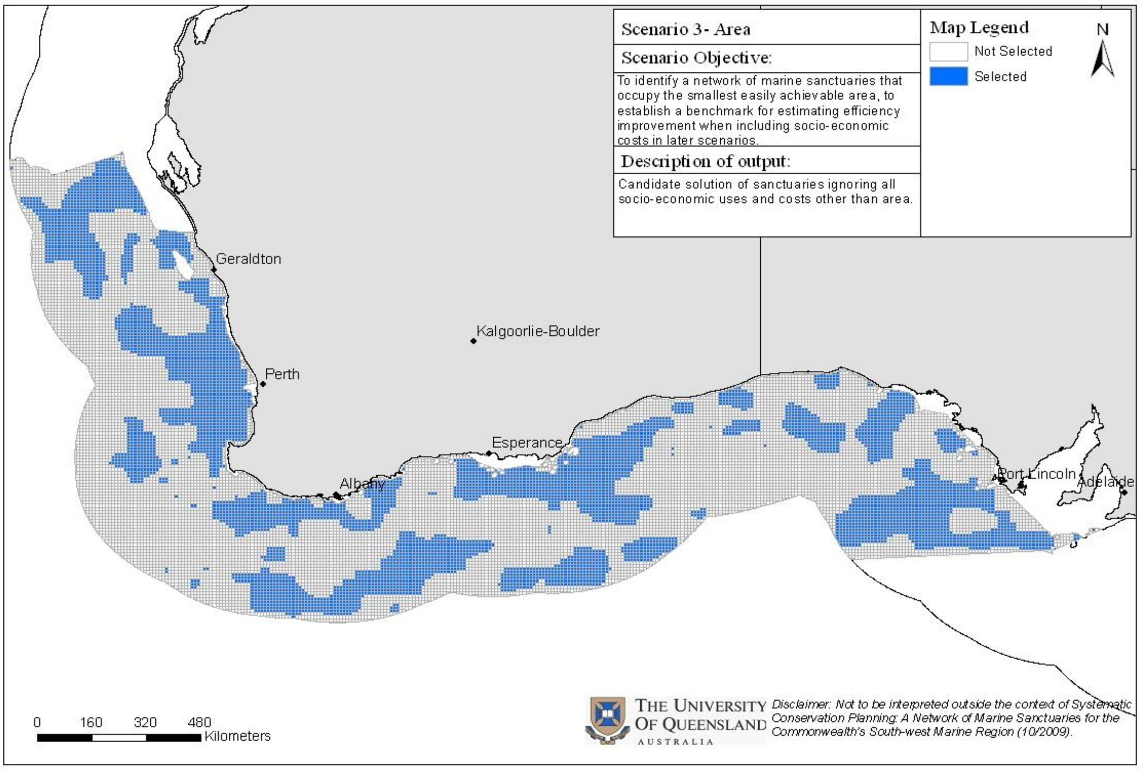


Figure 6.15 Selection frequency map for Scenario 3 Area, ignoring all socio-economic uses and costs other than area.

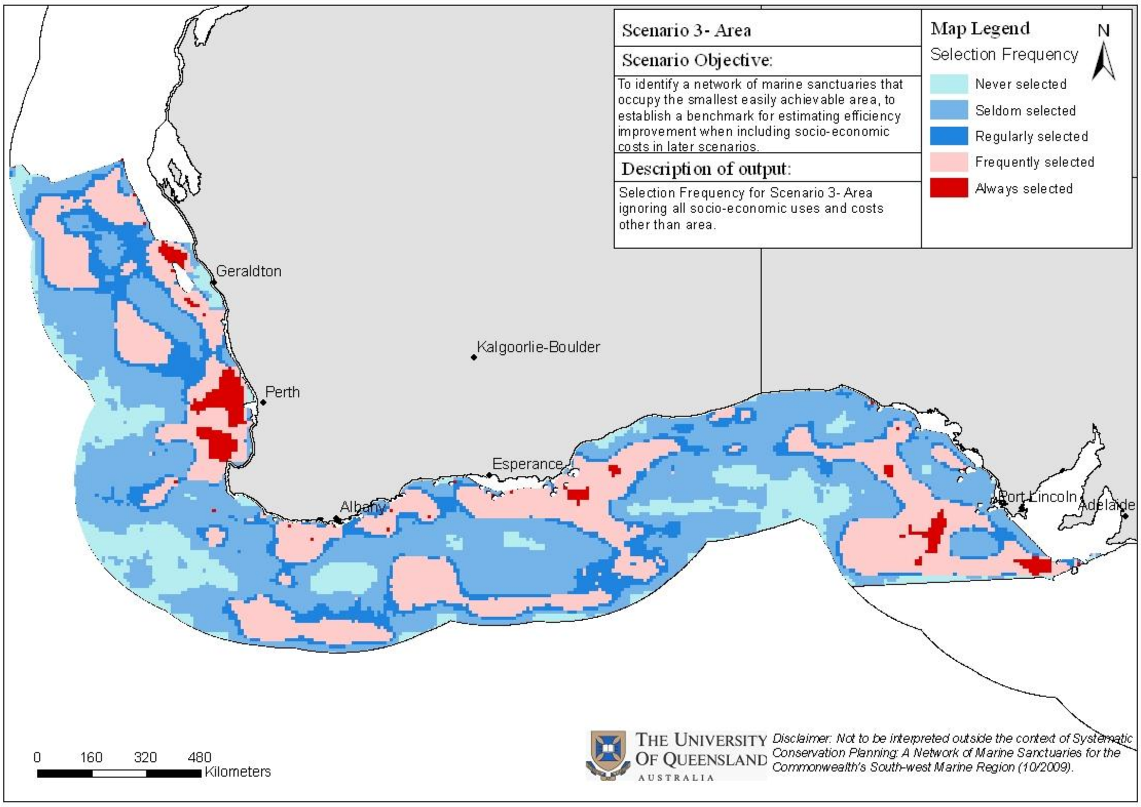


Figure 6.16 A candidate solution for Scenario 4 Petroleum, minimising impact on the petroleum industry.

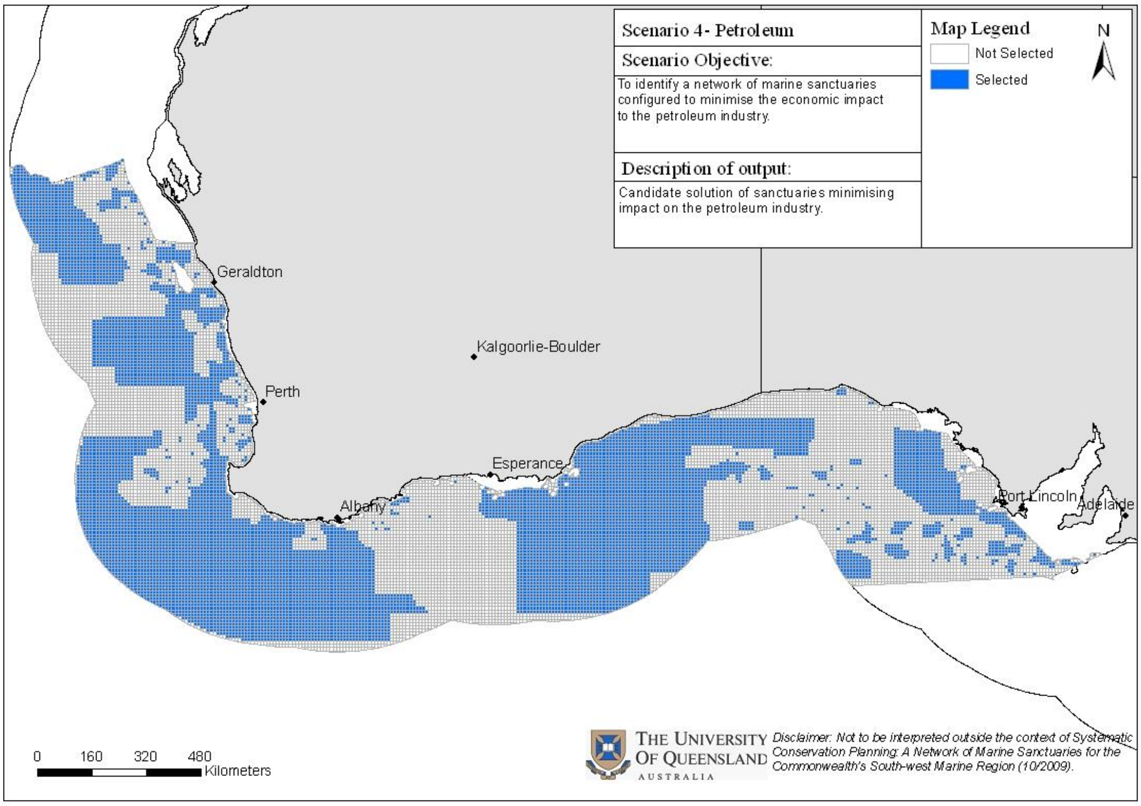


Figure 6.17 Selection frequency map for Scenario 4 Petroleum, minimising impact on the petroleum industry.

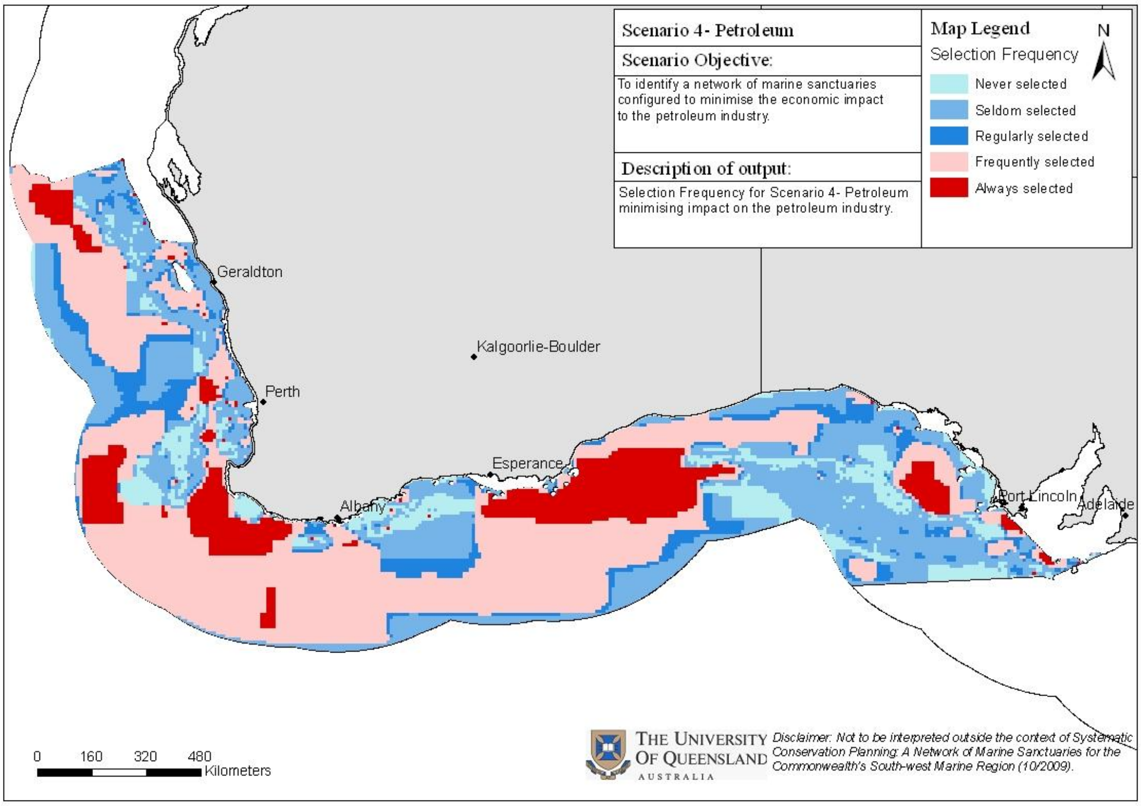


Figure 6.18 A candidate solution for Scenario 5 Recreational Fishing, minimising impact on recreational fishing.

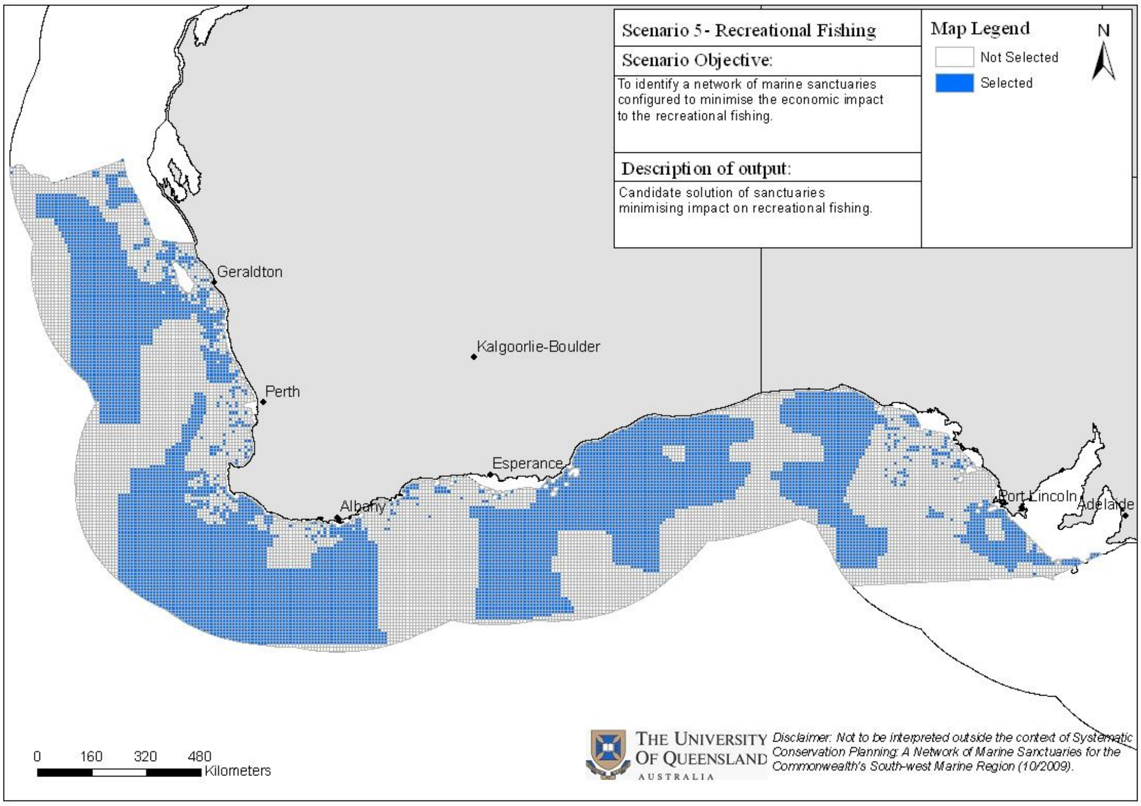


Figure 6.19 Selection frequency map for Scenario 5 Recreational Fishing, minimising impact on recreational fishing.

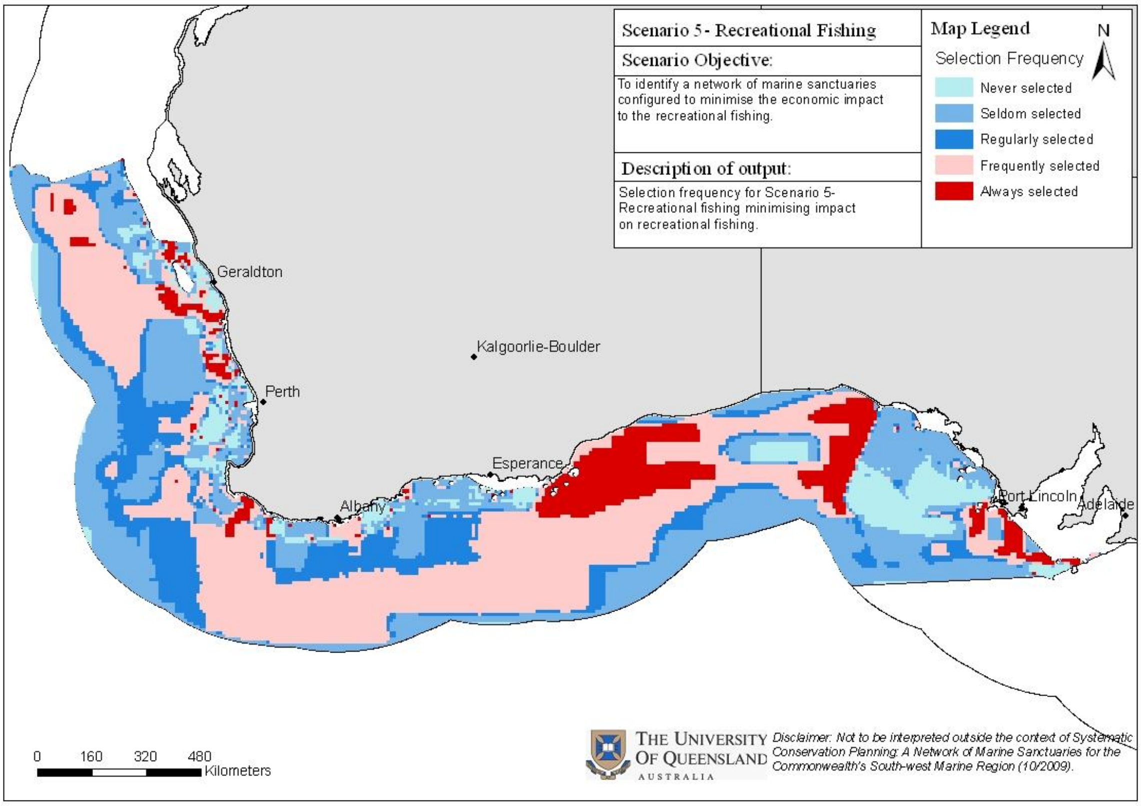


Figure 6.20 A candidate solution for Scenario 6 Fisheries GVP, minimising impact on commercial fishing GVP.

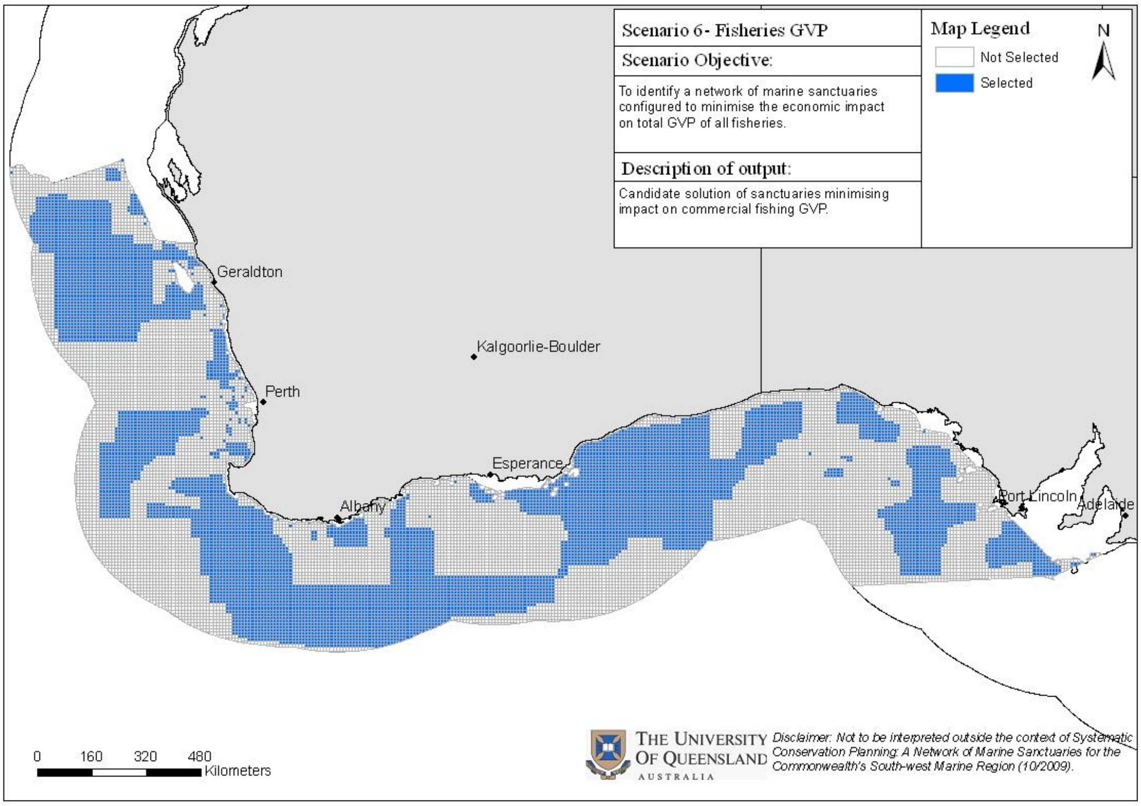
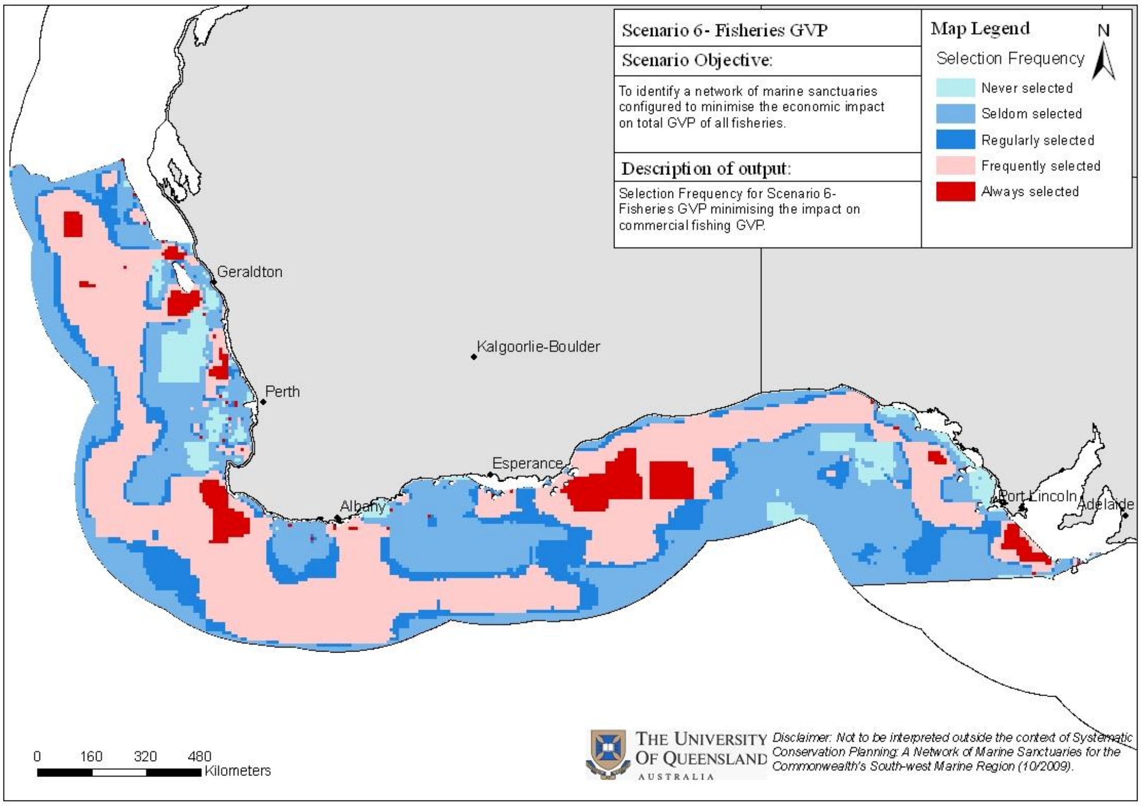


Figure 6.21 Selection frequency map for Scenario 6 Fisheries GVP, minimising impact on commercial fishing GVP.



6.6 Marxan Assessment Discussion

6.6.1. Efficiency

The Marxan analysis addresses the problem of identifying a set of marine sanctuaries for the SW Region that are configured to represent acceptable conservation objectives for each important conservation feature known to exist in the region while simultaneously achieving two other objectives related to minimising the costs—the minimum area that sanctuaries will occupy and the extent to which any existing users will be displaced because of the creation of the sanctuaries. The set of sanctuary solutions provided by Marxan from Scenario 1 Principles for Sanctuaries provides one or more good candidate solutions to this problem. The subsequent scenarios explore various issues associated with the cost of user displacement. They show that it is possible to establish a set of sanctuaries that meet the conservation targets and have lower costs for one sector (such as the petroleum sector), but that this results in higher costs to the other users.

We demonstrate that the benchmark scenario of sanctuaries provides an equitable allocation of reasonably low costs across each of the sectors for which we were able to obtain data. This demonstrates the way in which efficiency works in the Marxan context—there is a trade-off between area and cost, and the relationship is not linear, so there will be an optimum point where minimal area of sanctuaries is achieved at minimal cost to users. Moving away from this point of optimum sanctuary arrangement will incur both higher costs to users and more area required to meet the feature targets. While this may seem somewhat inevitable (the non-optimal solution) because of stakeholder negotiations and other socio-economic issues, ensuring solutions are efficient is an important attribute of the sanctuaries design process.

Where solutions are efficient they infer a measure of equitability (all sectors have to share the cost of displacement), and this creates an explicit process of benchmarking amongst sectors. Searching for efficiency in solutions therefore offered a number of important advantages in our assessment. These included the requirement to be explicit about what data sets were used, why they qualified for admission to the process, how specific targets for features were set, and what costs were incurred by specific sectors in the various solutions. We recognise that better data would possibly have increased the efficiency of our solutions—better cost data would have probably enhanced our efficiency overall. Nonetheless the process of searching for efficient solutions at any scale promotes the sustainability of the final choice of sanctuaries through the explicit demonstration that every possible feature is sought for protection and every possible cost is avoided, to the extent these can be achieved in an equitable way.

6.6.2. Selection Frequencies

We present the outcomes of the Marxan analysis in two map forms, a map of a good solution and a map of selection frequencies (of planning units within the 100 Marxan runs). One of the dangers of presenting selection frequency maps is that they will be interpreted as a stand-alone product—sufficient on their own for generating a revision of the good sanctuaries solutions (such as to reflect a specific stakeholder concern) without taking account of the underpinning assumptions. Because of the statistical properties of the classification used in selection frequency maps, if only the areas that were selected in every run (the 'Always selected' planning units) were placed in a sanctuary, then less than 10% of conservation features would be represented at their target level, and 55 features would have no representation at all (Table 6.18). Table 6.19 reports the mean level of feature class representation within each of the selection frequency ranges. Features with no representation in areas that are always selected in the candidate solution from Scenario 1 Principles for Sanctuaries include three of the Key Ecological Features (Geographe Bay, Head of the Bight, and the West Coast inshore lagoons) as identified by DEWHA in the regional profile. It is also important to note that even if the areas within the top three selection frequency classes were to be placed into sanctuaries 55% of the region would be in sanctuary, but 4% of features from Scenario 1 would still not be represented at their target level.

Table 6.18 Summary of target achievement if all of the region in a specified selection frequency range were to be converted to sanctuary.

	Selection Frequency Range		
	Always Selected	Frequently Selected (or higher)	Regularly Selected (or higher)
Regional Extent (%)	9%	44%	55%
Targets achieved if locked into a sanctuary (%)	9%	89%	96%
Features with no representation (#)	55	3	0

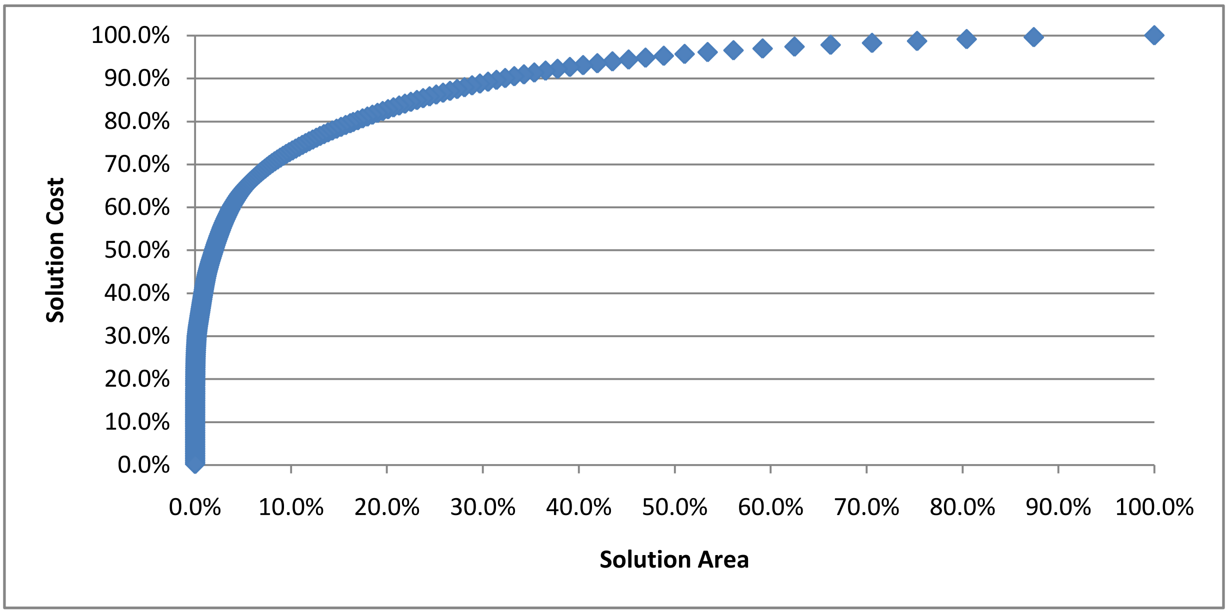
Table 6.19 Feature classes summarised by mean representation within each of the selection frequency ranges. Representation means derived from Scenario 1: Principles for Sanctuaries.

	Selection Frequency				
Feature Class	Always Selected	Frequently Selected	Regularly Selected	Seldom Selected	Never Selected
AquaMaps endangered	7%	46%	11%	27%	7%
AquaMaps general species	16%	29%	7%	34%	13%
AquaMaps listed	13%	33%	9%	36%	8%
AquaMaps listed wide	8%	37%	11%	35%	7%
AquaMaps vulnerable	10%	39%	8%	29%	12%
AquaMaps wide	9%	36%	11%	35%	8%
Bioregions	14%	32%	7%	32%	14%
Demersal fish provinces	12%	29%	7%	38%	12%
Depth by bioregion	29%	23%	6%	30%	11%
Depth zones	17%	26%	8%	36%	12%
Eddy kenetic energy	10%	40%	8%	33%	8%
Energetics	7%	38%	11%	34%	9%
Geomorphic Features	19%	34%	9%	28%	7%
Key ecologic features	14%	30%	9%	36%	10%
Latitudinal Bands	10%	40%	8%	33%	8%
Pelagic regionalisation (1b)	10%	36%	9%	36%	8%
Phytoplankton Provinces	11%	35%	9%	32%	11%
Primary productivity	7%	37%	10%	35%	10%
Seabird foraging	15%	35%	7%	30%	12%
Seabird foraging - wide	7%	38%	12%	34%	7%
Seascape	16%	30%	8%	37%	9%
Stratified geomorphic features	33%	26%	7%	26%	6%
Vertical Velocity	9%	38%	9%	35%	8%

6.6.3. Solution Costs

Costs are not uniformly distributed in planning units throughout the planning region. The skewed nature of the cost surface means that there are likely to be a small number of high cost regions that will be the primary drivers of cost within any solution set. Considering only the unweighted costs with direct user groups associated with the activity, which excludes population pressure and area from the costs, the cost to solution area relationship is more intuitive—at 30% of solution cost the mean impact across all costs will be 30% of the total impact. Figure 6.22 demonstrates the non-linear shape of the relationship between these costs and solution area for the candidate solution from Scenario 1.

Figure 6.22 Cost accumulation curve for the candidate solution from Scenario 1: Principles for Sanctuaries.



A more detailed examination of the solution cost in the candidate solution reveals that 50% of the total cost of the solution is contained within less than 5% of the solution area (Table 6.20). The skew is even more extreme in the most expensive planning units—10% of the solution cost was contained in less that 29 of the planning units in a solution that contains over 9,000 planning units.

Table 6.20 Solution cost associated with solution area and number of planning units. Summary drawn from the Candidate Solution from Scenario 1: Principles for Sanctuaries.

% of total cost	Number of Planning units	% of total solution area
10%	29	0.32%
20%	83	0.94%
30%	162	1.83%
40%	265	2.98%
50%	410	4.56%

The inference of these findings is that even in efficient solutions, some planning units of high cost may still need to be included within a set of sanctuaries in order for feature targets to be achieved. In a highly efficient sanctuary solution, these high cost units may be few in number and small in area as they are in our Scenario 1 Candidate solution, but their identification may be an important part of the implementation process—moving from sanctuary network design to declaration and management. The extent to which they become important in implementation depends on the extent to which the real costs relate to the costs included within our assessment.

6.6.4. Worse-case Costs

Our Marxan analysis uses the best costs data that could be secured within the time and budget of this project. While some of these data are public domain, others are tightly guarded and can be released only under strict confidentiality agreements. Even when such data was made available, we found that the spatial resolution was typically very coarse in relation to the conservation issues of interest, and also, much of the data was from disparate surveys or sources and used different units of measurement or sampling designs. We therefore were forced to use modelled, and often coarse-scale, data as the basis of our costs estimates for the various activities and sectors. And further, apportioning costs amongst different sectors infers an equivalent ‘currency’, such as $ or hours at sea, etc. However, in our case, we were forced to use normalised unitless data for the costs to be able to aggregate costs from different sources, which forces number assumptions about the internal scaling of values. Because the data was typically also only available in a broad spatial scale, we had to assign costs to the planning units (usually) at the same scale that it was provided, and so enforcing an assumption of homogeneity within data blocks and planning units. For example, fishing may only occur in one corner of a fishing statistical block of 25 x 25 nm, yet in fisheries statistics that whole statistical block will be assigned with a product value, and in our analysis all the planning units that fall within that that block have the average fishing value assigned to them. This process results in the enforced assumption of homogeneity within the cost data, applied at the finest scale of the available data.

We consider therefore that the costs associated with the various scenarios are to be considered as worst-case costs. Any level of heterogeneity within the planning units will act to reduce the real cost from the level we have found in the analysis. The real cost to those sectors/uses will therefore depend on first, the distribution of their activities within the data blocks we use as a basis for estimating costs, and second, on the extent to which displaced activities can be accommodated in non-sanctuary areas of the region. Taking both of these into account, we consider that our cost findings may be considerable over-estimates of true cost, but that without fine-scale and more accurate data on costs we are unable to provide any better estimates of costs associated with any of the Scenarios. The levels of heterogeneity can be estimated for each sector and applied to further analysis of the costs to establish impacts to sectors with higher levels of precision, but such work is beyond the scope of this contract.

7. DISCUSSION

Sanctuaries, which are the focus of this analysis, confer benefits beyond those of multiple-use marine protected areas (Lester and Halpern 2008). However, we fully recognise that a range of MPA zones are an important part of protecting the full range of Australia's marine biodiversity while minimising constraints on other activities. In this discussion section we consider some of the key technical issues involved in implementation of a network of sanctuaries and embedding sanctuaries within a broader spatial framework of other MPA zones.

7.1 Implementation: Moving from Scenarios to Declaration

Spatial prioritisations like those presented in this report represent a major step forward in meeting societal needs for the management of marine areas. However, the outcomes are a *decision-support* tool not a *decision-making* tool. The next phase is to start drawing lines on maps with local stakeholders that are informed by these maps, by taking into account fine-scale issues and data or issues that are not accommodated in our analysis. During this process there needs to be a continuous re-checking of how actual lines on maps are delivering biodiversity conservation outcomes and affecting other users. This process of verification must use information from the SWMR as a whole. While small changes to sanctuary design at a local scale may seem to have only limited impact on a final map of sanctuaries, if they result in the removal of areas then those losses need to be compensated from elsewhere in the system. The refinement of boundaries and verification based on local knowledge and issues is a normal part of the MPA design process, but it can only be conducted efficiently and effectively through the iterative use of a region-wide spatial prioritisation process such as the one we have deployed in this project.

The refinement and verification process described above can also be used by agencies (or users) to explore the types of efficient solutions that might best match their institutional objectives. This could include exploration of new policy imperatives from state or commonwealth government agencies, or solutions that more properly represent the direct interests of specific user groups. For example, since the fisheries data we used was of a coarse scale, a fishing organisation with access to high quality fishing data could conduct more detailed explorations of solutions that best matched their sector objectives while still meeting conservation outcomes. These types of exploratory approaches are much more efficient than manual exploration of possible further solution options, because they deal simultaneously with all the relevant issues rather than narrow incremental adjustments that can very easily create other problems (such as missing key conservation feature targets, shifting costs to other users in an inequitable way, etc).

7.2 Sub-regional Nesting of the Decision Problem

This work has provided a range of efficient sanctuary solutions for the South-west marine region that are consistent with the sanctuary component of the Scientific Principles. Our analysis, and basic theory, suggests that restricting our attention to a spatial subset of the region (such as the AFAs) reduces the chance of meeting all conservation targets while minimising the impact on industries. As the solutions move away from the spatial structure of our Scenario 1 Candidate Solution, the area required and the costs (extent of displacement of users in general) increase, decreasing the solution efficiency. The more the scope of the decision problem is spatially constrained, the more acute the loss of efficiency becomes when trying to meet specific requirements of minimum area and minimum cost. This makes it clear that in making the types of implementation adjustments discussed above (7.1), the scope of the decision problem should always be retained at the region level, and not artificially constrained to a spatial subset of the problem without a detailed analysis and justification. This means that AFAs cannot be considered as stand-alone areas of the region, and any contribution they make to conservation of the features can only be (generally) considered in the context of the region as a whole. The exception to this will be where there are unique conservation features that are wholly enclosed by an AFA, but this is not the general case. In effect, the use of a preliminary process to define AFAs that narrow the scale and scope of the decision problem contributes heavily to the problem of imposing unnecessary costs on users (always increases inefficiency), and should be avoided wherever possible. The only practical benefit we can see from defining AFAs is to reduce the number of stakeholders thereby reducing the negotiation costs.

7.3 Conservation Outside Sanctuaries

The potential sanctuary zones identified within the course of this project identify good representative areas, however we recognise that we have not captured all the decision variables within the scope of this analysis, and that (as above) there may be valid reasons for shifting reserve design away from the solutions we have identified. Any one of our candidate solutions that are consistent with the Scientific Principles could be the core of a SW network of MPAs. Where features could not be well represented within the sanctuary zones (such as the wide-ranging species, including iconic features such as marine mammals and some birds), other forms of management will be needed. This also applies to the linkages between the ocean and the land (such as the islands in state waters used by seabirds at various times for nesting or roosting etc). The flexibility of the solutions and the underlying decision support system itself provides for an efficient mechanism to spatially locate a sanctuary solution set within a system of other MPA zones designed to achieve other conservation purposes. Conducting the spatial zoning analyses within a single decision system that includes the sanctuary components as we have deployed in this project offers a highly cost-efficient answer to the difficult question of how to design multiple-use MPAs to meet scientific conservation objectives and that are also efficient solutions, minimising costs to users. New Marxan software systems are in development in The Ecology Centre to specifically deal with these highly complex issues of an integrated approach to real-world MPA zoning designs.

7.4 Providing for Climate Change Resilience

The impacts of future climate remain uncertain, but this uncertainty cannot be an excuse for inaction within marine planning. We have addressed climate change directly within our planning problem by ensuring that we have sampled from the range of environmental gradients that currently exist in the region today. As climate change reshapes the character of marine life in the region, ensuring that we have represented the range of processes and environmental surrogates within protected areas today is a first-principles approach to ensuring the full range of biodiversity will be represented in the region in the future. Given the high levels of uncertainty surrounding the potential impacts of climate change on the processes that drive the distribution of the biodiversity, we recognise that the sanctuary zones proposed within this document are the result of a specific snapshot in time of the present-day pattern. To extend this pattern and represent the variety of biophysical factors that creates diversity at different spatial and temporal scales, we have identified and included representative samples of the major driving processes in the region. As patterns of biodiversity begin to change in response to a changing climate there will be a need to continuously reassess the placement of the sanctuaries within the region. Given the paucity of data for much of the region, such an adaptive approach would be necessary even if climate change were not an issue. So, as we learn more about the region, there will be a need re-evaluate the sanctuaries at regular intervals to ensure that they continue to capture a comprehensive, adequate and representative sample of regional biodiversity. We should also explicitly recognise that, as patterns of biodiversity shift in response to climate change, so too will those socio-economic activities that depend on those patterns of diversity. Thus we cannot restrict our future evaluations to the sanctuary network alone to determine how well it continues to represent the biodiversity, but we must also continually evaluate how well the network functions with respect to socio-economic activities in the region.

7.5 Systematic Conservation Planning in all of Australia's Marine Regions

Systematic conservation planning is an incremental process, operating within a framework of continuous improvement. The central guiding theme, as captured in the MPA Scientific Principles in this project, is recognising and dealing cautiously with uncertainty, embedded in systems that provide for effective monitoring and progressive adaptation. We report here on the first detailed attempt at an integrated and scientifically-based conservation assessment in any of Australia's marine regions. The North-west, North, and East regions have been building capacity and datasets within their MPA design processes, and we would expect that these regions could also adopt the form of decision problem and design process we have developed here. We expect that use of the decision system framework and the best current understanding of scientific principles for MPA design, as reported here, would provide a robust guide for the conservation analysis within each of the regions. Following the model used to operationalise the scientific principles presented here, each region should also aspire to clearly express the objectives of the MPA network in terms of conservation features, present the problem formulation, and report on design outcomes in an open and transparent manner. Similarly, in the South-east, which has a declared base of MPAs, as the statutory review of management approaches, the decision-support tools we have deployed here could provide, in a very cost-effective manner, a robust approach to determination of any gaps in the system, including issues of design, the performance indicators and the performance benchmarks.

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APPENDICES

The Appendices to this report are provided in electronic format only, and are available from Pew Australia on request.

Appendix 1 The MPA Scientific Principles Guidance Statement

The Scientific Principles for Design of Marine Protected Areas in Australia: A Guidance Statement (also available at www.uq.edu.au/spatial ecology/mapguidelines) (provided here as the pdf file)

Appendix 2 The Datasets used in the Marxan Analysis

This is a list (xls file) of the datasets that have been used in the Marxan analyses reported here. A full list of datatsets the were investigated for use in the analysis is contained in the Milestone 1 report, April 2009 (available from Pew Australia on request).

Appendix 3 The Application of Principles to Conservation Features

This is a spreadsheet (xls file) showing the specific Principles and their sub-criteria that were used in framing the use of specific conservation feature datasets in the analysis.

Appendix 4 Conservation Features used in the Analysis

This is a list (xls file) of the conservation features that were used in the Marxan analysis.

Appendix 5 Cost Types used in the Analysis

This is a list (xls file) of the cost types that were used in the Marxan analysis.

Appendix 6 Distribution of Conservation Features within the AFAs

This is a list (xls file) of the conservation features showing the extent of their SWMR representation (% spatial distribution) that is contained within the AFAs.

Appendix 7 Powerpoint Presentation of the Project Findings

This is a copy (updated) of the client presentation of the Final Report (ppt file).

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