The usage of systematic reserve planning software *MARXAN* in the Pilbara/Eighty Mile Beach marine conservation reserve planning process

Version 1.1

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14 September 2010

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Department of
Environment and Conservation

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Document Control: This is version 1.1.

DOCUMENT HISTORY

Version	Date	Updated By	Modification
1.1	13/9/2010	Ewan Buckley	Original document

ACKNOWLEDGEMENTS

Judy Zuideveld assisted with the writing of the Introduction of this report, and drove the processes of creating reserve design criteria, operational targets, and with Leanne Thompson, liaised with stakeholders to ensure that the Marxan project represented the broader planning process as closely as possible with the data and resources available. Ray Lawrie as Senior Marine Information Officer supervised the set-up and implementation of Marxan, and Ray and Michael Higgins collated the information required for the broader Pilbara and Eighty Mile Beach planning process and assisted with the translation of source data into Marxan-ready datasets. Michael produced many of the Marxan input files, and ran several analyses of proposed reserve designs. As Principal Marine Planner and A/Manager, John Lloyd provided the project supervision, advice on targeting, and support to pursue and complete the Marxan project, with much support from Mark Sheridan A/Senior Marine Information Officer as supervisor of the production of this report. The administrative support of Dale Harvey and Melinda Cartner is also gratefully acknowledged!

Analysis and discussion of the results and of the use of Marxan in the WA marine conservation reserve planning context involved all the staff of Planning and Marine Information Sections of the Department of Environment and Conservation Marine Policy and Planning Branch, with the assistance of scientific staff of the DEC Marine Science Program.

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Ray Lawrie
Judy Zuideveld
Michael Higgins
Leanne Thompson
Matt Fossey
Mark Sheridan
Chris Nutt
Barb Green
Dr Fran Stanley
Dr Chris Simpson
Kev Bancroft
Dr Bob Prince

Advice on data inputs and targeting was sought from other scientists and experts, as well as advice on the usage of Marxan from University of Queensland researchers:

Dr Ian Eliot (Damara Pty Ltd)
Dr Kellie Pendoley (Pendoley Environmental)
Dr Romola Stewart (University of Queensland)
Dr Lindsay Kircher (University of Queensland)
Matthew Watts (University of Queensland)
Dr Trevor Ward (MPRA, Greenward Consulting)
Daniel Beaver (WWF)

An informal workshop was held to discuss the use of Marxan in other DEC planning areas, on 16th June 2010. Discussions held during this workshop informed many of the conclusions in this report. Participants were:

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Liesl Ludgerus (Marine Policy and Planning)
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Geoff Barrett (Swan Region)
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Front cover photograph of an Osprey in the skies above the Great Sandy Islands by Chris Nutt, DEC.

EXECUTIVE SUMMARY

This report documents the set-up, implementation and key results of the Pilbara/Eighty Mile Beach (PEMB) Marxan project 2008-2010, and discusses the benefits and limitations of using Marxan in the PEMB process, and in potential future applications.

In December 2006, the then- WA Government announced its commitment to expand the marine conservation reserve system in the Pilbara and lower west Kimberley (Eighty Mile Beach) regions as part of its consideration of environmental mitigation and offset measures associated with the proposed Gorgon Gas development on Barrow Island Nature Reserve. New marine parks and reserves in the Pilbara and Eighty Mile Beach region would preserve representative and special marine ecosystems and improve protection for marine environmental values at most risk from the proposed Gorgon Gas development, particularly flatback turtles.

DEC Marine Policy and Planning Branch adopted a systematic planning approach in selecting and designing new marine conservation reserves in the Pilbara and Eighty Mile Beach region. This included the development of upfront goals and objectives to reflect Government and community aspirations and to guide reserve planning and development of an outcome-based draft indicative management plan which incorporates a framework for a periodic management audit. The use of systematic reserve planning software, Marxan (Ball *et al.* 2009) was trialed, to investigate the practical requirements of implementing Marxan in a regional reserve planning process and to assist in the PEMB reserve design.

The PEMB Marxan project described in this report used available broadscale habitat mapping data, and data on turtle nesting beaches and regionally significant mangrove areas for an objective regional assessment of these ecologically important areas in the region. Due to data, time and resource limitations, socio-economic and cultural information was not included, other than the inclusion of existing or existing proposals for marine conservation reserves and the exclusion of existing ports and industrial marine tenure. Conservation feature targets were determined based on broad guidelines of representation of marine habitats available in the literature, and modified upon review and consultation with marine science experts.

The main result of the PEMB Marxan project was the analysis of ecologically important areas, based on the input data and targets, represented by Marxan's output of summed irreplaceability of planning units. The number of times a planning unit (area) was selected as part of a successful Marxan reserve output helped to highlight areas that were the most important for the achievement of several planning objectives able to be included in the Marxan analysis. Marxan was also useful for post-analysis of proposed reserve designs against the input data and conservation targets, to show which conservation features were or were not adequately represented in the proposed design/s. Marxan results were used in conjunction with other information from stakeholders and scientists in the production of the proposed reserve designs in the draft Indicative Management Plan of June 2009.

Marxan was useful in the analysis of ecologically important areas for the PEMB planning process, but the results need to be considered in the context of the limited data, targets and costs input into the Marxan analysis. A Marxan problem set is essentially a model of a reserve planning process and is highly dependent on the input data. As such, it follows that analyses that include more representation of reserve design criteria and operational objectives and with higher quality and more detailed information to support targeting and costing will represent the real world situation more closely. Therefore the results of those analyses would be more instructive in eventual reserve design.

The set-up and implementation of a Marxan analysis is technically challenging and requires a relatively high degree of GIS skill and computer literacy. There is much support amongst the international Marxan user community via a mailing list that acts as a general forum for questions and problem solving, and the Marxan development team based at the University of Queensland provide excellent training and support for the software. However, the technical glitches, complex geoprocessing tasks and high requirement for documentation of data processing and results analyses that are a normal part of GIS require extra resourcing when combined with a Marxan analysis.

Marxan is a highly valuable tool for objective analysis of the multiple objectives in marine planning, and if properly implemented should lead to more efficient reserve design that minimises impacts on existing users whilst ensuring the achievement of conservation objectives. It captures the key elements of marine planning processes within an objective mathematical function that can deal with multiple objectives and supply many planning options rapidly. However, the success of a Marxan-based planning process,

including the suitability of the output reserve solution options, and their acceptance by stakeholders and government relies on adequate resourcing of data development, data management, target setting and stakeholder consultation throughout the process. If structured carefully, a Marxan-based planning process may not necessarily require significantly more resources than other planning methods, but would certainly not require less. It is not a 'magic bullet' for the complex task of marine protected areas planning, and it does not provide 'the answer' but if properly implemented, has the capacity to add to the scientific rigour and stakeholder acceptance of reserves, and to ensure the achievement of conservation objectives in a multiple-stakeholder situation.

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1 INTRODUCTION

This report is intended to provide a thorough technical summary of the development of the Pilbara/Eighty Mile Beach (PEMB) Marxan project and its implementation in the broader Pilbara and Eighty Mile Beach marine reserve planning process. The PEMB Marxan project was the first time that systematic reserve planning software had been trialled as an integrated part of a Department of Environment and Conservation (DEC) marine reserve planning process. This report summarises the use of Marxan in the PEMB planning process, the results of the Marxan analyses and concludes with recommendations for the future usage of Marxan, or other systematic reserve planning decision support software.

1.1 Marine Conservation Reserves in WA

The Western Australian (WA) Government is committed to the establishment and management of a world-class system of marine conservation reserves to preserve representative as well as special marine ecosystems and provide a formal management framework to ensure human uses of marine parks and reserves are managed in an equitable, integrated and sustainable manner. The WA system of comprehensive, adequate and representative multiple use marine conservation reserves contributes to the National Representative System of Marine Protected Areas (NRSMPA) which helps fulfil several of Australia's international agreements and obligations relating to biodiversity conservation.

Marine conservation reserves in WA are established under the *Conservation and Land Management Act 1984* (CALM Act), vested in the Marine Parks and Reserves Authority (MPRA) and managed by the Department of Environment and Conservation (DEC). DEC collaborates closely with the Department of Fisheries which also has significant management responsibilities in marine conservation reserves. Management of marine conservation reserves is not done in isolation, but as part of a complementary suite of management tools implemented by other agencies such as Department of Fisheries, Department of Transport, Department of Planning, Department of Mines and Petroleum, Department of Indigenous Affairs, Office of Native Title, Department of Tourism and WA Museum which also have responsibilities within or adjacent to marine conservation reserves.

New marine conservation reserves are developed under a risk-assessment framework and using an outcome-based management approach which includes an assessment of the values, pressures and knowledge of the marine environment and the development of management objectives, strategies, targets and performance measures for important ecological and socio-economic values. In addition to active-adaptive management of marine conservation reserves, the WA Government is also committed to open and extensive consultation with the stakeholders and the community in the development of new marine conservation reserves as is embedded in the CALM Act.

1.2 Background to the Proposed Pilbara & Eighty Mile Beach Marine Parks

In December 2006, the then- WA Government announced its commitment to expand the marine conservation reserve system in the Pilbara and lower west Kimberley (Eighty Mile Beach) regions as part of its consideration of environmental mitigation and offset measures associated with the proposed Gorgon Gas development on Barrow Island Nature Reserve. New marine parks and reserves in the Pilbara and Eighty Mile Beach region would preserve representative and special marine ecosystems and improve protection for marine environmental values at most risk from the proposed Gorgon Gas development, particularly flatback turtles.

In July 2007, DEC commenced a resource assessment and data gathering project to provide the necessary ecological and socio-economic information for the development of a network of marine conservation reserves in the region and the development of an indicative management plan including zoning scheme. Both spatial and non-spatial information was gathered from many sources including other Government agencies, universities and private industry. A habitat survey of key study areas was undertaken to provide a base level of information on benthic habitats for use in the planning process. Meetings were held with scientists to verify information for specific ecological values, including marine turtles. A bibliography of literature relevant to the study areas for proposed marine parks was developed, spatial data was collated into DEC's Marine Information System and a summary of known information on the values and uses in the region was recorded in a draft resource assessment summary.

A Government Interagency Working Group (IWG) was established to ensure a whole-of-Government approach and support was achieved. The IWG assisted in gathering spatial and non-spatial information on human usage and statutory Government responsibilities in the region. The IWG comprised representatives from DEC, Department of Fisheries, the then Department of Industry and Resources, the then Department for Planning and Infrastructure, Office of Native Title, Department of Indigenous Affairs, WA Tourism and WA Museum.

An Aboriginal engagement program was undertaken to ensure an appropriate level of engagement with Aboriginal people. DEC worked closely with the Department of Indigenous Affairs, Office of Native title and native title representative bodies and working groups. Similarly a fishing consultation group was established to assist in understanding issues associated with fishing and collating fishing information on appropriate scales for use in zoning discussions. A broader community engagement program comprised a series of community information sessions in local communities and meetings with key stakeholders. The information obtained during these engagements was valuable in providing local knowledge to support developing an appropriate system of marine parks in the region.

1.2.1 PEMB planning process flowchart

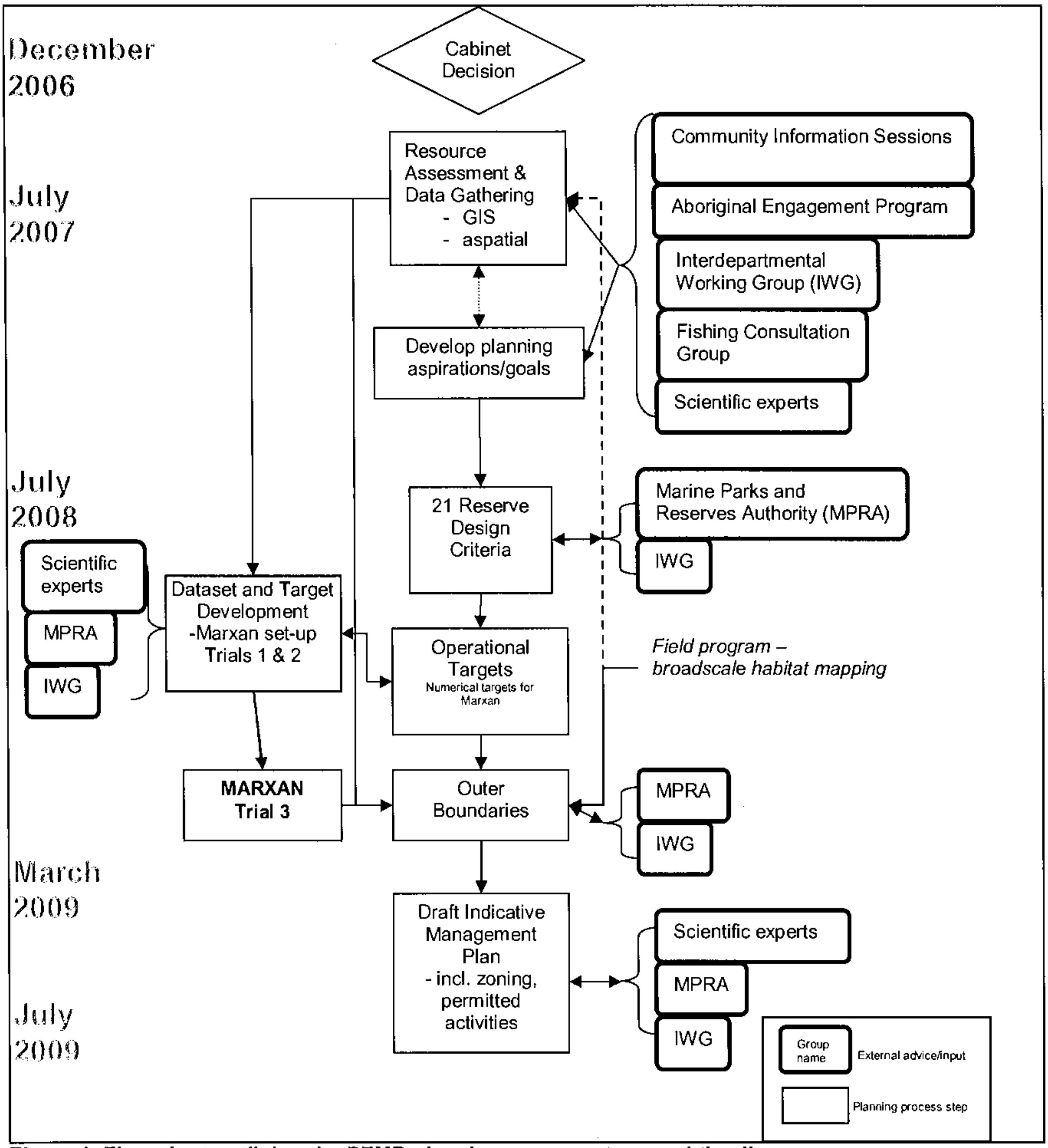

Figure 1: Flow chart outlining the PEMB planning process steps and timeline.

1.3 Applying systematic planning in the Pilbara and Eighty Mile Beach process

DEC Marine Policy and Planning Branch adopted a systematic planning approach in selecting and designing new marine conservation reserves in the Pilbara and Eighty Mile Beach region. This included: development of upfront goals and objectives to reflect Government and community aspirations and to guide reserve planning; the use of Marxan to identify 'irreplaceable areas' and assess achievement of goals; and development of an outcome-based draft indicative management plan which incorporates a framework for a periodic management audit.

Early in the planning process, a planning framework was developed in collaboration with the IWG to provide strategic direction for the planning process. DEC, in liaison with the MPRA and IWG, developed 21 ecological and socio-economic principles to guide the selection and design of marine conservation reserves in the Pilbara and Eighty Mile Beach region. The design principles reflect the primary goals of the WA system of marine conservation reserves for conservation while providing opportunities for commercial and recreational use where appropriate. The ecological principles are consistent with those identified for the NRSMPA and are aspirations of reserve design which when implemented will work towards achieving comprehensive, adequate and representative marine conservation reserves. The socio-economic principles were developed to ensure marine conservation reserves where appropriate provide opportunities for compatible commercial and recreational uses and to ensure reserves complement existing human uses, Aboriginal interests and community aspirations. These 21 principles are summarised as reserve design criteria in Table 1.

Rapid acquisition, assessment and development of spatial data was undertaken including meetings with scientists, Government agencies and key stakeholders (including local people) and a risk assessment was undertaken by DEC to identify values, pressures and gaps in current knowledge of biodiversity in the region. Based on the available data and reserve design criteria, spatially explicit targets were developed for use in Marxan and reserve design scenarios were iteratively developed. The final selection of reserve boundaries was developed using the reserve design scenarios, habitat ground-truthing data collected in a field survey additional human usage information collected during the IWG and community engagement, and expert scientific advice. A review of the achievement of targets was conducted.

DEC in liaison with the IWG and MPRA developed an outcome-based draft indicative management plan which includes reserve boundaries and zoning, management objectives, strategies, targets and performance measures and incorporates a framework for periodic management auditing.

Table 1: Reserve design criteria for the Pilbara and Eighty Mile Beach Marine Parks and Reserves planning process. Note that these criteria are divided into 'Ecological' and 'Socio-economic' criteria. Shaded criteria are those that are considered to be at least partially represented within the Marxan analyses presented in this report.

Design criteria	Principle & explanation
Ecological	
1. Represent examples of each ecosystem within each bioregion in marine parks and reserves*.	**Comprehensiveness.** The full range of ecosystems at an appropriate scale within and across the marine bioregions should be included in marine parks and reserves. The bioregions described by the *Interim Marine and Coastal Regionalisation for Australia* (IMCRA) are the recognised classification units within which marine parks and reserves should be established, with ecosystems used as the basis for determining comprehensiveness.
2. Represent examples of the main marine habitats, flora and fauna of each bioregion in marine parks and reserves.	**Representativeness.** The marine flora and fauna of each IMCRA bioregion should be represented in marine parks and reserves. Marine parks and reserves should reasonably reflect the biotic diversity of the marine ecosystems from which they are derived i.e. local marine habitats, flora and fauna.
3. Represent longitudinal and cross-shelf (where necessary) diversity in marine parks and reserves.	**Comprehensiveness and representativeness.** Recognising the length and width (predominately intertidal in some areas) of the study area, representative examples of the longitudinal and cross-shelf diversity should be included in marine parks and reserves. This reserve design criteria recognises the nature of population dynamics that not all habitats are equal across the study area (e.g. seagrass diversity in the east and west may be very different).
4. Have 'adequate' no-take areas** in all marine parks and reserves.	**Adequacy and no-take areas.** Adequacy means having the required level of reservation to ensure the ecological viability and integrity of populations, species and communities. No-take areas are integral for biodiversity conservation in marine parks and reserves. No-take areas assist with resilience, persistence, minimum viable population, connectivity and risk management. No-take areas also provide relatively undisturbed areas to monitor and assess the performance of the marine parks and reserves system as well as areas for nature appreciation and low impact recreation and tourism activities. Adequacy refers not only to size and representativeness of no-take areas but also their replication and configuration across the region.
5. Have a preference for larger versus smaller no-take areas, however flexibility will need to be maintained.	**Adequacy.** The long term integrity of an area increases with increased size. As such, increased reserve size is likely to produce increased conservation benefits. Larger no-take areas minimise edge effects, the influence of external impacts, and the risk of failing to implement a comprehensive, adequate and representative reserve system. However, in marine conservation planning, flexibility is required to allow for limitations (such as costs/benefits where available conservation area is small).
6. Maximise replication of no-take areas within marine parks and reserves	**Replication and precautionary principle.** Replication of no-take areas within marine parks and reserves minimises the risks that reserves may not represent important components of biodiversity or fail to provide adequate protection to ensure long-term viability. Such risks are generally associated with inadequate knowledge of biodiversity and data deficiencies. Replication adds a measure of insurance. The precautionary principle means that the absence of scientific certainty should not be a reason for postponing measures to establish marine parks and reserves to protect ecosystems and decision making should proceed in a manner that provides safeguards for marine ecosystems.
7. Have a preference for including 'whole systems' rather than 'part systems' in no-take areas.	**Adequacy and representativeness.** Ecological function and integrity is more likely to be maintained by including whole systems (e.g. reefs, mangrove communities) rather than parts of systems within no-take areas. Adequacy and representativeness are maximised.
8. Represent examples of outstanding naturalness and preferentially include undisturbed ecosystems and habitats in marine parks and reserves.	**Naturalness and scientific interest.** Marine parks and reserves should include areas that display outstanding naturalness, amenity or cultural landscape values. Representing undisturbed areas generally assists with maintaining ecosystem integrity. Undisturbed areas are required to monitor and assess the performance and adequacy of the marine parks and reserves system.
9. Represent biophysically special and/or unique areas and rare and/or endemic species in marine parks and reserves.	**Uniqueness, productivity and scientific interest.** Inclusion of special, unique, rare and endemics will ensure that comprehensiveness and adequacy principles are maximised to protect biodiversity. This includes areas and habitats with unusually high levels of biodiversity (i.e. species richness), rarity (i.e. numbers of rare species), and uniqueness (i.e. endemism richness).
10. Represent habitats or areas on which species or other systems depend in marine parks and reserves.	**Ecological importance and productivity.** Marine parks and reserves should aim to protect habitats or areas on which other species or systems depend to ensure integrity of the ecosystem as a whole. This can include important areas for migratory species or economically important species (e.g. nursery, spawning, feeding, breeding and resting areas) as well as habitats that contribute to the productivity of the system without which other species would not persist (e.g. mangrove, seagrass and coral communities).
11. Represent critical habitat for turtles and other vulnerable, threatened, rare or endangered species in marine parks and reserves.	**Ecological importance.** Marine parks and reserves should provide for the needs of vulnerable, threatened, rare or endangered species. This can include feeding, nesting, resting and aggregation areas.
12. Provide for ecological connectivity in the configuration of marine parks and reserves.	**Adequacy and connectivity.** Providing for ecological connectivity helps to maintain the integrity and resilience of ecosystems and minimises the risks of failing to protect important relationships for maintaining biodiversity. This criteria provides for the complex connectivity between the land and sea as well as connectivity between State and Commonwealth waters. Connectivity is particularly important in areas with large tidal ranges where species move in and out of Commonwealth waters on a daily basis.
13. Recognise the contribution of existing marine parks and reserves in the region the other criteria and attempt to create an effective and compact reserve system.	**Efficiency and complementarity.** One of the distinctive characteristics of systematic planning is that it recognises the extent to which conservation goals have been met in existing reserves. This results in 'efficient' marine parks and reserves. The biodiversity values represented in existing and proposed marine parks and reserves in the regions (i.e. Montebello/Barrow islands and Dampier Archipelago/Regnard) should be considered in the selection of new marine parks and reserves in the region and the reserve design process should aim for effective and compact reserves.

Design criteria	Principle & explanation
Socio-economic	
14. Maximise complementarity of marine parks and reserves to Indigenous and broader community access, activities, values and aspirations.	**Social and Indigenous importance and practicality/feasibility.** Marine parks and reserves should aim to complement existing community access, activities, values and aspirations. Complementarity can be achieved through no-take area configuration and other types of zones as well as agreement of strategies with the community. Best achieved through a participatory planning approach, complementarity can greatly assist with creating community support and ownership which can later result in self-enforcement. Indigenous access, activities, values and aspirations should be considered specifically and in a manner that recognises Native Title rights, past and future use, contemporary Aboriginality and caring for country aspirations.
15. Provide opportunities for Indigenous use within marine parks and reserves (where appropriate).	**Indigenous importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes indigenous uses and interests which should be considered specifically and in a manner that recognises Native Title rights, past and future use and contemporary Aboriginality. Providing opportunities could include specific zones or strategies that recognise Indigenous use.
16. Provide opportunities for commercial use within marine parks and reserves (where appropriate).	**Social importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes commercial uses and interests. Providing opportunities could include specific zones or strategies that recognise commercial use.
17. Provide opportunities for recreational use within marine parks and reserves (where appropriate).	**Social importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes recreational uses and interests. Providing opportunities could include specific zones or strategies that recognise recreational use.
18. Provide for the preservation of any feature of archaeological, historic or scientific interest within marine parks and reserves.	**Social and indigenous importance.** Consistent with the purposes in the CALM Act, marine parks and reserves should provide protection for features of archaeological, historic or scientific interest.
19. Provide for Indigenous participation and joint management.	**Indigenous importance.** Marine parks and reserves should create opportunities for Indigenous uses and values (criteria 15) and maximise complementarity to Indigenous access, activities, values and aspirations (criteria 14). Marine parks and reserves should also provide opportunities for Indigenous people to participate in management of country and receive benefit from management (e.g. protection of important sites, economic development, capacity-building, training and employment). Indigenous participation is crucial to success and effectiveness of marine parks and reserves. Joint management options should be explored and options developed with Indigenous people.
20. Maximise complementarity of marine parks and reserves management with adjacent tenure and management arrangements (both existing and future).	**Economic and social importance and practicality/feasibility.** Where possible and appropriate, marine parks and reserves should complement other tenure and management arrangement within and adjacent to the marine parks and reserves. In particular, within WA Government (e.g. Department of Fisheries, Department of Industry and Resources, Department for Planning and Infrastructure, WA Tourism) and cross-jurisdictional (e.g. Northern Territory and Commonwealth). Complementary management arrangements should assist in providing an integrated approach.
21. Zoning should be simple for people to understand and easily enforceable.	**Practicality/feasibility.** Marine parks and reserves zoning should be simple for people to understand and easily enforceable. This could include: a preference for straight boundaries along definable latitudes/longitudes; using headlands, reefs and other definable sites as boundary markers; including whole physical structures (i.e. reefs, creeks etc). Practicality of implementing the zoning scheme is an important factor in the success of marine parks and reserves. Consideration should also be given to remoteness of proposed reserves and existing nodes of management in respect to ease of enforcement and management.

1.4 Systematic planning with Marxan

Systematic reserve planning is the open and transparent process of designing reserves that best achieve clearly stated objectives. One of the distinctive characteristics of systematic reserve planning is that it is an open, defensible and flexible process of selecting proposed reserve areas that complement existing reserve areas. Thus, an important characteristic is the ability to recognise the extent to which conservation goals have been met in existing reserves which results in complementary and efficient marine reserves. The most important feature of any systematic reserve planning process is the clearly stated objectives and the assessment of different potential reserve areas against these objectives to achieve a cost-effective reserve design while meeting the objectives.

While systematic reserve planning can be as simple as the establishment of reserve design criteria with clearly identifiable and measureable goals, more recently it involves the use of decision support tools which use computer based algorithms and spatial software to achieve spatially explicit objectives. Benefits of using decision support tools include the objectivity of computer-based computations of complex reserve design issues, and the speed with which a number of planning options can be produced; however, draw-backs can include the heavy reliance on high quality data in a data-poor planning environment, and on the difficulty of translating planning aspirations into numerical targets required for such objective analyses.

Marxan systematic reserve planning software (Ball *et al.* 2009) was chosen for the planning exercise, as it is a reserve planning tool commonly used worldwide, and has been used in several comparable marine reserve planning processes or reserve assessments in Australia (Great Barrier Reef Marine Park, analyses of the South Australian Marine Reserve network and Rottnest Island Marine Park). Furthermore, a substantial knowledge base exists in a broad and active Marxan user community engaged in marine and terrestrial reserve planning around the world, with the development team based at the University of Queensland.

Staff members of the DEC Marine Policy and Planning Branch and Marine Science Program attended training sessions run by members of the Marxan development team (Dr Romola Stewart and Matthew Watts), and in 2006 the CALM Marine Branch (precursor of the DEC Marine Policy and Planning Branch) provided assistance to Dr Romola Stewart to run a hypothetical case study on marine reserve planning for the Rottnest Island Marine Park. Thus the PEMB planning team had a thorough conceptual and practical understanding of systematic planning with the Marxan software.

Marxan objectively calculates a user-defined number of near-optimal solutions to a reserve planning problem that achieve stated conservation goals whilst minimizing the cost (e.g spatial cost, financial cost of acquisition or exclusion of existing activities/industries, etc) of the reserve solutions, according to the *objective function*. The objective function is calculated for a reserve configuration before and after a random change to that configuration is made. If the resultant objective function score is better (smaller) than before the change, then the change is kept, and another is made. Thus reserves develop iteratively towards an efficient optimum. This report assumes a basic level of understanding of the Marxan analytical method. More detail about the Marxan algorithm is found on the University of Queensland development team's website http://www.uq.edu.au/marxan/ or from the *Marxan User Manual* (Ball and Possingham 2000).

Resultant reserve cost (or score) =
∑PUs*Cost* + ∑PUs*Boundary x BLM* + ∑ConsFeat*Penalty x SPF* + *CostThresholdPenalty*

Where:

- **∑PUs*Cost*** is the total sum of the cost of the areas (Planning Units) selected in the reserve solution. The cost for each planning unit can be user assigned for specific PUs, or calculated based on PU areas or any other datasets using GIS methods.
- **∑PUs*Boundary x BLM*** is the sum of the outer boundaries (perimeters) and inner boundaries (i.e. 'donut' inner perimeters) of areas selected as part of a reserve network solution. *BLM* refers to a scaling factor, the Boundary Length Modifier, which can be adjusted by Marxan users to multiply the 'cost' of having large outer boundaries relative to reserve areas. Thus the Marxan system can be skewed towards a preference for fewer, larger areas (smallest boundary cost) vs more smaller areas (higher boundary cost), given that all conservation targets are achieved, and the acquisition cost of the reserve area is minimised. By increasing the BLM, 'donut holes' in potential solutions can be forced to fill in, as the increased cost of adding the required planning units to fill the hole is

reduced relative to the cost of adding the internal hole boundary length (multiplied by the BLM) to the resultant reserve cost of that solution.

- **∑ConsFeat*Penalty x SPF*** is the base penalty for non-achievement of a conservation feature target, calculated as the minimum cost required to achieve the target. This penalty in effect adds a cost to the reserve score so that it costs more to fail to achieve a target than it does to achieve it by adding more areas, and therefore more **PUs*Cost***. The *SPF* is a species-specific multiplier of the base penalty factor of the species. Thus by manipulating the SPF of a species, users can either provide flexibility to the system by not penalizing for failing a target, or they can force 100% achievement of the target by creating a very large penalty for non-achievement.

- ***CostThresholdPenalty*** allows the user to add an additional cost penalty to the system for exceeding a threshold level of **∑PUs*Cost***. For example, if a certain amount of money was available for purchasing land for conservation, and property prices contributed to **PUs*Cost***, then creating a high ***CostThresholdPenalty*** would help force the system to achieve conservation goals within the threshold value for **∑PUs*Cost***.

1.5 Resourcing of Marxan implementation

In addition to the Planning and GIS team members engaged in the PEMB process, one staff member was employed full-time (1 FTE) for 6 months of the project, and an additional 3 months of part-time (0.2 FTE) to focus specifically on implementing Marxan for the PEMB process.

Supervision and guidance for Marxan data management was provided by the Senior Information Officer, data management and Marxan implementation support by the Project Officer (GIS), and advice on the translation of the PEMB operational targets and planning policies into Marxan terms by the Marine Conservation Officer (Planning).

Table 2: Staff roles in the Pilbara and Eight Mile Beach planning process, including 1 FTE specifically for Marxan implementation.

Staff Position	Role	**FTE**
Principal Marine Planner	Lead Planner	**1**
Marine Conservation Officer (Planning)	Planning Officer	**1**
Marine Conservation Officer (Planning)	Indigenous Engagement Program	**1**
Senior Marine Information Officer	Data gathering, management and planning support	**1**
Project Officer (GIS)	Data management and planning support	**1**
Marine Conservation Officer (GIS)	**Marxan Implementation**	**1 (6 months) + 0.2 (3 months)**

No additional operational funding was provided for the implementation of Marxan for the PEMB process. Meetings and data gathering that supported the Marxan project were generally undertaken as part of the broader planning process.

2 DATA PREPARATION AND MARXAN SET-UP

MARXAN requires several input files to be created specifically for the analysis problem, derived from files designed and/or calculated using Geographic Information Systems (GIS) to supply the data required for the calculation of the objective function. The various GIS files were prepared for this project primarily using ESRI ArcGIS 9.1 and on occasion, where particular processing tools or methods were better suited, ESRI ArcView 3.2. The raster processing extension *Spatial Analyst* was required for some processing tasks.

The Marxan input files reflect the reserve planning study area, planning objectives, reserve design criteria and available spatial information describing the distribution of features, habitats, species or human uses to be considered. The input files are designed to allow computationally efficient calculations of the objective function score of reserve solutions. The following brief descriptions of the Marxan input files are provided for the context of this report, for detailed descriptions and discussions of the various input files and their parameters, refer to the *Marxan User Manual* (Ball & Possingham 2000) and *Marxan Good Practices Guide* (Ardron et al 2008).

Table 3: Explanation of parameters of the Marxan objective function, and their application through the Marxan Input Files.

Objective Function (a.k.a. Resultant reserve Cost, *or* Score) =
∑PUs*Cost* + ∑PUs*Boundary x BLM* + ∑ConsFeat*Penalty x SPF* + *CostThresholdPenalty*

Objective function parameter	Parameter explanation	Application in Marxan Input Files
∑PUs*Cost*	Sum of total reserve solution 'planning unit cost', the inherent cost of each individual PU in the reserve configuration.	The 'cost' of each PU is determined by GIS calculation or direct assignment by the user, based on conceptual costs relevant to the planning exercise. This cost is then listed against each PU in the ***Planning Unit File***.
∑PUs*Boundary x BLM*	The total sum of all of outer (and inner, if holes exist) boundaries of all of the areas included in a resultant reserve configuration.	The length of the boundary between each PU and its neighbour are determined by GIS calculation or direct assignment by the user. These lengths are described for each pair in the ***Boundary Length File***. For a given reserve configuration, the boundary length between reserved and non-reserved PUs are summed to provide **∑PUs*Boundary***. The ***BLM*** (Boundary Length Modifier) is a scaling factor that the user can apply at the time of running a Marxan scenario, to emphasize or minimise the effect of **∑PUs*Boundary*** in the total resultant reserve cost (objective function cost).
∑ConsFeat*Penalty* x *SPF*	Cost penalty applied to the resultant reserve score, for non-achievement of the conservation targets. If all targets are 100% achieved, no **∑ConsFeat*Penalty*** is added to the reserve score – i.e. the configuration will cost less and be more favourable. If a conservation feature target is 0% achieved, the cost of the minimum set of PUs that would provide the target are added to the score, multiplied by the ***SPF*** (Species Penalty Factor). The relative proportion of the penalty is applied for the respective percentage of target achievement.	The amount of each conservation feature present in each PU is calculated by GIS, and listed in the ***Conservation Feature File***. Thus, the amounts of the different conservation features in a potential reserve configuration can be calculated, by summing the amount of each conservation feature in all PUs in that configuration. The ***SPF*** can be modified for each conservation feature as required, to make the calculation of the **∑ConsFeat*Penalty*** higher, which makes it cost more for non-achievement of the targets, or lower, to cost less and potentially allowing less achievement of the targets. Targets for each conservation feature, and the ***SPF*** of each conservation feature, are determined by the user and contained in the ***Species File***. Targets are usually determined according to the reserve design planning principles. ***SPF*s** are determined through an iterative calibration process to find values of ***SPFs*** required to force a change in their achievement, when balanced against the other costs calculated for the resultant reserve configuration.
CostThresholdPenalty	Adds an additional cost penalty to the resultant reserve score, if a threshold **∑PUs*Cost*** value is exceeded.	If there are constraints to how much the total **∑PUs*Cost*** can be, such as the amount of funding available for land purchase or other financial compensation, this threshold value and the penalty can be assigned at the time of running a Marxan scenario. This provides the constraint to the objective function algorithm that reflects this constraint in the planning scenario.

2.1 PEMB Planning Unit File

A Marxan Planning Unit File is derived from a GIS layer describing the planning study area, and dividing this area into spatial planning units of a user-determined shape and size, which form the basis for the cell-based calculations used in the iterative optimisation processes of the Marxan software. Each planning unit is assigned a unique identifying number and a number of other attributes including whether it is available for reservation (available, not available, already reserved or in an initial 'seed' reserve) and a conceptual or real 'cost' of that planning unit. The cost may be expressed in financial terms (examples are a real or conceptual cost of acquisition, cost of ceasing an economic activity such as fishing, cost of managing for conservation), or in terms of spatial cost (area) cost or any other relevant concept of 'cost' of reservation.

Example of a PEMB Planning Unit File:

```
id    cost  status
1     4     2
2     4     2
3     4     2
4     3.99  2
5     4     2
6     4     2
....
```

2.1.1 Study Area

Initially, the study areas for the network of reserves were focused on several areas of particular importance for the conservation of flatback turtle nesting sites, as part of an offset package for the (then) proposed Gorgon Gas Joint Venture project.

In keeping with several of the reserve design criteria regarding comprehensiveness, adequacy and representativeness (see *Reserve Design Criteria* in Table 1), these initial study areas were broadened to include all state coastal waters of the Eighty Mile Beach (EMB) and Pilbara Inshore (PIN) Integrated Marine and Coastal Regionalisation of Australia (IMCRA) Bioregions. At the time of planning, these Bioregions were considered to be under-represented in the conservation estate, with no established marine reserves in EMB, and two reserves in PIN in planning stages – the Proposed Dampier Archipelago Marine Park, and Proposed Regnard Marine Management Area. These two proposed MPAs were included in various planning scenarios as described in more detail below (Section 2.1.2 Marxan planning scenarios – a planning unit's status).

The Pilbara Offshore (PIO) IMCRA Bioregion was also included in analyses and eventual reserve network design, to ensure that the final reserve configuration would complement existing marine protected areas already established in the PIO – the Muiron Islands Marine Management Area, the Barrow Island Marine Park and Montebello Islands Marine Park. The inclusion of these existing, neighbouring marine reserves into the planning unit file allowed the Marxan analysis to address the reserve design criteria of efficiency and complementarity with existing conservation reserves.

In order to reflect the study area and broad goals of the planning process, the Marxan Planning Unit GIS layer was determined according to the following criteria –

The planning unit file should be bounded by:

- WA Coastal Waters (nominal 3 nm offshore limit AMBIS boundary);
- The Pilbara Offshore (PIO), Pilbara Inshore (PIN) and Eighty Mile Beach (EMB) Integrated Marine and Coastal Regionalisation of Australia (IMCRA) Bioregions;
- The best available mapping of High Water Mark (Landgate);

And that the planning unit file should:

- Include Cabinet submission Pilbara/Eighty Mile Beach (Gorgon offset) focus areas;
- Include planning units of an appropriate regional scale for marine reserve network outer boundary planning;
- Reflect the desire for reserve boundaries to generally align with definable north-south and/or east west latitudes and longitudes;
- Include existing marine tenure such as Port Authority or State Agreement Act area boundaries;

- Include existing and proposed Marine Protected Area boundaries (Ningaloo Marine Park, Muiron Islands Marine Management Area, Barrow Island Marine Park, Montebello Islands Marine Parks and Proposed Dampier Archipelago Marine Park and Regnard Marine Management Area);
- Include existing nature reserve boundaries (primarily island nature reserves) that are gazetted to low water mark as providing existing protection for intertidal areas.

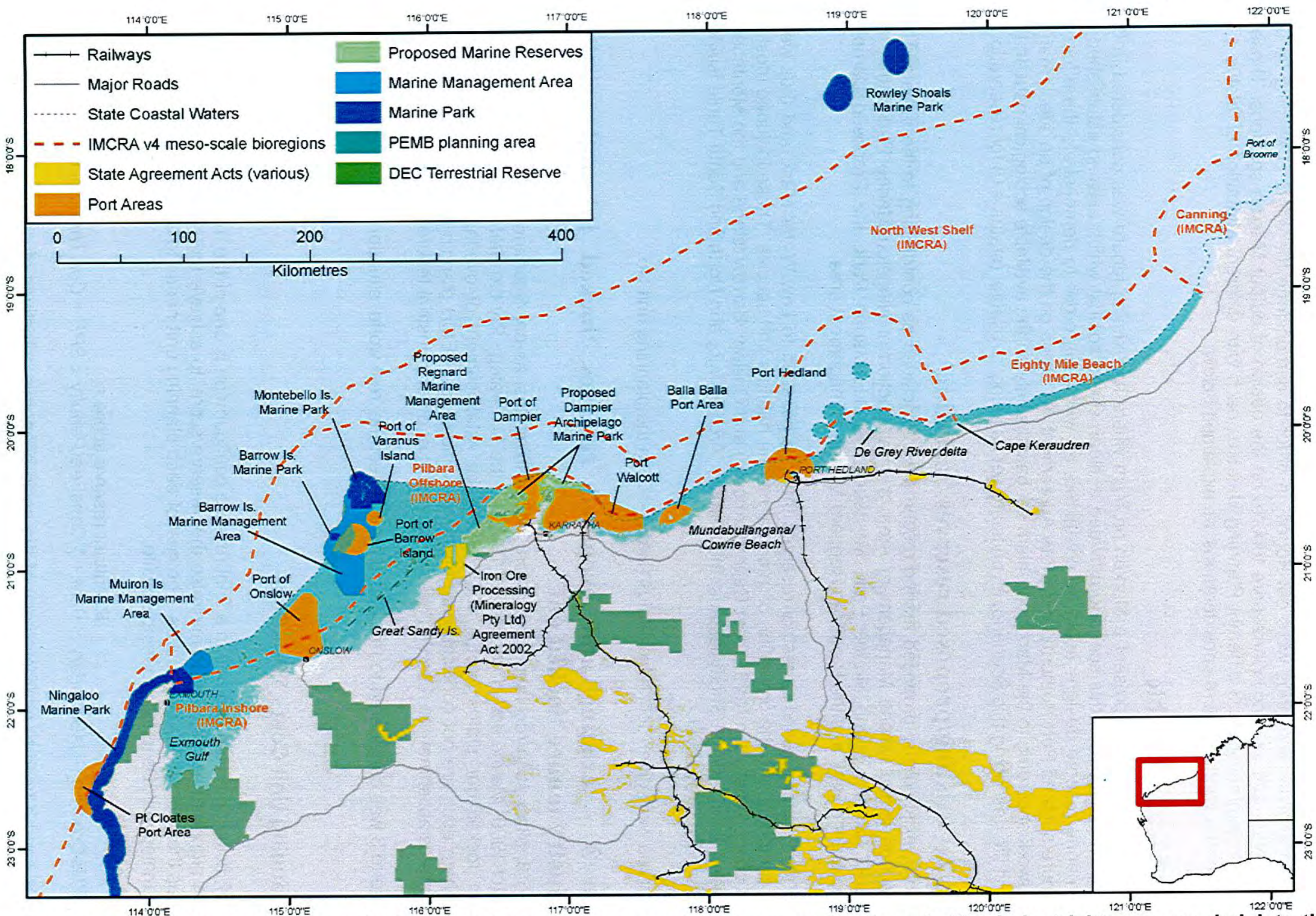

Figure 2: Regional setting of the planning area, including existing and proposed reserves, and ports and other industrial tenure or administration areas.

2.1.2 Marxan planning scenarios – a planning unit's status

Three Marxan analysis scenarios were developed, in order to demonstrate the effect of existing tenure (existing reserves, and existing non-reserve tenure) on the design of output Marxan solutions. These 3 scenarios were expressed as 3 different Planning Unit files each with different attribution of 'status' (i.e. availability) for the various tenure considerations, as explained below.

Scenario 1 – all available

Scenario 1 was designed to present a Marxan problem where no existing tenure was considered in the (hypothetical) process. Thus this scenario provided a 'clean sheet' against which existing established or proposed marine reserve designs could be compared, as well as in order to demonstrate the effect of existing tenure such as Port Authority and State Agreement Act areas on the design of an 'ideal' marine reserve network according to the Marxan problem set based solely on the available ecological data. In the planning unit file describing this Scenario, all units are set as being 'available' (status = 0) for reservation.

Scenario 2 – existing/proposed reserves 'locked in'

In Scenario 2, existing and proposed marine reserves were included as contributing to the targets. This included Muiron Island Marine Management Area, a small section of Ningaloo Marine Park within the planning area, Barrow Island Marine Park, Montebello Islands Marine Park, the Proposed Dampier Archipelago Marine Park and the Proposed Regnard Marine Management area.

It also included several island terrestrial reserves that are gazetted to Low Water Mark, and thus were treated as contributing to the protection of intertidal marine habitats and species. These included most of the islands offshore between North-West Cape (Exmouth) and Onslow, Barrow Island and the Montebello and Lowendal Islands, Great Sandy Islands, the Dampier Archipelago, and North and South Turtle Islands offshore of the De Grey River.

These reserves were given 'locked in' status (status = 2) in the planning unit file.

Scenario 3 – existing and proposed reserves 'locked in' and existing port/industry tenure 'locked out'

In Scenario 3, all existing reserves were given 'locked in' status, as per Scenario 2, whilst existing *Port Authority Act* 1999, *Marine and Harbours Act* 1981and the Mineralogy Pty Ltd *State Agreement Act* areas were given 'locked out' status (status = 3). Whilst the establishment of overlapping tenure is legally possible where uses are not conflicting, a guiding principle of the PEMB planning process was to avoid proposing the establishment of reserves over existing port or other industrial tenure/usage areas.

Thus Scenario 3 was considered to most accurately reflect the 'real world' situation of the PEMB planning process.

2.1.3 Planning Unit Cost - ∑PUs*Cost*

The cost of including a planning unit in a final reserve configuration is one of the main driving variables of the Marxan algorithm as it strives to minimise the 'reserve score' to achieve the smallest reserve design that satisfies the conservation objectives. The cost of each planning unit needs to be calculated and listed with the planning unit IDs in the planning unit file.

Resultant reserve score =
∑PUs*Cost* + ∑PUs*Boundary x BLM* + ∑ConsFeat*Penalty x SPF* + *CostThresholdPenalty*

These costs can be used to address many of the socio-economic objectives of a Marxan analysis, such as minimising impacts on existing social, cultural and economic uses, by ascribing a higher cost to the planning units where these activities occur. The Marxan objective function algorithm will then strive to avoid these areas, so as to reduce the total reserve system cost, whilst still achieving the conservation planning goals. By balancing penalties for non-achievement of targets with the real or perceived cost of acquiring more area for conservation, an optimal outcome can be approached.

Several potential sources of planning unit 'costs' of a reserve system were identified for the PEMB process:

- Spatial cost of the total area of reserves - generally, it is more desirable to have reserves that are as small as possible but which still provide the required measure of protection. Smaller reserves are less financially costly and easier to manage, and have less potential for socio-economic impact on extractive user groups.
- Financial cost – if reserves are situated well offshore or far from available permanent port or mooring sites for patrol vessels, then the cost of patrolling, monitoring and research of reserves will be higher than if close to regional maritime centres.
- Financial cost - if commercial fishing, pearling/aquaculture and oil and gas exploration/extraction were to be restricted by biodiversity conservation management strategies.
- Financial cost – if port or industrial activities were to be restricted by biodiversity conservation management strategies.
- Potential perceived social/political/financial cost if recreational activities such as fishing or island visitation were to be restricted by biodiversity conservation management strategies.

For the PEMB process, it was possible to describe some of these costs spatially and in qualitative terms, for example by using statistics describing the spatial distribution of fisheries catch and effort in the study area, oil and gas prospect assessments or lease value, pearling lease values, and other such data. In other cases, where the concept of cost is more qualitative, surveys of user groups and other such methods could have been used to generate a relative cost (whereby some areas are determined to be 'more important' than others, though this would not necessarily be quantified).

Such an exercise requires extensive and detailed consultation with user groups, and the ultimate quantification of the costs would have also required extensive negotiation between parties. For example the translation of the cost of potentially excluding access to oil and gas exploration and development, commercial fishing, recreational fishing and indigenous fishing would need to be balanced – which usage is the most important, and in what terms (social, cultural, economic)? How can they then be combined and expressed numerically, as required by the Marxan planning unit file? The constrained budget and timeframe available to undertake such assessments precluded a thorough inclusion of these costs to the Marxan system.

Additionally, as the proposed PEMB marine reserves were to be designed as multiple-use marine parks where existing recreational, social, cultural or economic activities are provided for, potential impacts on user groups would most likely only develop through management zoning planning later in the planning process, as the zoning scheme was developed through stakeholder consultation. Therefore the main driver of the reserve design optimization was simply to keep the reserves as small (ie. *efficient*) as possible, and so after a preliminary assessment of the likely costs and how they could be accommodated in an eventual reserve design, the calculation of 'costs' of each planning unit was set to be a simple spatial cost, derived from a GIS calculation of the planning unit areas.

2.2 PEMB Conservation Feature File

The Conservation Feature File – also known as the *species file* lists the conservation features to be targeted in the MARXAN problem, with their target values (as areas), penalty factors for non-achievement of targets, minimum clump size, minimum number of occurrences and others as described in Table 4.

Table 4: Conservation Feature file parameters.

Variable Name	Notes/Description
id	The ID number of the conservation feature. It must correspond to the planning unit versus conservation feature file.
type	Type is a user defined 'type' of conservation feature. It is used for 'block definitions'. For example, 'coral' or 'seagrass' conservation features may be assigned to the 'habitat' type.
target	The target amount for the conservation feature.
spf	The penalty factor for that conservation value.
target2	Minimum clump size. If a clump of a number of planning units with the given conservation feature is below this size then it does not count toward the target.
sepdistance	Minimum distance at which planning units holding this conservation feature are considered to be separated
sepnum	Target number of mutually separated planning units in valid clumps
name	The name of the Conservation Feature in words. Can include spaces, all words in name must start with a letter.
targetocc	The number of occurrences of the conservation feature required. This can be used in conjunction with or instead of 'target'.

The determination of the features or species (hereafter the term *feature* will be used to discuss either a feature, such as an area of habitat or a nest, or the species/group of interest) to be listed in the Conservation Feature File, and how they are to be targeted, is a crucial step in running a Marxan analysis. The combination of features and their targets, and the penalty for not achieving the targets need to reflect the objectives of the planning process. These objectives are rarely expressed in scientific or planning literature in the quantitative terms that Marxan requires, so there needs to be a process in place to set appropriate and defensible targets, or ranges of targets to use as options in the planning process.

Depending on the information available both to map the features/species spatial distributions (in terms of area, density, occurrence, abundance, probability, etc) and to determine minimum areas/occurrences and clump sizes, the setting of targets and penalty factors needs to be undertaken based on the best available knowledge. Target and penalty setting may then also reflect the certainty or confidence in the information that describes the feature as well the importance of that particular feature/species target to the planning objectives. A risk assessment (e.g. what is the risk that our information is inaccurate? what is the risk of not adequately including the feature in the resultant reserve system?) is another important factor to include in the setting of targets and penalties.

An example of a Conservation Feature File (also known as Species file) used in the PEMB analysis is shown below. Compare with Table 4 and note that only the parameters that apply to the particular problem set need to be included. Including the full set of variables increases computation time considerably. In this case, the only parameters required were the target area for reservation, and the species penalty factor, to ensure achievement of targets:

```
id    target      spf   name
1     43.21386    1     1
2     354.20508   1     2
3     2.8713      1     3
4     1264.80039  1     4
5     447.60864   1     5
6     941.00418   1     6
...
```

A Marxan conservation feature is a measurable and spatially definable biodiversity unit that is of interest in the conservation planning process, and may be broken down into *coarse filter features* and *fine filter features* (Ardron *et al.* 2008). Coarse filter features are those conservation features that are of (usually) larger nominal scale, and occur across the whole study area, such as habitats, ecosystems or geomorphic features. Fine filter features represent (usually) smaller scale biodiversity values, such as the location of rare/threatened/endemic species, or their crucial habitats such as nests, breeding or feeding areas.

A successful Marxan analysis requires good spatial data to provide the information on the distribution of conservation features targeted in the planning process. A resource assessment exercise was undertaken as part of the planning process, identifying the suite of spatial and non-spatial data available to identify biodiversity and human usage values across the planning area. A bibliography of literature relevant to the identified marine ecological values in the study area was produced, from which many spatial datasets were sourced (Appendix A).

For the Marxan analysis, datasets needed to be of sufficient quality to align with the specific targets, or alternatively, the targets needed to be reviewed with respect to the quality of the available data. For example, it is of little use to set a target of protecting at least 20 breeding sites of a species if the available data can only describe opportunistic sightings of that species. In such a case it may be more appropriate to set a target of an appropriate percentage of sighting locations, based on knowledge of the relationship between observational efforts and the species' habits with respect to their breeding. Or a dedicated field survey could be carried out to identify and map the species' breeding sites.

Comprehensive coverage of the whole study area was also important in identifying features/datasets that describe the targets of the Marxan analysis, to avoid bias towards selection of areas that have the only mapping of that particular feature or which appear to show higher abundance of features, due to greater sampling effort in those areas.

Data quality was assessed in terms of spatial and thematic accuracy, precision or resolution, coverage across the study area, and distribution of survey/mapping efforts. Following this review, it was determined that insufficient data were available, within the time and budgetary constraints, to use Marxan for the spatially and thematically detailed analyses required for the identification of specific management zones within reserves. Management zones are designed to manage human usage for the primary purpose of biodiversity conservation, and the secondary purpose of managing conflicting human activities. Thus, for a data-intensive exercise such as a Marxan analysis, suitable detailed spatial information must be available that accurately describe the biodiversity values and human usage to be managed, at a scale appropriate to zoning schemes.

This level of analysis would require detailed habitat mapping information, to the level of local scale habitats (e.g. the distribution and densities of various genera or species of seagrasses (e.g. ephemeral vs perennial species), or coral reef types), specific priority species distributions, foraging areas and breeding locations, and detailed human usage and values mapping that were not readily available across the whole region. Thus the Marxan analysis was designed to assist with broad-scale, outer boundary design. Planning decisions based on information collected through targeted field work (Oct-Nov 2008), community information sessions, the indigenous engagement program and industry-specific stakeholder group meetings would later be used the primary method of zoning scheme design.

The key information layers available to use, or that were developed for use in the Marxan Conservation Feature File are described below, along with their use in addressing reserve design criteria through the Marxan analyses. These were the datasets determined to have sufficient accuracy, resolution or scale of mapping, and spatial coverage of the study area, to be used in the Marxan analysis assisting with reserve outer boundary development.

2.2.1 Coarse filter features

Coarse filter features are those conservation features that are of (usually) larger nominal scale, and which occur across the whole study area, such as habitats, ecosystems or geomorphic features.

The development of the key datasets used as coarse filter targets in the creation of the conservation feature file is described below:

Bioregions - Integrated Marine and Coastal Regionalisation of Australia

The Integrated Marine and Coastal Regionalisation of Australia Bioregions were developed by the IMCRA Technical Group coordinated by the (then) Australian Government Department of Australia, a collaboration of State, Northern Territory and Commonwealth marine management and research agencies, beginning in 1992 and published as the *Interim Marine and Coastal Management of Australia Bioregions version 3.3* in 1998 to support planning for marine conservation and sustainable marine resource use.

Through the work of individual agencies and in a series of workshops, marine scientific experts used both a Delphic approach based on expert opinion, and quantitative analytical methods to assess a range of biogeographic parameters for the creation of a national-scale ecosystem classification. Biological and physical datasets such as the distributions of species or habitats, bathymetry, geomorphology, sediments, currents, water chemistry and temperature were compiled, validated and classified into macro-scale provincial and meso-scale regional ecosystem units based on a spatial hierarchical structure. The goal was to produce a set of inshore (continental shelf) bioregions with minimal internal heterogeneity at the meso- and macro-scales as shown in Table 5 below.

Thus, the provincial and meso-scale bioregions represent a national-scale ecosystem classification and spatial dataset, suitable for national or regional scale marine planning. In 2006 the IMCRA version 3.3 inshore marine bioregions were combined with an off-shelf classification into the *Integrated Marine and Coastal Regionalisation of Australia verson 4.0.*

The IMCRA Bioregions were established as the main ecosystem-based framework for the planning of a National Representative System of Marine Protected Areas, which the WA system of marine reserves contributes to. As the Western Australian marine jurisdiction is of similar spatial scale, covering approximately one third of Australia's coastal marine environment, the IMCRA meso-scale bioregions have also provided a useful regional framework for the planning of WA's marine reserve system.

Three IMCRA meso-scale bioregions span the PEMB study area: the Eighty Mile Beach (EMB), covering the inshore waters from Cape Missiessy to Cape Keraurdren, the Pilbara Nearshore (PIN) covering the inshore waters between Cape Keraurdren to North West Cape, and the Pilbara Offshore (PIO) covering the islands and waters offshore of the PIN (Figure 2). One of the guiding principles of the PEMB reserve planning process was to contribute to the representation in the marine conservation estate of all IMCRA bioregions in WA coastal waters. Thus this dataset needed to be included in the Marxan analysis as a conservation feature target, to ensure that a quantifiable target percentage of IMCRA bioregions could be input and achieved through the reserve design process.

The IMCRA spatial data and supporting literature were easily accessed from Geoscience Australia (www.ga.gov.au) and little manipulation was required to use the data in the PEMB Marxan analysis.

Habitats and habitat surrogates

As the main *coarse filter target* for the PEMB Marxan analysis, spatially comprehensive marine habitat mapping at the finest resolution possible was one of the most important data layers to capture. The remoteness and vast expanse of the study area, with the time and budget constraints of the project precluded a dedicated habitat mapping exercise across the region, and so a desktop GIS review and compilation of the best available mapping was undertaken as the primary source of habitats information.

Later in the planning process (Oct-Nov 2008), site assessment field trips were also undertaken to capture information on several priority areas of the region that had little or no information available (see PEMB Field Program Data Report). The information obtained from these field trips was spatially limited, as they targeted only several areas with no existing information, the areas of Cowrie Beach and Spit Point to Cape Keraurdren, and the Great Sandy Islands. Thus habitat mapping products derived from these surveys were not directly used in the Marxan conservation feature file. However, the information derived from the field trips would prove to be highly useful in validating desktop habitat mapping studies, and in providing the only site information available for these ecologically important areas, of potential use for later management planning.

The main source for marine habitat mapping information was the *Ecosystem characterisation of Australia's North West Shelf* (Lyne *et al.* 2006) of the North West Shelf Joint Environmental Management Study (NWSJEMS), published in 2007 by the Australian Commonwealth Scientific and Industrial Research Corporation (CSIRO) and the Western Australian Government. An important part of the NWSJEMS project was to develop a hierarchical ecosystem/habitat classification applicable at a range of spatial scales and nested within the IMCRA provincial and meso-scale bioregions. Table 5 shows a how the CSIRO model compares with IMCRA bioregional mapping and WA Department of Environment and Conservation habitat mapping schemes.

As is common in region-scale marine planning, the information available to cover the whole NWSJEMS study area was mostly limited to physical datasets such as bathymetry, temperature, geomorphology, energy regimes (storm, wave, tide, etc). These physical datasets are commonly used as surrogates for describing the broad-scale distribution of habitats and biodiversity, further informed and validated by site-specific biodiversity or habitat mapping surveys, and by information provided by fishing catch data. The most detailed level of verified habitat mapping produced by the NWSJEMS was the Level 3C classification, which describe depth-based classifications, combined with subcomponents of major geomorphological elements of the region, such as mud flats, tidal flats and mangal systems of major river deltaic systems island fringes, shoals and other offshore geomorphic features (see Figure 3)

The NWSJEMS level 3C classes extended across most of the planning area from Exmouth Gulf to Cape Keraurdren. Based on the same depth-based and geomorphic parameters and source data as the original work, DEC Marine Policy and Planning Branch Marine Information Section extended mapping further east to extend as far as Cape Missiessey.

The NWSJEMS level 3C classification provides a useful delineation of ecologically significant depth classes – an important driver of biodiversity distribution – based on the best available chart information. However, it also includes some community-level habitat units – mud flats, tidal flats, salt flats and mangals, and several discrete habitat substrate or geomorphic classes, the near-shore and offshore reefs, and shallow island fringes. Thus it is a combination of some broad-scale habitats, and what were treated as 'habitat surrogates' – the depth classes and geomorphic features. The NWSJEMS level 3C mapping therefore directly provides the information required to address the reserve design criterion concerning the representation of cross-shelf diversity.

Table 5: Comparison of CSIRO, IMCRA and DEC habitat mapping spatial hierarchies. The shaded region shows the best available habitat mapping information for the PEMB Marxan analysis. Adapted from Bancroft 2003.

Nominal scale		IMCRA	CSIRO NWSJEMS (2006)		Coastal compartments (Eliot *et al*, 2010 in prep.)	DEC Shallow-water Marine Habitat Classification Scheme (Draft 2003)
			Hierarchy	Level		
macro-scale	> 1000s km	Provinces	Province	1		
meso-scale	100s - 1000s km	Meso-scale bioregions	Biome	2A, 2B, 2C	Primary	
micro-scale	10s - 100s km	micro-scale	Geomorphic units	3A, 3B, 3C	Secondary	
pico-scale	1 - 10s km	pico-scale	Primary biotopes	4	Tertiary	Community groups (e.g. sand, seagrass, macroalgae, coral reef)
			Secondary biotopes	5	Sediment cells	
	< kms		Biological facies	6	local sediment cells	Functional groups (e.g. *Posidonia* seagrass, *Sargassum* macroalgae, *Porites* coral reef)
			Micro-communities	7		

Used in isolation, the NWSJEMS level 3C does not include any long-shore division – for example a 5 - 10m depth class in the Exmouth Gulf is attributed the same as the same depth class offshore of Eighty Mile Beach. However, equivalent depth classes in each of these areas are likely to exhibit different biodiversity and habitat characteristics, corresponding to differences in underlying geology and geomorphology, different coastal aspects, coastal energy regimes and latitudes.

Long-shore classification is provided in the NWSJEMS scheme through the lower hierarchical levels 2B, 3A and 3B, representing relatively larger scale ecosystem divisions interpreted from broad changes in bathymetry and structural geomorphology along the coast. Preliminary investigation of the usage of NWSJEMS 3A data for the Marxan exercise suggested that this scale of ecosystem mapping, when combined with the 3C data, would drive the analysis too much towards selection of many small reserves, in order to capture a given percentage of each 3A unit. Preference was given towards using a broader scale sub-regionalisation of the NWSJEMS 3C information.

The NWJEMS Technical Report 12 indicated that the geomorphologic interpretation of level 3A should be further developed. DEC Marine Policy and Planning Branch engaged a specialist coastal geomorphologist, Dr Ian Eliot, to review the NWSJEMS level 3A and 2B geomorphologic classifications. The aim of the investigation was to produce a dataset that covered the whole region with consistent mapping of areas that are broadly consistent in geomorphologic terms, and which would further develop a dataset to satisfy the reserve design criterion of representing long-shore diversity of habitats.

Using the 'coastal compartments' structural geomorphologic approach, DEC Marine Information Section produced a hierarchical classification of the region's coastal geomorphologic features. This referred to the NWSJEMS 3A mapping, as well as Dr Eliot's assessments of geological and energy controls on coastal geomorphology of the region. The hierarchy was divided into *primary*, *secondary* and *tertiary* coastal compartments. Refer further to Eliot *et al* 2010 (in prep).

Broadscale geomorphology has been shown to be closely related to habitat distribution, as it summarises both underlying geological structure (substrates) as well as the processes governing sediment supply, distribution and deposition (e.g. Ryan *et al.* 2007), . Thus the existence, or likelihood of presence of various reef structures, areas of mobile sediment, high and low energy areas, riverine, estuarine and mangrove areas are captured within geomorphological classifications at a variety of hierarchical levels.

The broad habitat/surrogate mapping provided by the NWSJEMS 3C classification was divided by the longshore Primary Coastal Compartment mapping of Eliot *et al* 2010 (in prep) to provide a classification of regional biophysical values that would satisfy reserve design criteria regarding representation of cross-shelf and longshore diversity. For example, an area of 5 – 10 m water depth offshore from Dampier, in the 'Dampier' primary coastal compartment becomes the classification unit "Dampier offshore waters 5 – 10 m". In the resultant combined classification, this area would then be considered as having different biodiversity values (e.g. habitat communities) to an area of the same offshore water depths out from (for example) Cape Keraudren, which is in the De Grey primary coastal compartment ("De Grey offshore waters 5 – 10 m") (Figure 3). The broad scale of both datasets was considered appropriate for the regional assessment required for the PEMB Marxan analysis.

The combination of the 6 primary coastal compartments mapped for the region (Eliot *et al.* 2010, in prep.) with 19 marine ecosystem classifications of NWSJEMS 3C created a total of 56 classes of benthic substrates within broad primary coastal compartment geomorphic units. These classes were considered to be either broad habitat classes, or marine substrate classes as habitat surrogates, as shown in Table 6. The 'Shallow Island Fringe" NWSJEMS 3C class was further sub-divided into "offshore" and "inshore" classes, based on the IMCRA delineation between the Pilbara Inshore and Pilbara Offshore IMCRA bioregions. This sub-division was considered necessary to capture the different biodiversity values of the oceanic offshore islands (such as Barrow Is, and the Lowendal, Montebello, Muiron and Mackerel island groups) versus the turbid inshore island shallow fringing areas (such as the Mary Ann Islands or Mangrove Islands).

Table 6: 'Coarse filter features' for the Pilbara-Eighty Mile Beach Marxan analysis.

Feature	Origin	CONSERVATION FEATURES (examples)
Habitat **Surrogates** based on NWSJEMS 3C 'depth' classes, unioned with primary coastal compartments (Eliot *et al.* 2008)	NWSJEMS 3C depth classes divided by primary coastal geomorphic compartments (Eliot et al. 2010, in prep.).	For example, a feature mapped as 'Nearshore waters < 5 metres' within the Dampier Primary Coastal Compartment would become 'Dampier_Nearshore Waters < 5 metres' whilst the same substrate feature in the Barrow Primary Coastal Compartment would become 'Barrow_Nearshore Waters < 5 metres'
	NWSJEMS 3C - Shallow Island Fringe class divided by IMCRA (PIO, PIN) to separate inshore and offshore areas - oceanic vs coastal. Divided by primary coastal geomorphic compartments (Eliot et al. 2010, in prep.).	'PIN_Barrow_Shallow island fringe'; 'PIO_Barrow_Shallow island fringe'; 'PIN_Dampier_Shallow island fringe'
Habitats based on NWSJEMS 3C 'habitat' (*cf.* 'depth') classes, unioned with primary coastal compartments (Eliot et al. 2008)	Features mapped specifically in the NWSJEMS 3C as reef substrate - 'Nearshore Reef' and 'Offshore Reef'. Divided by primary coastal geomorphic compartments (Eliot et al. 2010, in prep.).	'Barrow_Nearshore reef'; 'Dampier_Nearshore Reef'; 'Dampier_Offshore Reef'; 'Exmouth_Nearshore Reef'
	Features mapped specifically in the NWSJEMS 3C as 'Mud and tidal flats' or 'salt flats'. Divided by primary coastal geomorphic compartments (Eliot et al. 2010, in prep.).	'Barrow_Mud and tidal flats'; 'Barrow_Salt flats'; 'Dampier_Mud and tidal flats'; 'Dampier_Salt flats'; 'De Grey_Mud and tidal flats'; etc
EXCLUDED	NWSJEMS 3C features that were either inconsistently mapped, or existed as isolated single or very small area features which could not be effectively targeted.	NWSJEMS 'Unknown' classes; Channel Deep (10-20m); Tidal Channel (subtidal); Roebourne Nearshore Reef; Roebourne Offshore waters 5-10m (island, shoal)

2.2.2 Fine filter features

Fine filter features represent (usually) smaller scale biodiversity values, such as the location of rare/threatened/endemic species, or their crucial habitats such as nests, breeding or feeding areas.

The targeting and penalty factor weighting of fine filter features can be a primary driver of the outcomes of Marxan analyses. For example, if a fine filter feature is given a high target percentage or occurrence value, and also a high penalty for non-achievement of targets, then these features will tend to be always selected, and the selection of other features will tend to clump around these features more and more as the boundary length modifier is increased.

Two conservation feature sets were considered to be fine filter features in the PEMB Marxan analysis – mangroves, and turtle nesting beaches.

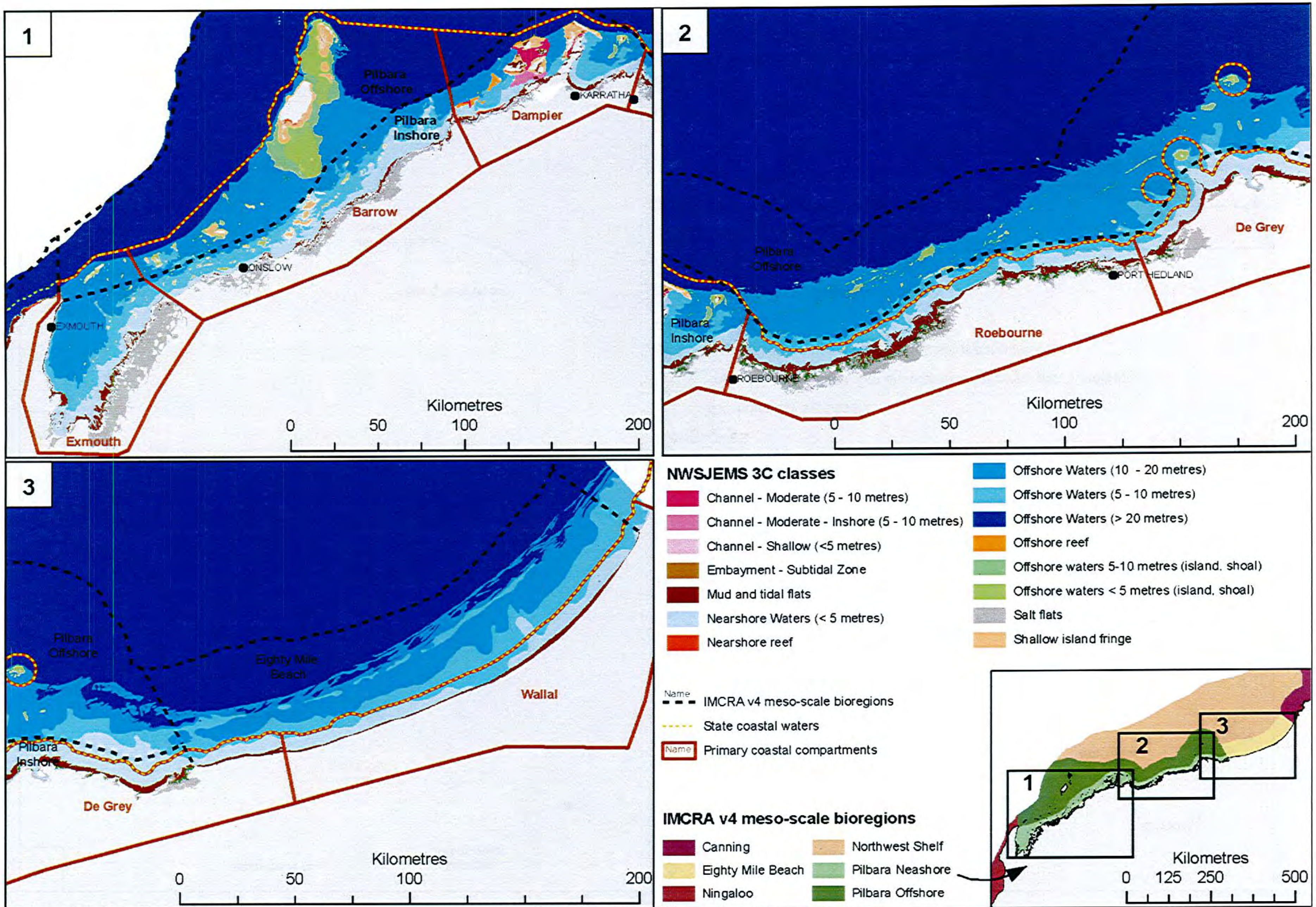

Figure 3: The distribution of 'coarse filter' conservation features used in the Marxan analyses of the Pilbara/Eighty Mile Beach region.

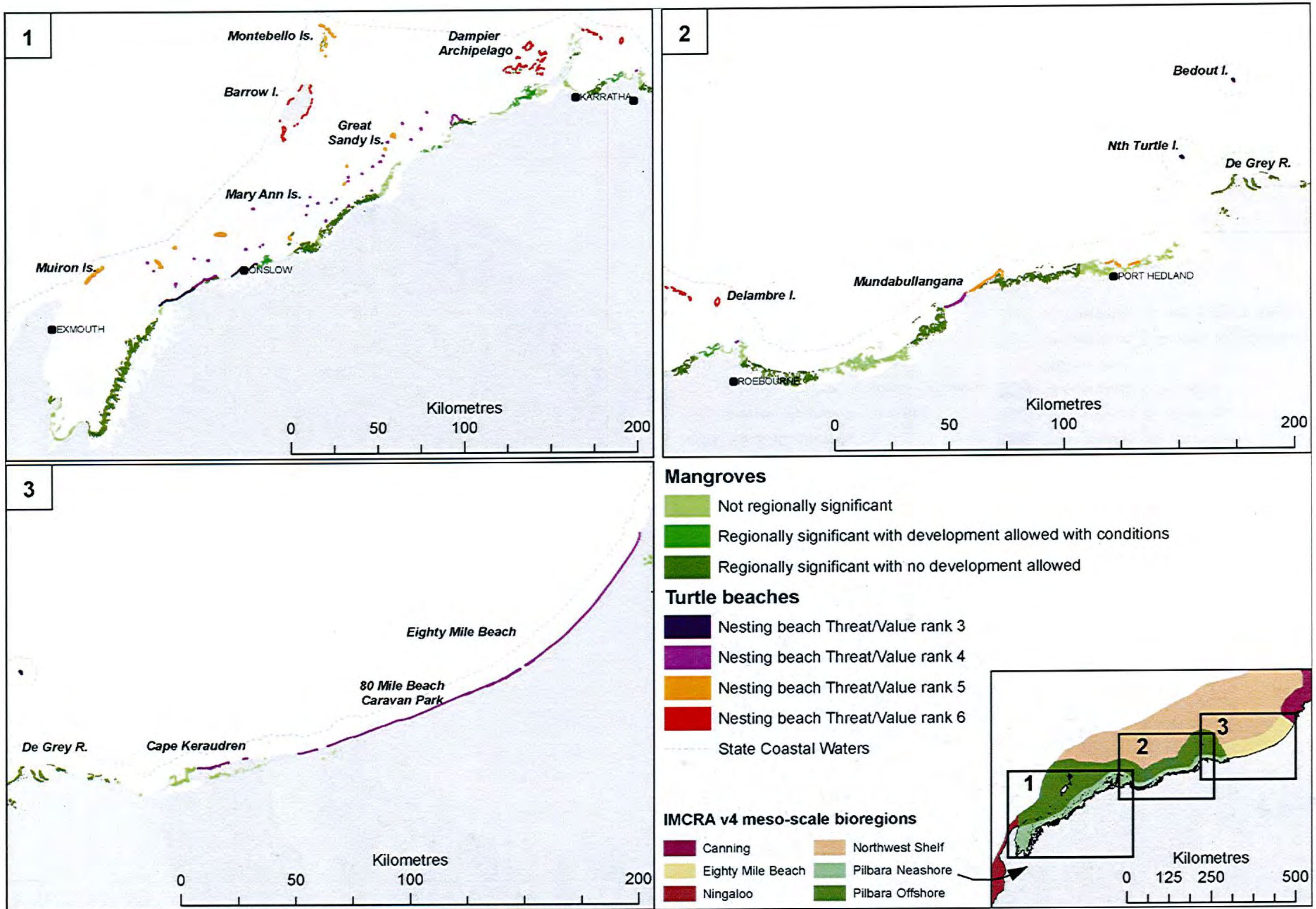

Figure 4: The distribution of 'fine filter' conservation features used in the Marxan analyses of the Pilbara/Eighty Mile Beach region.

Mangroves

The Pilbara – Eighty Mile Beach regions contain extensive stands of tropical arid coast mangrove communities, many which are largely unmodified making them of national and international importance (Carr & Livesey 1996). Pilbara mangrove species are not endemic, restricted or otherwise nationally or internationally significant (Semeniuk 1997). However, the large areas of pristine or near-pristine mangals are highly important for the provision of habitat and nutrients to numerous coastal and marine species and communities (many rely exclusively on mangals in the region) and also serve important functions in the maintenance of coastal stability (Carr & Livesey 1996, EPA 2001).

At the time of planning, mangals were considered to be under-represented in Western Australia's marine conservation estate, with developmental pressure in the region potentially coming from existing and proposed port and industrial activities and unmanaged recreational usage. Davidson (2008) discusses Pilbara mangrove conservation status and ecosystem functions, and the rationale for specifically targeting this community group in the PEMB Marxan analysis.

Mapping of mangroves was available in the NWSJEMS level 3C ecosystem classification, produced through manual digitization of aerial photography or satellite imagery (Landsat). DEC's Remote Sensing group (Graeme Behn) had also established a technique to rapidly and accurately map large areas of mangrove forest using Landsat satellite imagery. Upon comparison, it was found that these two sources of data were complementary. Manual digitization was able to map areas where mangroves were too sparse for Landsat imagery analysis, whilst the spectral discrimination and automatic classification of the remote sensing techniques provided more objective mapping of mangal areas, for example, finding small pockets of dense mangals isolated from the large forest areas, which were not captured in the NWSJEMS digitized mapping. These two data sources were merged together and each used to validate the other, using best available orthophotograpy as a contextual base for visual checking.

Following mapping of mangal spatial areas, polygons were attributed with their IMCRA bioregion, Primary Coastal Compartment, and classification under the WA Environmental Protection Authority's *Guidance statement for protection of tropical arid zone mangroves along the Pilbara coastline* (2001). This guidance statement provided 4 guidelines/management areas for assessing developments that may impact mangroves in the region, based on Semeniuk's 1997 assessment of priority areas for mangrove conservation, which considered each respective area's geomorphological, species diversity and plant morphological characteristics. These guidelines were translated into three classifications of mapped mangrove areas, based on the areas described in EPA (2001) and Semeniuk (1997).

Table 7: The translation of EPA Guidance statements into mangrove dataset attributes.

EPA Guidance	PEMB Mangrove dataset attribute
Regionally significant mangals outside of designated port and industrial areas	Regionally significant with no development allowed
Regionally significant mangals inside designated port and industrial areas	Regionally significant with development allowed under conditions (to reduce impact on mangroves)
Non-regionally significant mangals outside designated port and industrial areas	Not regionally significant
Non-regionally significant mangals inside designated port and industrial areas	

Thus, the mangroves in the region could be targeted within the Marxan analysis as a broad habitat/community occurring across the region, and/or as separate communities within IMCRA Bioregions, and/or within Primary Coastal Compartments, and/or as having different ecological values based on their EPA/Semeniuk classification. After initial set-up, only IMCRA and EPA guidance attributes were used to create separate mangrove conservation features used in analyses. In later analyses, only EPA guidance statement mangrove conservation features were targeted specifically, with a species penalty factor (SPF) to ensure achievement. In these analyses, IMCRA mangrove conservation features were not given a SPF, and so were used only for reporting the amount of mangroves 'protected' within reserve solutions, within each IMCRA bioregion.

Table 8: Mangrove conservation features.

Feature	Origin	CONSERVATION FEATURES
Mangroves	Mapped mangroves, classified by EPA Guidance Statement (2001), which was based on Semeniuk's (1997) assessment of regionally significant mangrove stands for conservation.	Mangroves not considered to be regionally significant
		Regionally significant mangroves with development allowed with conditions to reduce impacts on mangrove communities
		Regionally significant mangroves with no development allowed that would impact mangrove communities
	Mapped mangroves (all mangroves, i.e. not classified as above) within IMCRA Bioregions	Eighty Mile Beach IMCRA mangroves
		Pilbara Inshore IMCRA mangroves
		Pilbara Offshore IMCRA mangroves
	All mangroves mapped across the region, treated as one conservation feature	All mangroves

Turtle nesting beaches

The Pilbara coast from NW Cape to the West Kimberley is a highly significant region for marine turtle nesting, due to the existence of numerous offshore islands featuring suitable sandy beaches, as well as numerous and large mainland beaches. Islands are especially important as nesting areas, as they provide additional protection to eggs and hatchlings from terrestrial predators such as feral foxes, cats and pigs and are generally less likely to be susceptible to human interference and developmental pressures. The region also provides the variety of marine habitats suited to the omnivorous diets of marine turtles.

Flatback turtles are endemic to northern Australia and are highly dependant on beaches in the region, with approximately one third of flatback nesting occurring in the area, whilst the northwestern WA populations of green, hawksbill and loggerhead turtles are some of the largest in the world and genetically distinct from other Australian populations. All marine turtle species occurring in WA are listed as "rare or likely to become extinct" under the Western Australian *Wildlife Conservation Act* 1950 and as "threatened fauna" in the Commonwealth *Environmental Protection and Biodiversity Conservation Act* 1999.

Davidson (2008a) provides a discussion on the conservation status, threats and possible management actions available to protect marine turtles in the Pilbara – Eighty Mile Beach region, including the role that marine conservation reserves can take.

Expert advice (Dr Kellie Pendoley – Pendoley Environmental, Dr Bob Prince – DEC, Dr Fran Stanley – DEC, Roland Mau - DEC) was that most if not all beaches in the region provided habitat for turtle nesting, the level of which is likely to be related to beach characteristics such as beach width, depth of sand, extent of intertidal area offshore and other geomorphological factors. Thus mapping of turtle nesting beaches initially began with the mapping of all beaches in the region.

Beach spatial information was gathered from existing beach or sandy coastline habitat mapping in several existing habitat mapping datasets such as the NWSJEMS level 3C dataset, broadscale habitat mapping in the Dampier Archipelago – Barrow/Montebello Is area and new digitization of best available orthophotos undertaken specifically to fill gaps in beach mapping in these existing sources. Mapping of beaches in original datasets was either as linear features tracing the shoreline, or as polygons mapping visible beach in satellite or orthophoto imagery. Given that the Marxan Planning Unit reflected the High Water Mark planning area, inconsistency between the mapping of turtle nesting beaches and the mapping of HWM used for the Marxan Planning Units could have resulted in some whole or parts of beaches not being counted in the Marxan planning area. To ensure that beaches would overlap into the planning area, linear and polygon beach mapping was extended (buffered) by 200 m offshore. This meant that turtle nesting beaches would be located within the first planning unit offshore of the landward extent of the study area (planning units were 2000 m squares). The extent to which buffering of lines vs buffering of polygons of different sizes might be inconsistent, was considered marginal and not likely to affect the outcome of Marxan analyses based on broad percentage targets of turtle beach features.

Following the creation of a suitable spatial dataset to describe beaches in the region, the importance of each beach to turtle nesting was determined through a ranking process by DEC MPPB, based on information gathered through interviews with WA turtle experts, and later reviewed by the PEMB planning team and including Dr Fran Stanley (DEC) and Dr Kellie Pendoley (Pendoley Environmental). Beaches were ranked for their 'ecological value' (importance to turtle nesting particularly for flatback turtles in terms of the relative level of nesting use, e.g. density of nests on beaches), their 'level of threats' (e.g. from feral predators, industry developmental pressures, human recreational/commercial/cultural usage pressures), which were combined to produce an overall 'value/importance for protection' rating. The beaches' 'social value' was also ranked (e.g. for educational, cultural, research purposes), as was their level of 'existing protection' (e.g. under existing tenure, adjacent to nature reserves, etc); however, these were not used in the eventual overall ranking of beaches' importance for inclusion in a marine reserve system. This ranking exercise produced 4 classes of turtle nesting beach, as described in detail in Davidson (2008a) and in Table 9.

Table 9: Turtle nesting beach conservation features.

Feature	Origin	CONSERVATION FEATURES
Turtles nesting beaches	Mapped known nesting beaches, ranked for Ecological value and potential threats by experts, and based on track/nest densities following meeting with Dr Kellie Pendoley	Nesting beach Threat/Value rank 3 *(lowest)*
		Nesting beach Threat/Value rank 4
		Nesting beach Threat/Value rank 5
		Nesting beach Threat/Value rank 6 *(highest)*

Turtle internesting and foraging areas

Since 2001, Pendoley Environmental has been tracking Pilbara turtle movements through the use of satellite telemetry tags attached to nesting turtles at Barrow Is and Mundabullangana, and more recently, Cemetery Beach near Port Hedland. The resultant data from fourteen turtles, tagged between 2001 and 2008 were interpreted by Dr Kellie Pendoley, based on her extensive experience in marine turtle biology and ecology, for likely internesting and foraging areas of turtles. Internesting areas are areas where female turtles rest and incubate eggs in between laying episodes, and as such have high conservation value for the protection of breeding turtles.

The resultant interpreted data, from 14 individual turtles tagged at Barrow Island would not be robust enough for statistical analysis of likely internesting areas for the whole Pilbara/Eighty Mile Beach population. However, it was Dr Pendoley's expert opinion that the areas shown by the data as internesting areas adequately reflected the most likely areas of importance for internesting in the region.

Between them, the four species of marine turtles occurring in the PEMB region have an omnivorous diet consisting of seagrasses, macroalgae, sessile invertebrates and opportunistic predation of mobile invertebrates and small fish. Thus all habitats to maximum depths of approximately 20m are important as turtle foraging areas (Marine Turtle Recovery Plan, DEC in prep.). The interpretation of foraging areas from the satellite tagging data was considered to be too heavily biased by sampling effort relating to only 14 turtles to be useful for Marxan targeting of important turtle foraging habitat. It was considered that the normal CAR objectives relating to habitat conservation would be sufficient to target turtle foraging areas.

Table 10: Turtle internesting and foraging areas conservation features.

Feature	Origin	CONSERVATION FEATURES
Turtles	Turtle internesting and foraging areas, interpreted from satellite telemetry data by Dr Kellie Pendoley	Internesting areas
		Foraging areas (no penalty factor for non-achievement of targets)

2.3 PEMB Boundary Length File

The Boundary Length File lists neighbouring pairs of planning units with the length of their shared boundary, used in the calculation of possible reserve solution boundaries in the optimisation process. The purpose of the Boundary Length File is to give the software a measurement of the perimeter of reserve solution boundaries which can then be used as another cost to the system. Thus the optimization process can be tipped towards favouring few large (i.e. low boundary cost relative to other costs) versus many small (i.e. higher boundary cost relative to other costs) reserves, as required by the planning process.

Example Boundary Length File:

```
id1    id2    boundary
1      2      0.060858031
1      5      0.873091728
1      1      2.043145481
2      6      0.170580837
2      2      0.203549114
3      13     0.304287775
3      3      5.218518808
4      14     0.294409507
...
```

Where 'id1' and 'id2' are two neighbouring planning units, and 'boundary' is their shared boundary length.

The Boundary Length File (BLF) is used in the computation of total outer and inner (donut) boundaries of potential reserve solutions. The BLF was initially calculated using the free Joint Nature Conservation Committee (JNCC) ArcGIS extension, thus assigning the planning unit pairs with boundary lengths based on a spatial calculation.

http://www.uq.edu.au/marxan/index.html?page=83126

In the calculation of boundary lengths for the boundary length file, not only do shared boundaries get calculated, but also boundaries that are not shared with another planning unit, as at the edges of the planning area.

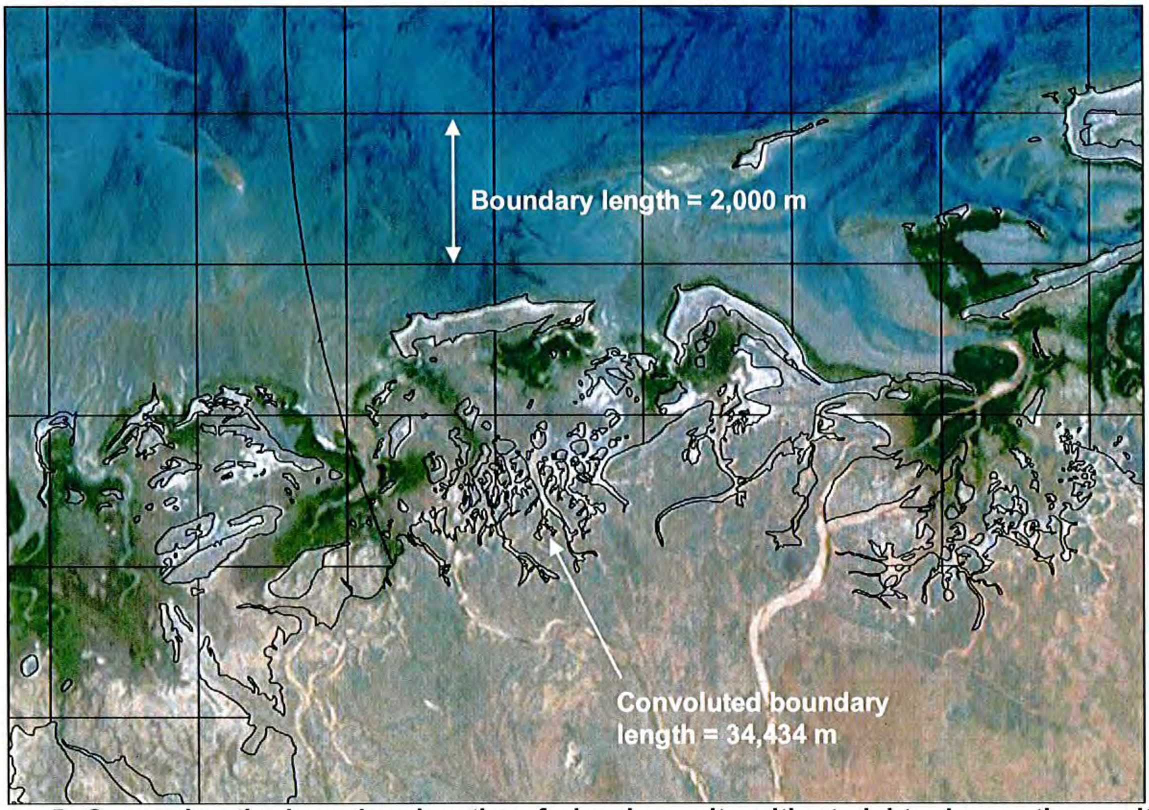

Figure 5: Comparing the boundary lengths of planning units with straight edge vs those with a convoluted high water mark edge. The underlying image is a Landsat TM image of part of the Port Hedland coast.

Following the initial set up and testing of the system, it was noted that planning units adjacent to the coast were routinely not included in reserve solutions, despite containing important conservation features and being adjacent to areas that *were* chosen for reservation by the system.

It was discovered that planning units that overlapped the coast, and so had been clipped by the coastal High Water Mark (Figure 5), had very large boundary lengths for the landward edge of the planning unit due to the linear complexity of particular coastal areas such as mangal systems or saltflat areas. Thus, if selected for a potential reserve solution, these planning units would incur a substantially higher boundary cost than a unit situated offshore. This effect is multiplied as the Boundary Length Modifier is raised, and the resultant reserve solutions tend to avoid such complex coastal areas. This effect was not considered to reflect any of the planning goals, and as such was treated as an undesirable artifact of the data and the Marxan algorithm.

In order to negate this effect, boundary lengths were set to 1 for all planning unit pairs. Thus boundary length costs would be calculated equally for planning unit pairs, regardless of the shape of the individual planning units involved. The broad scale of planning and of the source datasets meant that the detail of outer boundary shapes (driven by the boundary length modifier) was not considered important enough for the long boundary lengths of coastal units that would otherwise be uniform and simple (2 km), to remain as driving factors for planning unit selection.

2.4 PEMB Species vs Planning Unit file

The Species vs Planning Unit File lists the amount or number of each conservation feature in each planning unit, thus providing the base information of the spatial distribution of the conservation features. Once the planning objectives are determined, the specific conservation targets specified and the spatial datasets acquired, a GIS operation provides the calculation of the amount of each conservation feature in each planning unit.

Example Species vs Planning Unit File:

```
species     pu    amount
15          1     0.1225
21          1     0.4645
45          1     0.1225
15          2     0.0008
21          2     0.009
45          2     0.0008
15          3     0.1308
21          3     0.4989
...
```

The Species vs Planning Unit File is calculated based on input planning unit and conservation feature file and does not contain any variables that are manipulated through a Marxan process.

2.5 Marxan system calibration

In order to balance the importance of each parameter in the objective equation (note there was no cost threshold penalty in the PEMB analysis):

Resultant reserve cost (or score) =
∑PUs*Cost* + ∑PUs*Boundary x BLM* + ∑ConsFeat*Penalty x SPF* + ~~*CostThresholdPenalty*~~

to the resultant reserve solutions, a calibration needs to be done to determine the influence of each parameter, and to find the range of input values that drive changes in results. The *Marxan Good Practices Handbook* (Ardron *et al. (*eds*)* 2008) provides an excellent overview of calibration methods and the use of calibration in determining appropriate values to use for various effects in analyses.

Calibrations were done iteratively for Species Penalty Factor (SPF) and Boundary Length Modifier (BLM) parameters, each time a significant change in conservation feature targets was made. As they are the two main variables of the three (in the PEMB case) parameters of the objective function, a change in one can affect the influence of the other.

2.5.1 Species penalty factor setting

Suitable values for species penalty factors were set through the methods outlined in Ardron *et al.* (eds) (2008). Once conservation feature targets were set, species penalty factors were changed for a number of otherwise identical runs, iteratively upwards from 0, until a majority (approx. > 90 %) of solutions for a given scenario run was achieving all targets. Species Penalty Factors for particular features/targets that were commonly not reaching achievement were individually increased and input into additional scenario runs until they were also being routinely achieved.

If SPFs are set too high, the resulting system can be too rigid in the way it achieves targets. For example there may only be a limited number of configurations that can achieve 100% of all targets, whereas one of the main powers of a Marxan analysis is that they can offer a number of near-optimal solutions and provide flexibility to planners. SPFs were increased until all targets were routinely 100% achieved, and then SPFs were lowered slightly to where all targets were *usually* achieved (i.e. were achieved in approximately at least 80% of runs), to within acceptable thresholds (achievement of at least 95% of the target value).

2.5.2 BLM calibration

The Boundary Length Modifier (BLM) is perhaps the most important user-defined set-up variable in a Marxan analysis, driving the degree to which the selection of planning units, often containing disparate and widely distributed conservation features, are selected adjacent to each other. With proper usage of the BLM parameter, results can be made to favour the selection of many very small reserves, or one very large reserve, and the full spectrum of possible results in between. In this way, planning objectives such as a desire for a certain size or number of reserves can be met by the objective function of Marxan, whilst ensuring the achievement of goals at the lowest possible cost.

Boundary Length Modifier calibration was carried out as described in Chapter 8 of the *Marxan Good Practices Handbook* (Ardron *et al.* (eds) 2008) whereby suitable Species Penalty Factors were set, ensuring the achievement of targets, and a range of BLM values from 0 to several thousand were used in otherwise identical scenario runs. As the BLM value is increased, the average boundary length of resultant reserves decreases towards a minimum value (asymptote), as the smallest, most clumped reserves that achieve all targets are forced towards the only successful configurations possible.

Average outer boundaries of runs using a range of BLMs were graphed against BLM values, to find the range of BLMs that made the most difference to the clumping of reserves. As Figure 6 shows, BLMs larger than the optimal range have little influence on boundary lengths of resultant reserves, and serve only to increase the total boundary cost of near-identical resultant reserves.

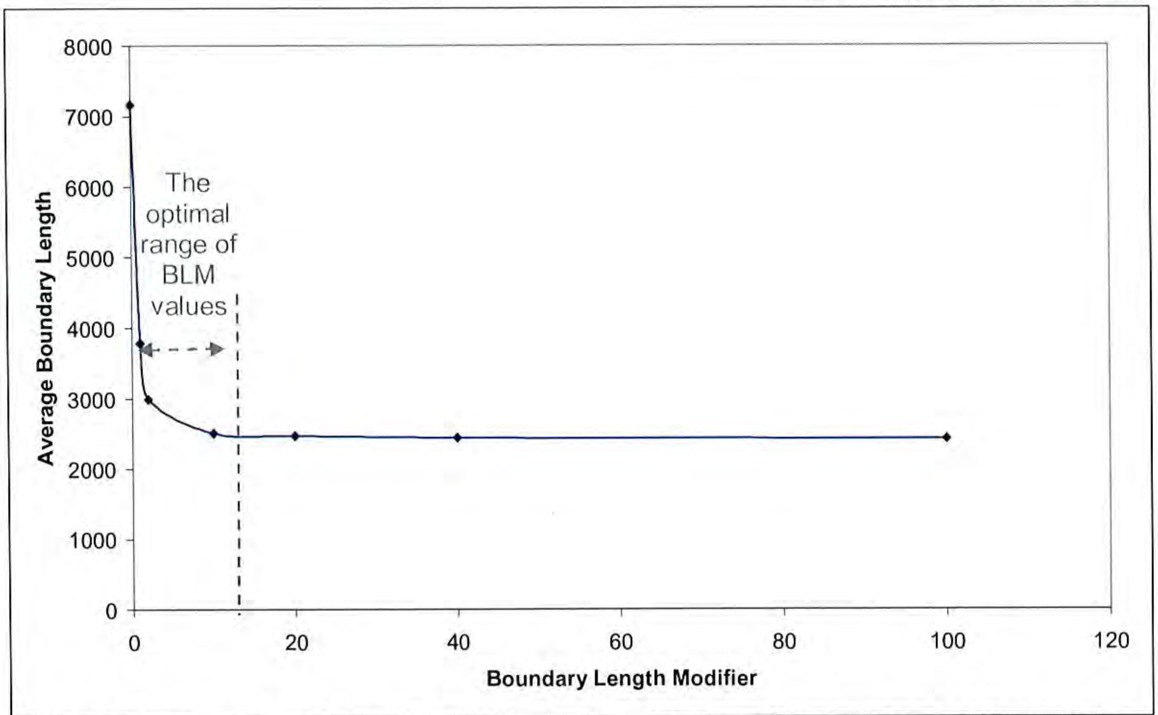

Figure 6: An example of the effect of increasing the Boundary Length Modifier on the average boundary length of solutions.

2.5.3 Number of iterations calibration

The number of iterations of Marxan's simulated annealing algorithm (see the Marxan manual for discussion of simulated annealing and it's parameters) that are required to produce a near-optimal solution also requires calibration. For a given problem, depending on its complexity (such as the number of planning units, conservation features, etc) there would be a theoretical maximum number of simulated annealing iterations that would be able to find the global optimum – that is, the single best reserve configuration that satisfies the targets at the minimum cost. If this maximum number of iterations was used to produce, say 100 different runs of a scenario, each run would be identical, or near identical.

One of the goals of a Marxan analysis is to provide a range of satisfactory *near optimal* solutions, in the understanding that source data and even the setting of operational targets is rarely precise enough for a single optimum solution to be the best. Instead, the input of a planning team is used to negotiate or choose the best of a range of near optimal reserve configurations provided by the Marxan analyses. Using very high numbers of simulated annealing iterations can also take a long time to process, and for complex problems, or when large numbers of runs need to be produced, this can be prohibitive.

Similarly to the Boundary Length Modifier calibration, the *Marxan Good Practices Handbook* (Ardron *et al.* (eds) 2008) suggests iteratively increasing the number of iterations used in the set-up of otherwise identical scenario runs. Graphing the resultant average cost of reserves produced from the differing numbers of iterations shows the range of iterations that can provide efficient results, whilst minimizing the time taken to produce results (Figure 7).

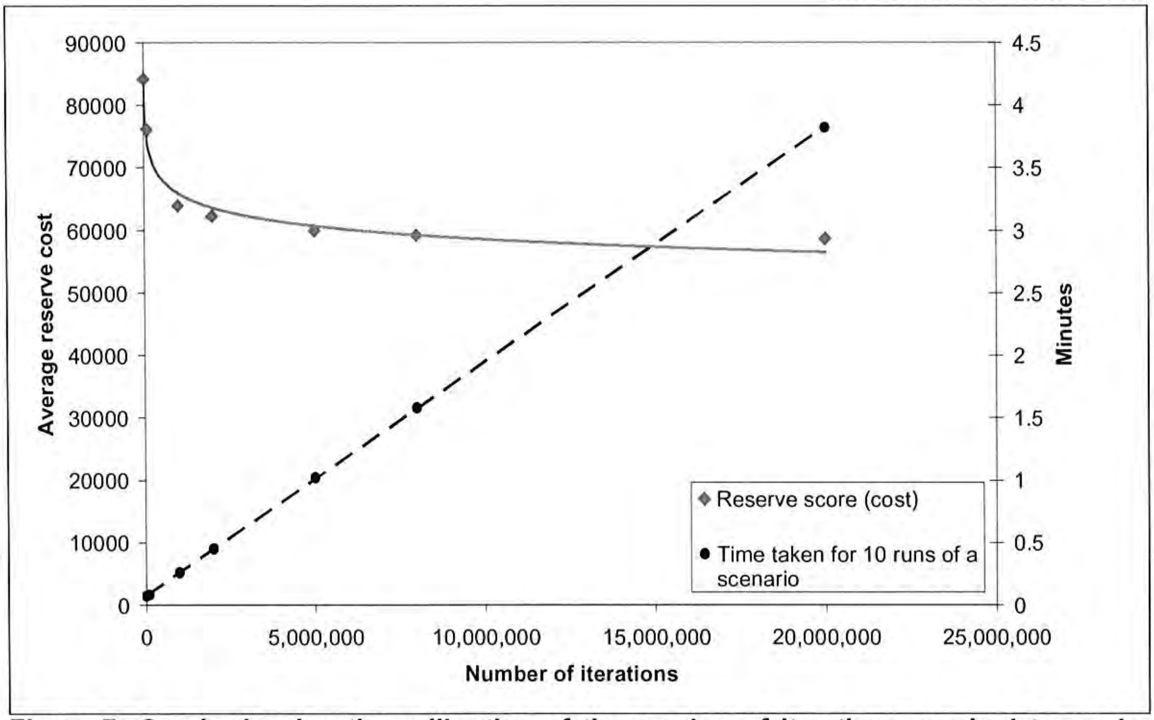

Figure 7: Graph showing the calibration of the number of iterations required to produce near-optimal Marxan solutions, with the corresponding time taken to produce 10 runs of a given scenario. It can be seen that reserve configurations only get marginally more efficient when using more than 5,000,000 iterations, whilst the time taken to produce the results continues to increase linearly with more iterations.

2.6 PEMB Conservation feature target setting

A Marxan analysis that accurately reflects the planning process is dependant on the interpretation of the *qualitative* planning goals and reserve design criteria, into *quantitative* targets of the amount or number required of the various ecological or socio-economic features of interest in the planning process. These targets must then be represented by appropriate datasets of sufficient quality and spatial coverage and resolution, and which suitably describe the conservation features in terms that match the targets.

For each of the 21 reserve design criteria (see Section 1.3 Applying systematic planning in the Pilbara and Eighty Mile Beach process), one or more *operational targets* were developed, to translate the qualitative descriptions of the various criteria into quantitative terms required for a Marxan analysis. These operational targets were set regardless of what data were available to describe them and without regard for their likelihood to be achieved in the final reserve design. Thus they purely represented a translation of the aspirations of the planning process into quantitative, measurable terms. A failure to achieve some targets in a Marxan analysis should not necessarily be considered a failure of the planning process, as some targeted features were either unknown or un-mapped, or in direct opposition to other targets where they overlap. Thus the Marxan process to achieve the targets aimed to provide optimised solutions, a compromise of all ecological and socio-economic targets, rather than achieving a hypothetical single ideal solution where all targets are achieved. Appendix A summarises the translation of reserve design criteria into operational targets and the information available to describe these targets.

At the time of planning there were no available quantitative assessments of the PEMB targets such as minimum areas of marine habitat required for long-term protection of the habitat itself or of dependant species, minimum population sizes of threatened species, minimum number of breeding areas, etc. Such targets can be in the form of, for example, minimum viable population sizes for specific species, or be based species/area curves for habitats. These levels of assessment require detailed information on population sizes, dynamics and distributions of species (e.g. flatback turtles), or detailed biodiversity sampling over a large geographic range, in the case of species/area curves. Whilst research is continually progressing in these fields (e.g. turtle tagging by Pendoley Environmental and DEC, tracking by Pendoley Environmental; biodiversity surveying by the WA Museum, DEC and DoF), such information was not yet available for this region.

Given the regional scale of planning and the broad nature of the available information, broad generalised targets for representation within a multiple-use marine park were considered appropriate. Targets were developed by DEC Marine Policy and Planning Branch using examples of other Marxan analyses at similar scales of planning (e.g. Great Barrier Reef Marine Park Authority Biophysical Operating Principles recommended 20-40% of the planning area in no-take zones) and through consultation with scientific experts based on the best available information. For example, a target of 30% of broadscale habitat/surrogate conservation features was used as the base for the Marxan analysis. These broad targets reflected the regional nature of the planning process.

2.6.1 Coarse filter feature target setting

Setting of coarse conservation feature targets in the PEMB process relied upon consultation and negotiation of suitable targets with DEC MPPB planning staff, scientific experts, the IWG and with advice from the MPRA. Using this approach, a broad 'base' for targets of 30% of all habitats (including bioregions) were applied and then modified for particular features according to their respective total areas or rarity in relation to the entire planning area. For example, habitat conservation features derived from the NWSJEMS level 3C '*Offshore Reef*', '*Nearshore Reef*' and '*Shallow Island Fringe*' classes were generally small in area, and rare in occurrence across the region. These habitat classes were also recognized to hold significant biodiversity value in their provision of shallow hard reef substrate for coral reefs, filter feeders, macroalgal and seagrass assemblages (see *PLWK Data Report*, Davidson *et al.* 2010). These small, rare and important features were thus assigned higher percentage targets than larger or more widespread features, such as '*Offshore waters > 20 metres*' or '*Nearshore waters < 5 metres*'.

A range of Targeting Options were iteratively developed, see Section 2.6.3 Compiling targets as targeting options.

As a trial, a range of coarse filter feature target options were explored to take into account the relative total areas of the different features (Table 11). Following a method described in the *Marxan Good Practices Handbook* (Ardron *et al.* (eds) 2008) an inverse proportional weighting method was trialed to assign percentage targets to habitat features, scaled downwards from a maximum value applied to the smallest features, to a minimum percentage applied to the largest features:
:

$$(X_p / Y_p) \approx \sqrt{(X_t / Y_t)}$$

Where "$_p$" represents the protected area of a given feature, "$_t$" is the total area of the feature, and X and Y are two different features with relatively large and small areas, respectively. Thus larger areas get assigned a smaller percentage target than the target for the smaller areas.

Several variations of weighting method were calculated:

1) using a 30% target area of the *smallest* feature as Y_p;
2) using a 30% target of the feature with a total area that is the *mean* of all features' areas as Y_p, scaling the target proportion upwards to a maximum of 100% for features with total areas smaller than the mean, and proportionally downwards towards 0%, for larger features;
3) using a 30% target of the feature with a total area that is the *median* of all feature areas as Y_p, scaling the target proportion upwards to a maximum of 100% for features with total areas smaller than the median, and proportionally downwards towards 0%, for larger features.

Table 11: Calculation of the proportional weighting of targets in relation to their respective total sizes. Upon review, the weighting of targets using 30% of the median value (as explained in the text) was used in the trial.

			Basic 30% target for all features		Inverse proportional weighting, based on methods in Marxan Good Practices Handbook Ardron *et al* (eds) 2008. ($Xp / Yp \approx \sqrt{(Xt / Yt)}$ where X and Y are two conservation features of different sizes, 'p' is the area to be protected and 't' is the total area of the feature.					
					using 30% of the feature with **smallest** area as Yp		using 30% of the feature with the **median** size as Yp		using 30% of the feature with the **mean** size as Yp	
Name	**Area km²**		**Target area**	**Target %**	**Target area**	**Target %**	**Target area**	**Target %**	**Target area**	**Target %**
Dampier Embayment subtidal zone	3.1	smallest	0.9	30%	**0.9**	**30%**	3.1	100%	11.0	100%
Exmouth offshore waters > 20 metres deep	154.1	median	46.2	30%	6.5	4%	**46.2**	**30%**	78.0	51%
Roebourne mud and tidal flats	438.2	mean	131.5	30%	11.0	3%	78.0	18%	**131.5**	**30%**
Barrow offshore waters 10-20 metres deep	4216.0	largest	1264.8	30%	34.2	1%	241.8	6%	407.8	10%

This weighting method was trialed as an example of how such a treatment may influence analysis results. However, it was considered that there was insufficient justification for reducing targets of larger features based solely on area statistics. Whilst there can be sound ecologically-based reasons for adjusting targets in this way (see Ardron *et al.* 2008), in the absence of suitable available information for the planning area, it was determined that maintaining a consistent level of representation across all features was more appropriate.

2.6.2 Fine filter target setting

Target setting for the fine filter targets of turtle nesting beaches and mangrove communities focused on preferentially representing the highest ranked beaches or regionally significant mangrove areas over lower ranked areas, adding up to a total percentage representation for all beaches or mangrove areas.

For all of the different planning scenarios, total percentage representation of turtle nesting beaches was set at 50% of all beaches identified as nesting beaches across the whole planning area. In order to achieve this broad target, 100% of beaches ranked highest (rank score of 5 or 6) were targeted, with the remainder made up of 20% of beaches with a rank score of 4. As shown in Table 12, the achievement of these targets would ensure a 50% representation of all turtle nesting beaches.

Table 12: Targeting of turtle nesting beaches. These targets were used in all scenario options.

	Total area of features	Target percentage	Target area
Rank score 6 (highest)	27.3 km^2	100%	27.3 km^2
Rank score 5	31.2 km^2	100%	31.2 km^2
Rank score 4	67.5 km^2	20%	13.5 km^2
Rank score 3 (lowest)	14.5 km^2	0%	0
No beaches scored lower than 3	-	-	-
sum			72 km^2
All beaches	*140.6 km^2*	*50%*	*70.3 km^2*

Similarly, after trialing several targeting strategies, the overall target for mangroves was eventually set to 30% of all mapped mangrove areas. Within this overall target, the three classifications of mangroves (regionally significant with development allowed, regionally significant with no development allowed, and not regionally significant) were targeted differently to place emphasis on conserving the most significant areas in terms of conservation value according to Semeniuk (1997) and the Environmental Protection Authority (2001). Mangroves considered to be regionally significant, and occurring outside of current or planned industrial development areas (i.e. *regionally significant with no development allowed*) were initially given the highest targets, up to 100% in some planning scenarios (Table 14). As targeting of mangroves developed through the different scenario options, all regionally significant mangrove areas were assigned 45% targets, whether or not they were in industrial areas. If achieved, this target would equate to approximately 30% of all mangrove areas represented in the reserve solution/s, made up only of those mangals assessed to be of regional significance (Table 13).

Table 13: Targeting of mangrove areas. These targets were developed through a number of options, and used in later ('final') scenarios.

	Total area of features	Target percentage	Target area
Mangals not regionally significant	194.4	0%	0
Mangals regionally significant with no development allowed	351.9	45%	158.4
Mangals regionally significant with development allowed	30.9	45%	13.9
sum			172.3
All mangals	*577.2*	*30%*	*173.6*

2.6.3 Compiling targets as targeting options

Table 14 shows how the various coarse and fine filter targets were developed as different targeting options. This development of targets followed the iterative analysis procedure outlined in Section 3.2 Setup, run and results analysis procedure.

Table 14: Coarse and fine filter target settings for the different planning options. Shaded cells show the final 'best' targets developed through the Marxan project.

Targeting Option	Marxan 'species file' reference	Coarse Filter Features: Habitats	Coarse Filter Features: IMCRA	Fine Filter Features: Mangroves	Fine Filter Features: All mangroves, by IMCRA bioregion	Fine Filter Features: Turtle nesting beaches	Fine Filter Features: Turtle foraging and internesting areas
1	specT3_2-1 specT3_3_1 specT3_4_1	30% of total areas of all habitat features	30% of IMCRA bioregions – for statistical reporting only, no SPF applied	Total of 30% of all mangroves, consisting of: 50% of regionally significant mangroves where development not allowed	30% of mangroves in EMB IMCRA bioregion (no species penalty) 30% of mangroves in PIN IMCRA bioregion 100% of mangroves in PIO IMCRA bioregion	Total of 50% of all beaches, consisting of: No target for beaches with ranking score = 3 (lowest) 20% of beaches with ranking score = 4 100% of beaches with ranking score = 5 100% of beaches with ranking score = 6 (highest)	30% of internesting areas No target for foraging areas
2	specT3_2-2						
3	specT3_2-3	100% of "*Nearshore Reef*" or "*Offshore Reef*" habitat classes, 30% of all other classes					
4	specT3_2-4 specT3_2-9 specT3_3_4 specT3_4_4	Proportional percentage targets, weighted by total areas of habitat features. This method assigns lower targets to features with largest total areas, according to a proportional weighing algorithm described in Ardron *et al.* (2008).					
5	specT3_2-5	100% of "*Nearshore Reef*" or "*Offshore Reef*" habitat classes, 30% of all other classes		100% of regionally significant mangroves where development not allowed			
6	specT3_2-6	100% of "*Nearshore Reef*" or "*Offshore Reef*" habitat classes, 100% of "*Shallow island fringes*" and 30% of all other classes		Total of 30% of all mangroves, consisting of: 45% of regionally significant mangroves where development not allowed 45% of regionally significant mangroves where development allowed with conditions			
7	specT3_2-7 specT3_3_7	100% of "*Nearshore Reef*" or "*Offshore Reef*" habitat classes, 70% of "*Shallow island fringes*" and 30% of all other classes					
8	specT3_2-8 specT3_4_7	Targets as per specT3_2-7 were adjusted (reduced) to reflect maximum achievable targets when using Scenario 3, where some areas are 'locked out' of solutions. Several feature targets could never be achieved as significant percentages of those targets lay within locked out areas of existing port or other industrial tenure/administration. Reducing these targets to the maximum achievable reduced species penalties for non-achievement providing more flexibility in the Marxan system, and allowing more influence of the Boundary Length Modifier on the resultant reserve configurations.					

2.6.4 Modifying targets for analysis of Scenario 3

Scenario 3 was created to analyse the effect of existing reserves and unavailable areas for reservation (locked in and locked out areas, respectively) on the analysis of targets. For some targets large proportions of their total area are found within existing port or industrial areas, such as reef areas in the Barrow or Dampier coastal compartments, within the Barrow Island and Dampier Port Authorities. As shown in Table 14 and discussed in Section 2.2.1 Habitats and habitat surrogates, some of these features were targeted with high (up to 100%) percentage values. These values were impossible to achieve, given the unavailability of an often high proportion of planning units containing the features, located within unavailable tenure areas.

For example, the "*Barrow_Nearshore Reef*" habitat conservation feature was targeted at 100% in Option 7 (*specT3_2-7.dat*). However, some 20% of the total area of this feature is within the Port of Barrow Island, and thus is always unavailable in a Scenario 3 analysis. This automatically adds a high penalty cost to the Marxan objective function calculation for this analysis, which cannot ever be lowered through the selection of alternative planning units through the simulated annealing and iterative improvement methods of the Marxan algorithm. When several such features caused high penalties for non-achievement to be added to the reserve objective function, then the influence of the Boundary Length Modifier is reduced and resultant reserve configurations tend to be relatively highly fragmented with all but extremely high values of a BLM. This causes inefficient and unwieldy analyses.

The solution was to lower the targets for these features to the maximum possible, given the area(s) locked out of potential solutions by existing unavailable tenure. Marxan Optimised v 2.0.2 outputs a file called *<filename>_MarOptTotalAreas.csv* which reports the total area, the reserved (locked in) area, excluded (locked out) area, and the target area of each conservation feature. This file can be analysed to show which features have too much excluded area so that their targets are unachievable, and thus they can be modified accordingly.

See Appendix B for the list of input files, including those with lowered targets for the analysis of Scenario 3 as described above.

3 IMPLEMENTATION OF MARXAN

The usage of Marxan in the PEMB planning process developed as the GIS and planning staff learnt more about Marxan's requirements, implementation and how to use the results.

This report documents the development of datasets, planning objectives and targets, results and usage of results *throughout the project*, culminating in Trial 3 discussed further below; however the input and output files for each of the different Trials were named and managed according to slightly different conventions as the project developed. **Only Trial 3 setup, analysis, file naming and data management conventions are discussed below.**

3.1 Marxan 'Trials'

Three different stages, termed '**Trials**' were established as the usage of Marxan was investigated and as the broader project developed.

3.1.1 'Trial 1' (Aug/Sept 2008)

Trial 1 was a rapid set-up and test of the Marxan tool for the PEMB planning area, for the purpose of understanding what would be required in terms of data, data management and operation of Marxan, integration of Marxan analyses with the broader planning process, etc. Planning units were designed as 2 km x 2 km grid squares to the mainland high water mark, and did not remove island areas or include existing marine tenure boundaries. Input datasets were the best available that broadly matched some planning objectives, and were used with little or no modification.

3.1.2 'Trial 2' (Nov/Dec 2008)

Trial 2 had more refined planning units, that included existing port, industrial and reserve tenure boundaries, and that eliminated island areas above their mapped high water mark (HWM). High water mark at the mainland extent was to the highest of either the mapped coastline HWM, or the extent of mapping of mud, silt or mangals in the NWSJEMS level 3c habitat mapping. This was because it was found that in some places, the coastline dataset 'cut off' some important intertidal areas, due to different mapping methods and objectives of the original datasets.

Through Trial 2, some irregularities in input data were identified and able to be removed in preparation for Trial 3. For example, some 'mud and tidal flats', 'salt flats' and 'mangrove' areas near Dampier, Onslow and Port Hedland were operational solar salt fields, and therefore not available and of no conservation value. These were removed from input habitat datasets.

Turtle beaches and turtle tracking datasets were also further developed through Trial 2, as described in Section 2.6.2 Fine filter target setting.

The boundary length file was modified to a unit boundary length file, rather than using calculated boundary lengths as described in Section 2.3 PEMB Boundary Length File.

The design of Marxan input files were modified to increase the speed of Marxan calculations. Including full text names for conservation features slowed down processing considerably, so names were shortened to numerical ID codes. Using a Block Definition file (see Marxan documentation) to set targets and SPFs for groups of conservation features (such as habitat conservation features) increased processing time, so species targets were calculated individually and set in the 'species files'.

3.1.3 'Trial 3' (Jan/Feb 2009, and re-runs in 2010)

Trial 3 was considered to be the final set-up and run, with the results used to support the design of the final draft proposed outer boundaries of the PEMB marine reserve network. Planning units and input datasets were considered to be the best available to match as many of the planning objectives as could be achieved with the available resources. As well as the set-up of Marxan (through Trials 1 and 2), by the time Trial 3 was run, the broader planning process had also developed, allowing the most up-to-date policies and objectives to be input into the Marxan system for objective analysis.

3.2 Setup, run and results analysis procedure

Once the input files were created (as described in Section 2), and the system calibrated, the iterative procedure of making changes to conservation feature targets and penalties, the Boundary Length Modifier and the number of runs began, for each of the scenarios and conservation feature targeting frameworks to be analysed. The flow chart in Figure 8 summarises the procedure that developed for running and interpreting the over-100 Marxan analyses for Trial 3.

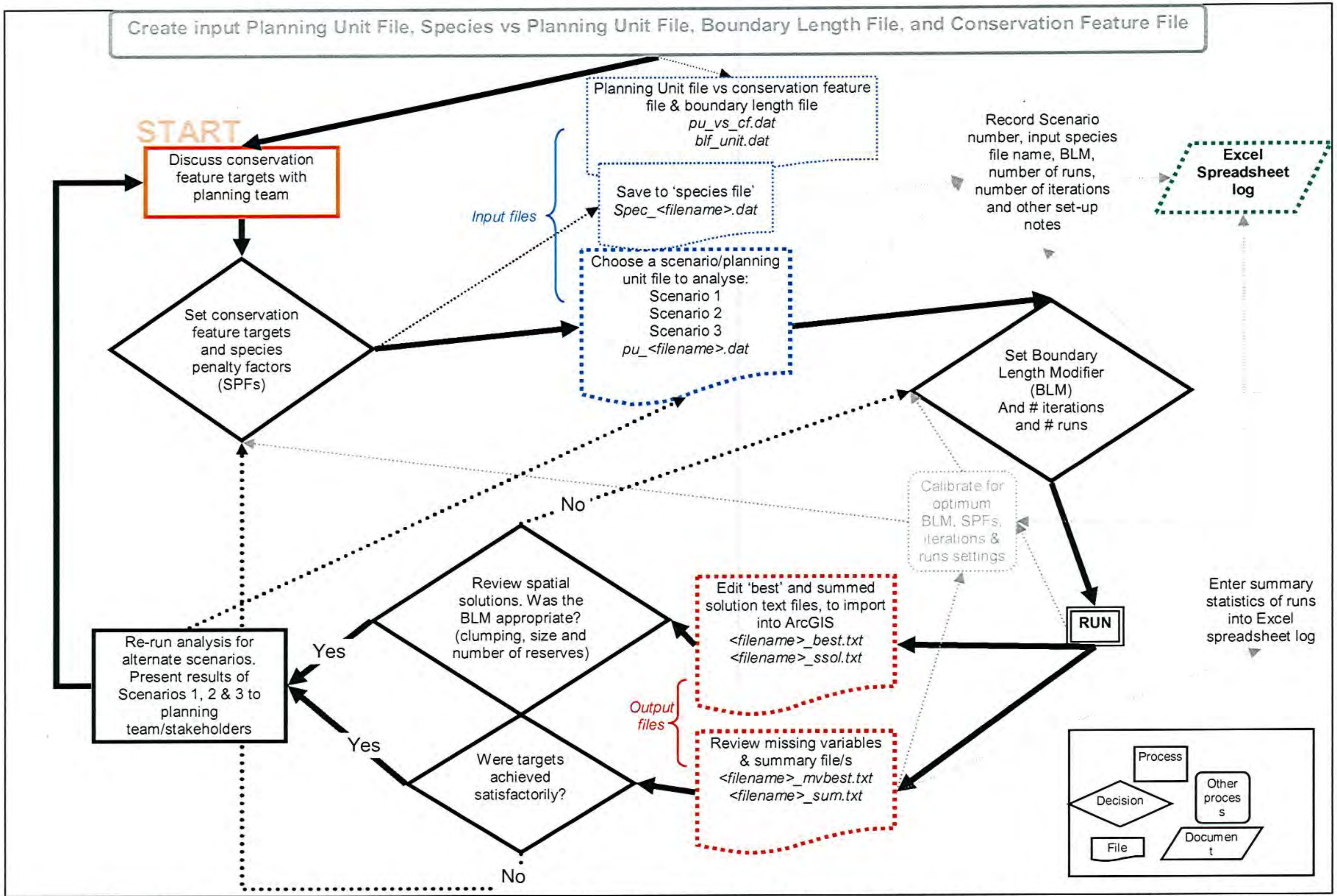

Figure 8: Flow chart outlining the work flow of analysing different conservation feature target settings, scenarios and boundary length modifiers. Described in more detail in Section 3.2 Setup, run and results analysis procedure.

Usually, for a given set-up and run situation, the following steps would be followed firstly using a smaller number of runs (e.g. 10 or 20), then once the analysis was working as desired, replicate the successful analysis with a larger number of runs (e.g. 100 or 200) to provide more analysis rigor, and more potential output reserve design options. The steps below elaborate on the flow chart in Figure 8.

1. Set new conservation feature targets

Meet with planning team/scientists/stakeholders and discuss the planning objectives in terms of available conservation features and limitations of the data. This requires the expertise of both the planning/scientific/stakeholder groups in the setting of appropriate targets for achievement of the broader planning goals, as well as the expertise of the GIS group in interpreting and explaining the available data, its origins and limitations. Target setting was usually done in an informal workshop setting between the planning officers and GIS officers, with reference to advice provided to the planners by scientific experts, stakeholders and relevant planning literature. Target setting is explained in more detail in Section 2.6 PEMB Conservation feature target setting;

2. Create a new species file

Enter the new conservation feature targets and species penalty factors into a new species file (via the Excel Spreadsheet log, see Section 3.3.4 MS Excel Spreadsheet log);

3. Edit the input file for Marxan

Use the *inedit.exe* GUI supplied with the Marxan software to create the key Marxan input file *input.dat*. The *Marxan User Manual* and *Marxan Good Practices Handbook* provides guidance for the setting of the simulated annealing and iterative improvement settings, which were set to 'simulated annealing' with 'normal iterative improvement' for all analyses. Calibration (see Section 2.5 Marxan system calibration) established an optimal number of iterations of 8,000,000 with 10,000 'Temperature Decreases'. The number of runs was set as low as 10 or 20 runs if the analysis was required quickly or was mostly for calibration or example purposes, and as high as 100 or 200 if the analysis was to be used for planning discussions. Boundary length modifier was set to provide the desired level of 'clumping' of reserves (see Section 2.5 Marxan system calibration) and was often altered for a given set of conservation feature targets, to provide alternative options for reserve network design (i.e. more, smaller and widespread reserves vs less, larger and more compact reserves). Input files were chosen, and the set of output files, along with an output <filename> designed according to the conventions described in Section 3.3.3 Trial 3 output file/folder naming protocols. Usually, the output files required were:

- Overall best: *<filename>_best.txt*
- Summary: *<filename>_sum.txt*
- Scenario details: *<filename>_sen.txt*
- Missing values of the 'best' solution: *<filename>_mvbest.txt*
- Summed solution: *<filename>_ssol.txt*
- Log file: *<filename>_log.txt*

The 'species missing proportion' was set to 0.95 – i.e. at least 95% of conservation feature targets needed to be achieved for the 'missing values' files to report the target as being achieved.

4. Run the Marxan analysis

Whilst running, enter the various parameters and settings described above into the Excel Spreadsheet Log (see Section 3.3.4 MS Excel Spreadsheet log).

5. Process and review the output text files

As described in Section 3.5 Marxan Output Files. In particular, review the summary file *<filename>_sum.txt* and missing values of the 'best' solution *<filename>_mvbest.txt* to ensure that the run results are viable reserve solutions. Import the summary file *<filename>_sum.txt* into Excel, calculate summary average statistics (see Section 3.3.1 Summary File: <filename>_sum.txt and enter them into the Excel Spreadsheet Log (see Section 3.3.4 MS Excel Spreadsheet log). Edit the output 'best' *<filename>_best.txt* and 'summed solution' *<filename>_ssol.txt* text files by deleting the inverted commas from field headings, to allow them to be imported into an ArcGIS personal geodatabase (see Section 3.5 Use of Marxan Output Files and Section 3.4 GIS data management). Link these two output files to spatial data and symbolize to view the results as a summed solution and 'best' result (see Section 3.4 GIS Data management and Section 3.5.4 Summed Solution <filename>_ssol.txt and Section 3.8.1 'Irreplaceable' areas – summed solution).

6. Re-run with changed targets, SPFs or BLM as necessary

If the review process above (*5. Process and review the output text files*) showed that some conservation feature targets were not being satisfactorily achieved, or that the spatial distribution of reserves in the resultant network was not as desired (shape, size, number of reserves, distribution of reserves), then change targets, SPFs or BLM as necessary and re-run the analysis as per the points above.

7. Replicate the analysis for all three scenarios

Once the steps above have been taken for the analysis of one scenario, repeat for other two scenarios. For example, once the input species file and Marxan settings were successfully established for a Scenario 1 run where all planning units were available, the repeat the analysis procedure above for Scenario 3, where existing reserves are locked into the resultant reserve configurations and existing port and industrial tenure is locked out of solutions.

8. Present results to planners/scientists/stakeholders

Organise maps of input data and results of runs analysing Scenario 1, Scenario 2 and Scenario 3 (as required). If some conservation features were not achieved, this information should be provided and discussed. Key parameters such as the input species file, Boundary Length Modifier and number of runs that make up the summed solution should be provided on maps to allow comparisons between map products.

9. Review targets and re-run as necessary

A range of targets may be considered as options by the planning team as the broader planning process develops, so targeting may need to be changed to reflect planning aspirations or policies, or options. Return to Step 1 above and implement new changes as necessary.

3.3 PEMB Marxan file management and changes tracking

Each Marxan analysis run as produced through the steps above can potentially produce hundreds of output text files, and as was the case for Trial 3 of the PEMB Marxan project, any given planning process may require tens to hundreds of re-runs of Marxan analyses. This places a heavy data management burden on the operator. Each change in user defined variables such as Boundary Length Modifier, the number of iterations of the simulated annealing algorithm, or the number of runs in a scenario all needed to be recorded, along with the input files and output file names of each scenario analysis. Input files also needed to be recorded or at least named in such a way that the operator could rapidly and accurately identify the version and origin of the file.

Input and output file naming and file/folder management evolved over the course of the PEMB Marxan project. This report documents the development of datasets, planning objectives and targets, results and usage of results *throughout all three trials*, culminating in Trial 3; however the input and output files for each of the different Trials were named and managed according to slightly different conventions as the project developed. **Only Trial 3 file naming and management conventions are discussed below.**

3.3.1 Trial 3 file/folder structure

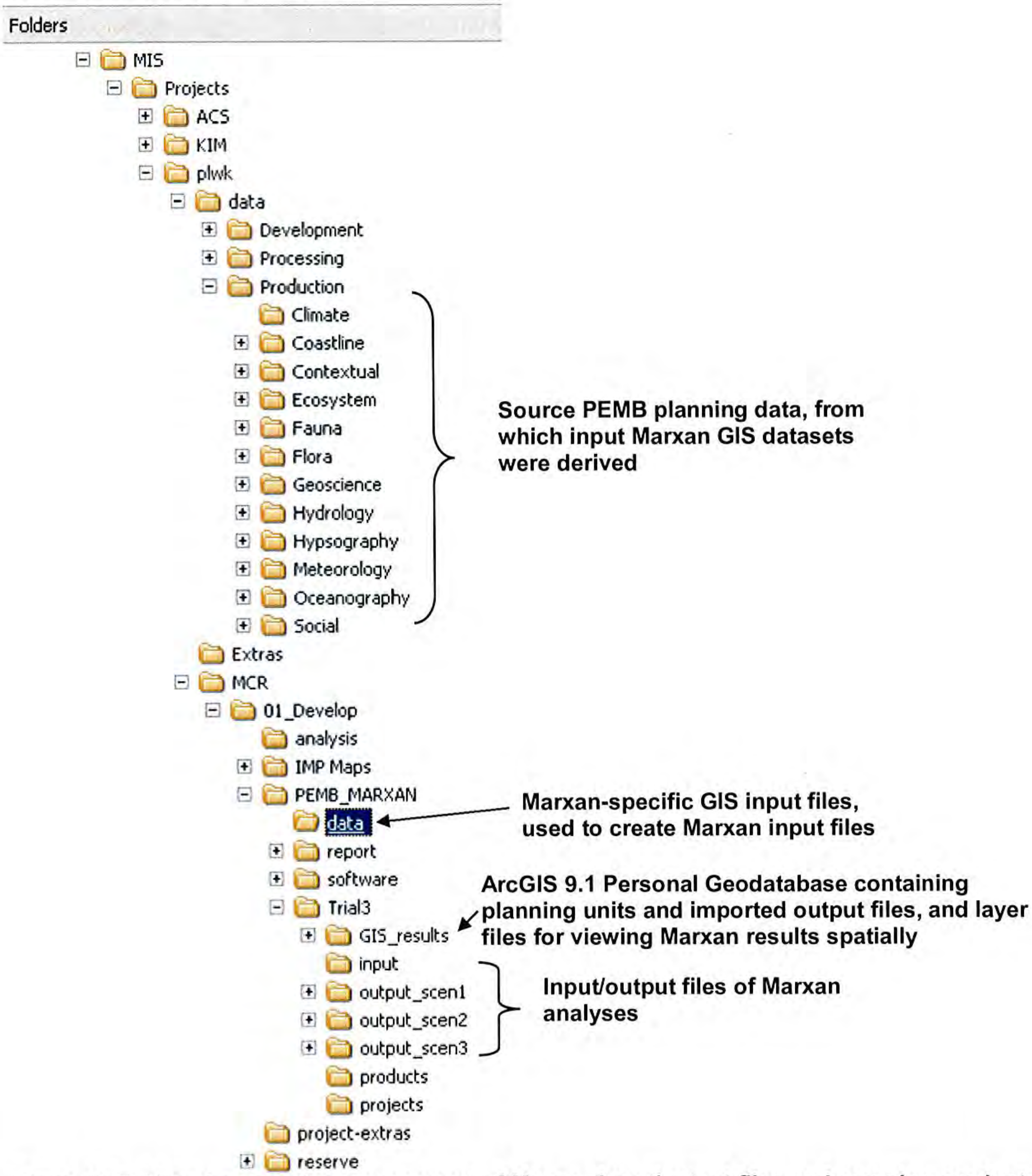

Figure 9: Folder structure for management of Marxan input/output files and mapping products for Trial 3.

As shown in Figure 9, input files and output files for Marxan were saved in separate directories, as recommended by the Marxan User manual. With the exception of the three different planning unit files for the three different scenarios, the same input files (boundary length file, planning unit vs species file, and for a given set of targets, species file) would be used for Marxan analyses of the three different scenario set-ups. Thus they were kept together in one input file directory. Output files, however, were kept in separate output directories for each scenario.

When setting up a Marxan run through the *inedit.exe* GUI, the user can choose whether to output the results of all runs in an analysis, or just the 'best' run, with the other summary results such as summed solution, summary file etc. When all the results were required, a sub-directory of the scenario's output directory would be created to house the hundreds of output text files that would be created. This sub-directory would be named with the same <*filename*> as described below.

3.3.2 Trial 3 input file naming protocols

With many iterations of analyses, it was extremely important to keep track of changes made to all input files, especially planning unit files and species files.

Input planning unit files and species files (conservation feature files) are listed and described in APPENDIX B.

Planning Unit Files for Trial 3 were named according to the convention:

- *pu_<trial number>_<scenario number>_<other status modifiers>.dat*

The basic planning unit files for Scenarios 1 (all planning units available) & 3 (existing reserves locked int, ports and industrial tenure locked out) were named *pu_3_1.dat* and *pu_3_3.dat* respectively. Scenario 2 (existing reserves locked in) planning unit files were created either as IUCN Category Ia reserves (no-take, sanctuary zones locked in, all other areas available for reservation) or as IUCN Category IV reserves (outer boundaries of existing marine parks locked in, all other areas available for reservation). Other variants were created to test hypothetical reserve configurations (see Section 4.1.2 Post-analysis of reserve design).

Species files (a.k.a. conservation feature files) for Trial 3 were named according to the following convention:

- *specT3_<species file version>_<species file version iteration>.dat*

The versions are described in APPENDIX B and the Species File Set-ups tab of the Excel Spreadsheet Log.

The Boundary Length File was set as a unit value for all boundaries, and wasn't changed after Trial 1. It was named *blf_unit.dat*.

Two **Planning Unit vs Conservation Species Files** were produced for Trial 3, one with 102 conservation features *pu_vs_cf_T3_km2_rel.dat*, and one with 106 conservation features *pu_vs_cf106_km2_rel.dat*. The file with 106 features contained updated turtle beach rankings and is the 'final' version of the file used for all subsequent analyses.

3.3.3 Trial 3 output file/folder naming protocols

In order to keep track of the origin of Marxan output files without having to refer to the Excel Spreadsheet Log to discover the parameters that produced them, some naming conventions were followed. These naming conventions had to be concisely coded, to avoid prohibitively long filenames.

Trial 3 output files were named according to the convention.

- *<Trial#>_Sc<Scenario #>_<species file version>_BLM<boundary length modifier>_<other reference>*

Where <other reference> might refer to the number of runs in the analysis, or any other variant of the same analysis, with changing numbers of iterations, etc.

Re-runs undertaken in Feb 2010 as part of the production of this report did not include the *<Trial #>* tag.

Output files and their input parameters are best identified on the "Set-up and Results" worksheet of the Excel Spreadsheet Log.

3.3.4 MS Excel Spreadsheet log

The PEMB analyses output files, their set-up parameters, and their summarised results were tracked through an MS Excel spreadsheet log of input files, output filenames, general notes about the analysis, and key parameters such as the Boundary Length Modifier, number of iterations and number of runs. The summary statistics from each scenario, calculated as described in Section 3.5.1 Summary File: <filename>_sum.txt, were also listed alongside these details, thus providing a snapshot of each scenario's set-up details and output results. These details were recorded in the 'Set-up and Results' sheet in the spreadsheet file.

This Excel file was also used to list the conservation features and their targets and species penalty factors used in the different input species files. This allowed all of the different targets, set in response to different planning options, to be visible and comparable side-by-side in the spreadsheet. It also allowed rapid calculation of target areas, based on the percentage targets required by the planning team.

The Trial 3 Spreadsheet Log is found in the 'Trial 3' folder (See Figure 9). ..\MIS\Projects\plwk\MCR\01_Develop\PEMB_MARXAN\Trial3\Marxan-PEMB_Trial3_SpreadsheetLog_20100913.xls

3.4 GIS data management

The usage of Geographical Information Systems is vital to the running of Marxan analyses, from the input data setup to the viewing of results spatially. GIS data management is important to allow analyses to be tracked and viewed in the future, and to minimise the risk of using inappropriate versions of datasets for viewing and analysis through the planning process.

3.4.1 Source GIS data

Datasets gathered and/or developed for the PEMB planning process were stored as per the standard DEC Marine Policy and Planning Branch data management structure and protocols. These datasets, which describe the various environmental and socio-economic values of the region, provided the source data for creating the Marxan conservation features and planning unit GIS layers, which in turn were used to create the input Marxan text files. See Figure 9.

3.4.2 Input Marxan GIS data

Input GIS data, used in the creation of Marxan planning unit, boundary lengths and planning unit vs species conservation files were primarily created and managed as ESRI shapefiles, with final versions stored in the \MIS\Projects\plwk\MCR\01_Develop\PEMB_MARXAN\data\ directory. These datasets contain the conservation feature numbers as attributes, and can be used to recreate the Marxan input files. They were specifically created for use in the set-up of the Marxan project, and are derivatives of their respective source dataset, which were managed through the normal DEC Marine Information System data management structure. They are further identified by the filename prefix with "*Mrxn*"...
See Figure 9.

3.4.3 Output spatial data

Whilst Marxan output files are simple aspatial text files, the 'summed solution', 'best' and individual run solutions are linked with the GIS version of the planning unit data to display their results spatially. In ArcGIS, this linking is most effectively done within an ArcGIS 9.1 Personal Geodatabase (or ArcGIS 9.2 File Geodatabase) structure, rather than link a shapefile with a text file, which tends to be very 'buggy' and/or takes a very long time to display or analyse.

The ArcGIS 9.1 Personal Geodatabase *PEMBMrxnTrial3_results_GDB.mdb* houses the basic planning unit file as an ArcGIS feature class, and has the various output tables from Trial 3 imported as geodatabase tables. A selection of these output tables are saved as ArcGIS Layer files *<filename>.lyr* which include the link between the spatial dataset and the aspatial table, as well as symbology information.

3.5 Use of Marxan output files

Several options exist for selection of the output files to be generated for Marxan analyses (see Marxan user manual for more details). For the PEMB process, the following output files were most commonly used:

- Summary file **<filename>_sum.txt** : the summary file lists the summary results for each of X number of runs of a particular Marxan analysis. Each run's score, total cost, number of planning units, total boundary length, total penalty, shortfall of conservation features and the number of targets that were missed;
- 'Best' result file **<filename>_best.txt** : lists the planning units that make up the statistical best solution out of the runs of the analysis – i.e. the solution with the lowest score;
- Summed Solution **<filename>_ssol.txt** :;
- Missing Values file **<filename>_mvbest.txt** :;
- Marxan log file **<filename>_log.txt** :;
- Scenario details **<filename>_sen.txt**

3.5.1 Summary File: <filename>_sum.txt

The summary file lists the summary results for each of X number of runs of a particular Marxan analysis. Each run's score, total cost, number of planning units, total boundary length, total penalty, shortfall of conservation features and the number of targets that were missed is listed.

Example Summary File output – a comma-separated file listing results for each run in an example scenario of 6 runs:

Run Number	Score	Cost	Planning Units	Boundary Length	Penalty	Shortfall	Missing Values
1	203350.3	10157.78	3533	2463	94672.5	29.71196	6
2	204102.8	10139.43	3522	2482	94683.32	49.97512	6
3	203536.4	10157.55	3514	2466	94738.84	50.7497	8
4	202122.5	10010.71	3470	2436	94671.81	85.28292	6
5	201309.3	9997.46	3497	2416	94671.81	118.6321	8
6	202330.7	9858.9	3458	2445	94671.81	22.31866	6

The main use for the Summary File Marxan output was to check the validity of results of each Marxan scenario run, and to be able to compare simple summary statistics of different scenarios. After each scenario was run, the averages of runs within the scenario were calculated and recorded for:

- objective function value (also called the reserve score);
- total cost (sum of planning units' cost for each run);
- number of planning units in the solutions;
- boundary lengths;
- total penalty;
- shortfall, and;
- numbers of missing values (i.e. how many features' targets were not achieved within the user-defined tolerance).

These averages were then used to calibrate the effects of changing various user-defined Marxan parameters such as Boundary Length Modifier, the number of iterations of a run, or the achievability of certain targets. This calibration is further explained in the Section 2.5 of this report: Marxan system calibration.

3.5.2 'Best' result file: <filename>_best.txt

Example 'Best' result file:

pu	solution
10346	1
10345	1
10344	1
10343	1
10340	1
10339	1
10338	1

...

The 'best' result file lists all of the planning units that are selected in the statistical best reserve configuration of X number of runs in a scenario. This equates to the least-cost reserve of all of the different reserve configurations output by Marxan for a given scenario. This output was used with the 'Best Solution Missing Values file' described further below to ensure that the statistical best solution was a successful run that achieved the conservation targets satisfactorily.

The 'Best' result files were linked with spatial data describing the PEMB planning units to show the location of the PUs chosen in the 'best' reserve configuration for a given scenario/target set-up.

This output file was used primarily to give an example of what a successful reserve configuration for the given scenario would look like, in conjunction with the Summed Solution file which shows 'irreplaceable areas', described further below.

At all times, it was emphasized that the 'best' result file simply showed an example of what a successful reserve would look like. It was used to compare the 'typical' results of different scenario runs, and to show, for example, which areas would to need be added to existing reserves in order to achieve the planning goals, given the available data and planning objectives.

3.5.3 Best Solution Missing Values file <filename>_mvbest.txt

Example 'Best Solution Missing Variables' (MVBest) file:

Conservation Feature	Feature Name	Target	Amount Held	Occurrence Target	Occurrences Held	Separation Target	Separation Achieved	Target Met
1	1	43.21386	46.2739	0	69	0	0	yes
2	2	354.2051	356.248	0	228	0	0	yes
3	3	9.571	7.7309	0	27	0	0	no
4	4	1264.8	1266.546	0	567	0	0	yes
5	5	447.6086	449.7573	0	226	0	0	yes
6	6	941.0042	941.5183	0	369	0	0	yes

The MVBest file lists, for the 'best' solution of the analysis, the conservation features along with their target values, the amount of the feature and/or the number of occurrences of the feature captured in the solution, the target for separation and whether it was achieved, and whether the area target was met to within the user-specified tolerance (for example, the user can set whether a target must be 100% achieved, or whether it can be within a certain percentage of the target amount)

The MVBest file was used to verify that the 'best' solution was a viable reserve option, in that it achieved targets satisfactorily. It was also compared with the Summary file to quickly identify which targets may not be being achieved, and by how much they were missed. In a well-configured Marxan analysis, the summary file would be consistent in the reporting of the number of targets missed through a set of runs. For example, if every run of 100 in a scenario analysis showed 4 or 5 'missing values' in the summary file, and the mvbest file also had 4 or 5 missing values, then it is most likely that the conservation features with missed targets in the best solution, are the same as those in all of the solutions. A judgement was then made on whether the missed targets were missed by too much, or whether the failure to achieve those targets was acceptable. If missing targets were deemed unacceptable, then Species Penalty Factors, Boundary Length Modifiers and targets could then be modified as required.

3.5.4 Summed Solution <filename>_ssol.txt

Example of a 'summed solution' file (SSol):

pu	number
10346	21
10345	57
10344	62
10343	44
10342	1
10321	0
10320	0

...

The SSol file lists the planning units with the number of times they were selected out of the total number of runs in the analysis. This provided users with a measure of how important each planning unit was in the achievement of targets. Planning units that were selected very frequently could be interpreted as 'irreplaceable areas'- those which are essential in all (or most) successful reserve configurations. The SSol file was one of the most useful outputs for input into final (draft) reserve designs, as discussed more in Section 3.8.1.'Irreplaceable' areas – summed solution

SSol files were linked with Planning Unit GIS files via the Planning Unit ID numbers. Then the selection frequencies of planning units could be displayed along a colour ramp with planning units of low selection frequency of light colours and high selection frequencies of darker colours, highlighting areas of most importance to reserve designs.

3.5.5 Marxan log file <filename>_log.txt

For each scenario run, Marxan records a user-specified level of detail of the progress of the analyses, from start-up parameters and input files, to the progress of the simulated annealing algorithm. The log file records the same information that is displayed on-screen through the Marxan calculations of an analysis. The level of detail displayed/recorded can be set in the set-up of an analysis, as explained in the Marxan user manual.

The log file was mostly used for debugging analyses that failed, and for tracking the progress of the simulated annealing algorithm through the runs. The effect of changing annealing parameters could be tracked, and the progress of the annealing as it worked to find the most efficient solutions could be monitored in real time, or following and analysis.

3.5.6 Scenario details <filename>_sen.txt

The Marxan scenario set-up file (SEN) saves the scenario setup details such as the number of runs, boundary length modifier, annealing parameters and all other user variables that are manipulated for different scenario runs. This file was rarely used, but serves as a record of the details of the scenario runs that may be reviewed in the future.

3.6 Use of Marxan with stakeholders

Marxan was used in the PEMB process as a systematic analysis of the planning criteria and operational targets using the best available information, run parallel to, and informing the main process. Stakeholders were involved in the Marxan analysis mainly through the provision of data and advice on targeting of the conservation features as well as assisting with a review of the use of Marxan in the overall planning process. Marxan was used to assist with the identification of highly important areas for conservation, using the best information available within the short amount of time available to planners. Planning of management zoning within the proposed multiple use marine park outer boundaries were to be planned through negotiation with stakeholders, outside of the Marxan analysis.

3.6.1 Fishing Consultation Group

The PEMB Fishing Consultation Group was established to assist with information exchange between planners and commercial and recreational fishers and aquaculturalists operating in the region. The PEMB Fishing Consultation Group consisted of representatives of:

- WA Fishing Industry Council (WAFIC)
- Aquaculture Council of WA (ACWA)
- Pearl Producers Association (PPA)
- Recfishwest (RFW)
- WA Charter Boat Operators and Owners Association (WACBOOA)

Minutes of meetings with the PEMB Fishing Consultation Group were documented and held at DEC MPPB. (T:\144-Marine Policy and Planning Branch\Shared Data\5-RESERVE-PLANNING\1-Marine-Conservation-Reserves\plwk\1_Initiate-Process\2_Consultation-Informal\Peak body consultation).

The PEMB Fishing Consultation Group were provided with an overview of the information being collected and input into the Marxan analysis in order to demonstrate how fishers' information regarding their fishing activities could be used in a systematic planning process. Existing WA Department of Fisheries spatial information on catch and effort in the area was not considered suitable for the scale of planning of the PEMB process, being reported in 60 nautical mile reporting grids. Additionally, for years when 3 or less fishers operate within a reporting grid block, within a fishery, catch and effort information is withheld to preserve commercial confidentiality interests of the fishers.

Thus information gathered directly from fishers was the most appropriate and accurate information available to PEMB planners. Marxan was used to demonstrate how fishing information is essential for planning for multiple objectives in a marine reserve planning process, where information showing high fishing values could lead to those areas being excluded from potential no-take or other restrictions, where biodiversity conservation objectives could satisfactorily be met elsewhere. Alternatively, such areas may also be included as conservation features for target in the Marxan process, for example, if a certain percentage or area of recreationally important fishing areas were to be conserved in a multiple-use marine park.

Initially, it was proposed that information about priority fishing areas could be incorporated into the Marxan planning system as a 'cost' layer, increasing the cost of acquisition of the planning units most important to commercial, recreational and charter fishers, or aquaculturalists. This usage in a Marxan process was demonstrated to WAFIC and the PPA, who then consulted with several of their members operating in the area to gather valuable information about priority areas and their uses by fishers.

Later investigations and trials with Marxan led to the decision to use it solely as an outer reserve boundary planning tool (i.e. not for management zoning planning), due to a lack of detailed ecological and socio-economic spatial information to represent the reserve planning criteria and operational targets relating to management zoning of the resultant reserve/s. This, combined with short timeframes for planning and Marxan scenario development, meant that fishing area information was not included in the eventual planning unit/reserve cost. Whilst it was considered preferable to avoid the selection of heavily exploited fishing areas (such as prawn trawl fisheries) in the reserve network, this information was not readily available in a spatially explicit format over the whole planning area, as the information from fishers and fishery managers was that fishing areas varied extensively from season to season and over longer (e.g. decadal) time scales. Additionally, as the marine parks were being planned as multiple use marine parks that can still allow a level of commercial exploitation, decisions that may result in restriction of commercial activity would occur at the stage of management zone planning, outside of the Marxan analysis.

Ultimately, Marxan was used with the PEMB Fishing Consultation Group mainly as a communication tool to demonstrate the use of the established reserve planning criteria and the operational targets derived from them, in combination with the available environmental and socio-economic information, to deliver an efficient and effective reserve network that minimized impacts on existing users.

3.6.2 Interagency Working Group - IWG

The Government Interagency Working Group was established to ensure a whole-of-government approach to PEMB planning, and to facilitate information sharing between the state government stakeholders:

- WA Department of Environment and Conservation (DEC)
- WA Department of Fisheries (DoF)
- WA Department of Industry and Resources (DoIR)
- WA Department of Planning and Infrastructure (DPI)
- WA Office of Native Title (ONT)
- WA Department of Indigenous Affairs (DIA)
- Tourism Western Australia (TWA)
- WA Museum (WAM)

The use of Marxan in the PEMB process was demonstrated to IWG representatives at several IWG meetings. The primary purpose of these demonstrations was to outline how DEC proposed to use Marxan for the identification of interest areas for the proposed marine reserve network, and to demonstrate how information obtained from IWG agencies and their stakeholders could be used in a Marxan systematic planning process.

The IWG were also shown how the 21 reserve planning criteria (initially developed by DEC, the IWG and the MPRA) were translated into operational targets and then into the Marxan analysis. IWG members were given the opportunity to comment on how Marxan should be used in the process, and how the operational targets were to be represented by the available information, and targeting options.

3.6.3 Marine Parks and Reserves Authority - MPRA

The Marine Parks and Reserves Authority (MPRA) are the vesting authority for marine parks and reserves in Western Australia, and contribute policy development in relation to new and existing marine reserves. The MPRA is made up of 7 members drawn from a variety of marine scientific, community and industry expert backgrounds.

Through quarterly meetings, the MPRA were kept informed of the progress of implementing the PEMB Marxan analysis, and towards the end of the process were fully briefed on the Marxan analysis development, results and usage of the results in the final design of the proposed reserve network.

The MPRA contributed to the initial development of the 21 reserve planning criteria, provided advice on the planning structure and goals throughout planning process and ultimately are responsible for delivering the marine reserve proposal to Government. It was important that members were familiar with the use of Marxan in systematic reserve planning, and in the specifics of how Marxan was used in the PEMB process to incorporate existing information and planning goals into the analysis. It was particularly important that members were comfortable that the usage of Marxan software and the interpretation of results provided an adequate basis for site selection, in conjunction with expert advice.

3.7 Use of Marxan in the broader Planning Process

Marxan was used in parallel with the broader stakeholder and scientific expert engagement undertaken for the PEMB process, partly as a trial to understand how Marxan could work in the WA marine reserve planning context, and partly to inform the selection of PEMB reserve network outer boundaries. Whilst the Marxan input data, methods, targets, scenarios and results were demonstrated openly to agency and stakeholder group representatives through IWG, MPRA and Fishing Consultation Group meetings, the setting of targets and running of various targeting options was largely an 'in-house' process due to time and resource constraints preventing widespread consultation and negotiation. Care was taken to ensure that the development of Marxan datasets and targets reflected developments in the planning process.

The power of Marxan to objectively analyse data using a potentially diverse range of input criteria/targets allows a rapid assessment of the effect of changes to conservation feature targets in response to different policy options that may be available to planners. This was the main usage of Marxan in the PEMB process, as the available data were assembled and the goals of the planning process were finalised, the most optimal areas for achieving planning goals of a CAR reserve system that also improved protection for flatback turtles were able to be identified as 'irreplaceable areas' (see Figures 10 - 13 and Section 3.8.1 'Irreplaceable' areas – summed solution).

The usage of Marxan in the PEMB process assisted the creation of quantitative operational targets from the qualitative reserve planning criteria. These operational targets were then useful in the simple and explicit communication of different planning options to stakeholders.

Importantly, the usage of numerical operational targets also directed the collection and creation of spatial information that could describe the habitat and turtle nesting targets appropriately for the Marxan input data requirements. The requirements of Marxan for spatially comprehensive information (i.e. information layers that cover the whole planning area) assisted in the appropriate setting of regional scale data collection efforts. For example, rather than focusing on the collection or creation of a habitat information layer that described community level habitats (coral reef, seagrass, macroalgae, etc), it was recognized that the broader geomorphic and depth-based habitat information provided by the NWSJEMS 3C classification would be more appropriate for the analysis of outer boundary locations across the region. Existing community-level habitat information was generally available only for existing or proposed marine reserve areas, and could only be expanded through a comprehensive and therefore costly field habitat mapping program. Conversely, the broader scale geomorphic and depth-based classifications could reliably be expanded to areas not previously mapped, through desktop mapping. Whilst this process of identifying available information sources is always done as part of a marine reserve planning process, the explicit focus on the kind of spatial data quality and coverage required for a Marxan analysis further focused data gathering and development efforts.

One of the main uses of Marxan in the PEMB process was as a communication tool for systematic planning methods. Marxan demonstrations to stakeholders showed how optimised reserve configurations could be achieved which satisfied conservation objectives and also minimised impacts on other users. In such a process, the gathering of stakeholder information is vital, but often difficult due to sensitivity about giving confidential or proprietary information (such as locations of fishery or mineral resources), or issues of mistrust over how the information is used. Demonstrating the objective nature of Marxan analyses was useful in satisfying concerns that some stakeholders had over how their information was to be used.

3.8 Use of Marxan results in eventual reserve design

As described above, the primary method of PEMB reserve planning was through the DEC MPPB planning team designing outer boundaries with advice from stakeholder groups, scientific experts, IWG and MPRA advice. This process was informed by the results of Marxan analyses of the various planning scenarios discussed by the planners and stakeholders.

The most effective way to communicate Marxan results was generally as mapping of the outputs, and as statistics of reserved and non-reserved areas of conservation features. The Marxan outputs of most use in the PEMB process are described in detail in Section 3.5 Use of Marxan output files.

3.8.1 'Irreplaceable' areas – summed solution

The Marxan outputs of 'summed solutions' – where the number of times a particular planning unit is selected in X number of restarts of a particular planning scenario – showed which areas were routinely included in solutions. These are commonly referred to as 'irreplaceable areas', so-called because they can identify areas that must be included in any reserve solutions that achieve the various objectives.

GIS analyses involving the overlay of summed solutions with input data layers showed which features are driving the selection of irreplaceable areas. These were usually areas that have a high diversity and abundance of different conservation features, or which contain rare and/or important features, and/or have a lower acquisition cost, and thus should form the basis of an efficient marine reserve network that achieves the stated (and input) objectives/targets.

When analysing a summed solution, it was important to ensure that most of the solutions that it is created from are achieving their targets, i.e. are viable, 'successful' configurations. It was also important to note that the summed solution is produced from numerous different reserve configurations, so the higher the selection frequency of a planning unit amongst a number of runs, the more irreplaceable it is. Thus leaving out some planning units of high but not 100% selection frequency from a final reserve design may still achieve all targets to satisfactory levels.

Providing a visual display of summed solutions of a given planning scenario to stakeholders can help demonstrate that the Marxan analysis is reflecting the broader planning process goals. For example, in the PEMB analyses, planning units containing high ranking turtle beaches that were close to regionally significant mangroves and a high diversity of habitat classes were routinely selected in various planning scenario runs. This demonstrated to planners and stakeholders that the Marxan analyses accurately reflected the PEMB planning goals, and that efficient solutions were being achieved.

Summed solutions of key planning scenarios are shown and discussed in the Marxan results section.

3.8.2 Post-analysis of reserve design

Marxan was used to analyse potential marine reserve network designs against the input data layers and targets. By using proposed (e.g. draft) marine reserve boundaries to set planning units status to 'locked in', the system is forced to select these areas in the computation of optimal reserves. This provides a spatial analysis and output showing how successful the proposed boundaries were in achieving targets, as well as a tabular output.

Spatial results of summed solutions (see Section 3.8.1 'Irreplaceable' areas – summed solution') using proposed boundaries as 'locked in' areas can highlight areas that are important for achieving targets, but which may fall outside of the proposed boundaries. These areas can then be reconsidered for inclusion in the proposed reserve network, or recommended for future acquisition or alternative conservation management arrangements.

The tabular output file (MarOptTotalAreas.csv) compares the target areas of conservation features with the areas of those features that are 'locked in' to existing, proposed and/or draft reserves, and 'locked out' of excluded areas (in the PEMB case existing port or industrial tenure or administrative areas). This allows a statistical analysis of the extent to which conservation features do or do not get captured in the input reserve boundaries and of which features and how much of them are found within 'locked out' areas.

Table 15: A sample of the output MarOptTotalAreas.csv file. 'spname' is the name or code of the conservation feature files. 'totalarea' is the total area of the conservation features, 'reservedarea' is the amount of the features contained in 'locked in' planning units, 'excludedarea' is the amount of the features contained in 'locked out' of planning units, 'targetarea' is the amount of the feature targeted by the analysis, and 'totalocc', 'reservedocc', excludedocc' and 'targetocc' are the equivalent statistics for occurrences of features (as opposed to areas).

spname	spindex	totalarea	reservedarea	excludedarea	targetarea	totalocc	reservedocc	excludedocc	targetocc
1	106	144.046	0.2379	23.7844	43.2139	366	4	86	0
2	105	1180.68	18.2498	113.378	354.205	752	41	118	0
3	104	9.571	7.7309	1.8401	7.6568	34	27	7	0
4	103	4216	258.393	958.689	1264.8	1572	224	346	0
5	102	1492.03	1.0464	230.06	447.609	740	10	131	0
6	101	3136.68	331.623	73.8663	941.004	1051	192	39	0

The ability to change and input planning objectives rapidly, by changing the conservation feature targets, and applying these changes to the underlying data allow planners a rapid and objective method to understand the effects of different boundaries and targets on the outcomes.

4 MARXAN RESULTS

Throughout Trial 1, 2 and 3 there were hundreds of output results. The following results are those that were considered to be 'final' outputs, for the various targeting options compiled. These outputs contributed to the final design of the proposed marine reserves, and demonstrate the 'successful' results of analyses of a range of targeting options – i.e. those that achieved the set of input targets within acceptable tolerances.

Regardless of the input targets, the effect of existing tenure is seen through all analyses of Scenarios 1 – 3, as the analyses move from a flexible situation of no existing tenure (Scenario 1) to having existing and current proposed reserves locked into solutions (Scenario 2), to the 'real world' situation where reserve selection is further constrained by being locked out of existing port and industrial tenure (Scenario 3).

In analyses of Scenario 1, reserve selection tends to be clumped, according to the Boundary Length Modifier setting, but reserves tend to be distributed evenly across the region, as habitat/surrogate features are targeted within coastal compartments.

The 'locked in' status of existing and proposed reserves focuses the Marxan algorithm to add on to existing MPA boundaries in Scenario 2, as existing reserves contribute to achievement of targets and the Boundary Length Modifier encourages planning unit selection adjacent to these boundaries. Many conservation features are fully or mostly captured within existing reserve boundaries.

The constraint of the port and industrial 'locked out' areas of Scenario 3 focuses reserve selection to areas between this unavailable tenure, particularly between Port Hedland and Onslow. Several 'rare' or small habitat/surrogate conservation features cannot achieve targets as significant proportions of their total areas fall within the 'locked out' tenure.

4.1 Targeting Option 1 – species file specT3_3_1.dat

The results of Targeting Option 1 (see Section 2.6.3 Compiling targets as targeting options) are presented in Figure 10 to demonstrate the effect of a basic 30% habitat/surrogate target, 30% of all mangroves (made up of 50% of the regionally significant mangrove areas) and 50% of turtle nesting beaches (100% of highest two rankings of beaches, and 20% of the third ranked beaches).

4.2 Targeting Option 4 – species file specT3_3_4.dat

The results of Targeting Option 4 (see Section 2.6.3 Compiling targets as targeting options) are presented in Figure 11 and demonstrate the effect of an alternate targeting option where target areas of coarse filter features (habitat/surrogates) were based on a weighting system where larger/widespread/common features were assigned proportionally lower targets than smaller/rare/uncommon features.

Other targets were as for Targeting Option 1: 30% of all mangroves (made up of 50% of the regionally significant mangrove areas) and 50% of turtle nesting beaches (100% of highest two rankings of beaches, and 20% of the third ranked beaches).

4.3 Targeting Option 7 – species file specT3_3_7.dat

The results presented for Targeting Option 7 in Figure 12 represent the full development of input data and targets throughout the Marxan component of the PEMB planning process. This analysis was considered the best representation of the broader planning process achievable with the available data and resource constraints. These results were the main Marxan output that contributed to the design of draft proposed outer boundary designs described in the draft indicative management plan as at July 2009.

This analysis targeted 100% of the small and rare habitat features mapped as 'Nearshore Reef' or 'Offshore Reef', 70% of 'Shallow Island Fringes' and 30% of the other broad depth- or geomorphology-based habitat classes. Fine filter targets of 30% of mangroves in the region (45% of regionally significant with, or without development allowed), and 50% of turtle nesting beaches (100% of highest two rankings of beaches, and 20% of the third ranked beaches) were used.

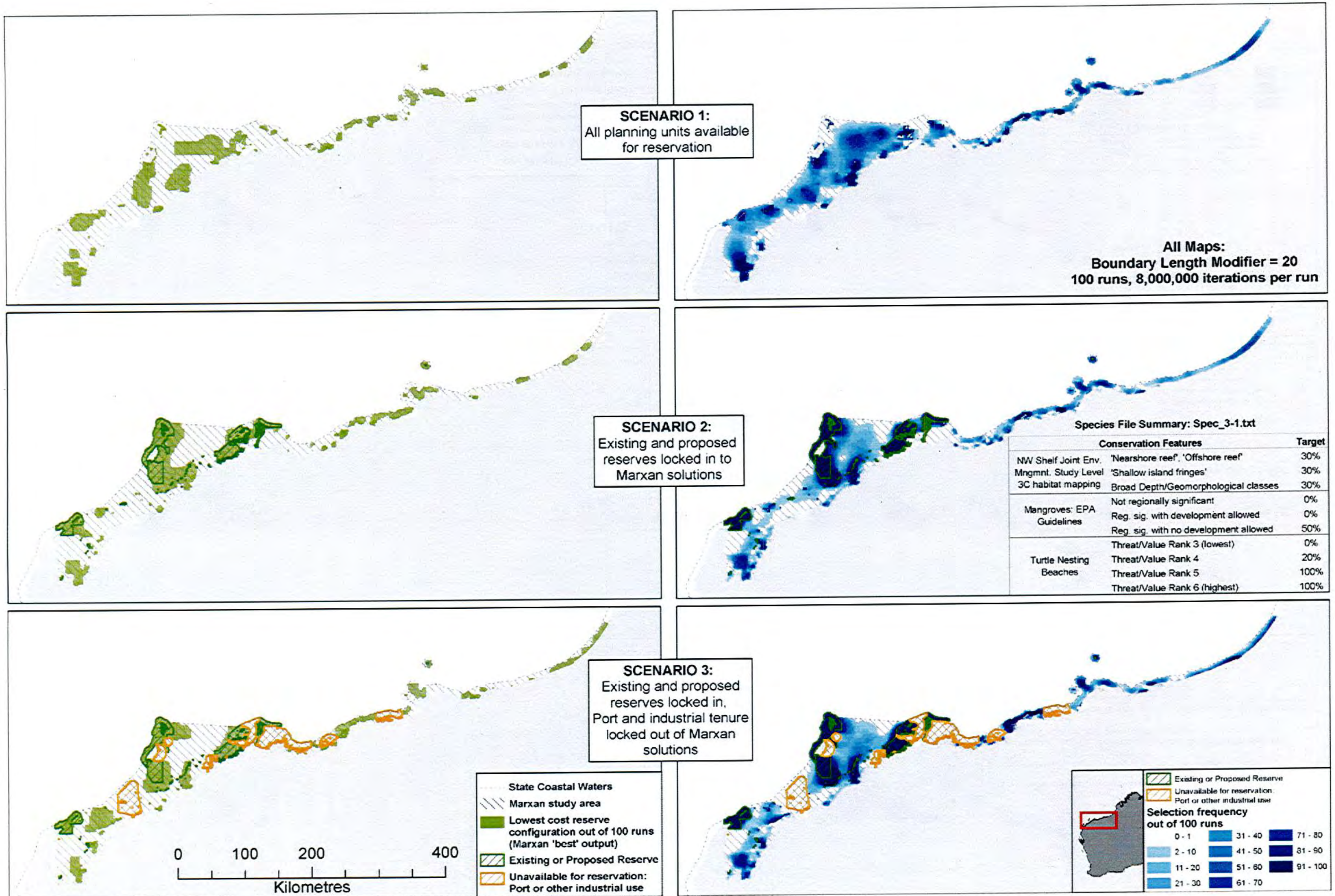

Figure 10: Summed solutions and 'best' results for Scenarios 1, 2 and 3, using Targeting Option 1: ***specT3_3_1.dat*****.**

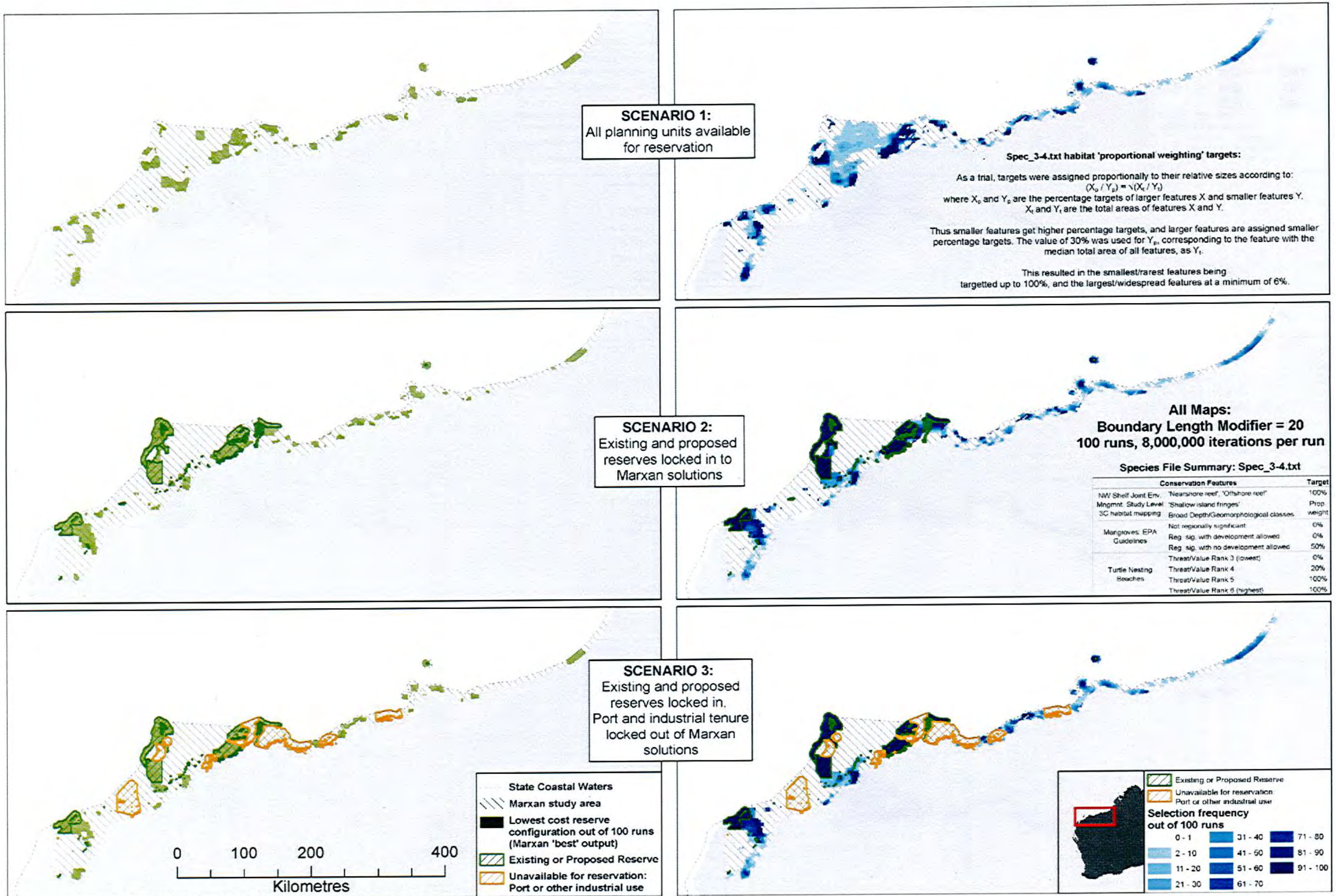

Figure 11:Summed solutions and 'best' results for Scenarios 1, 2 and 3, using Targeting Option 4: specT3_3_4.dat

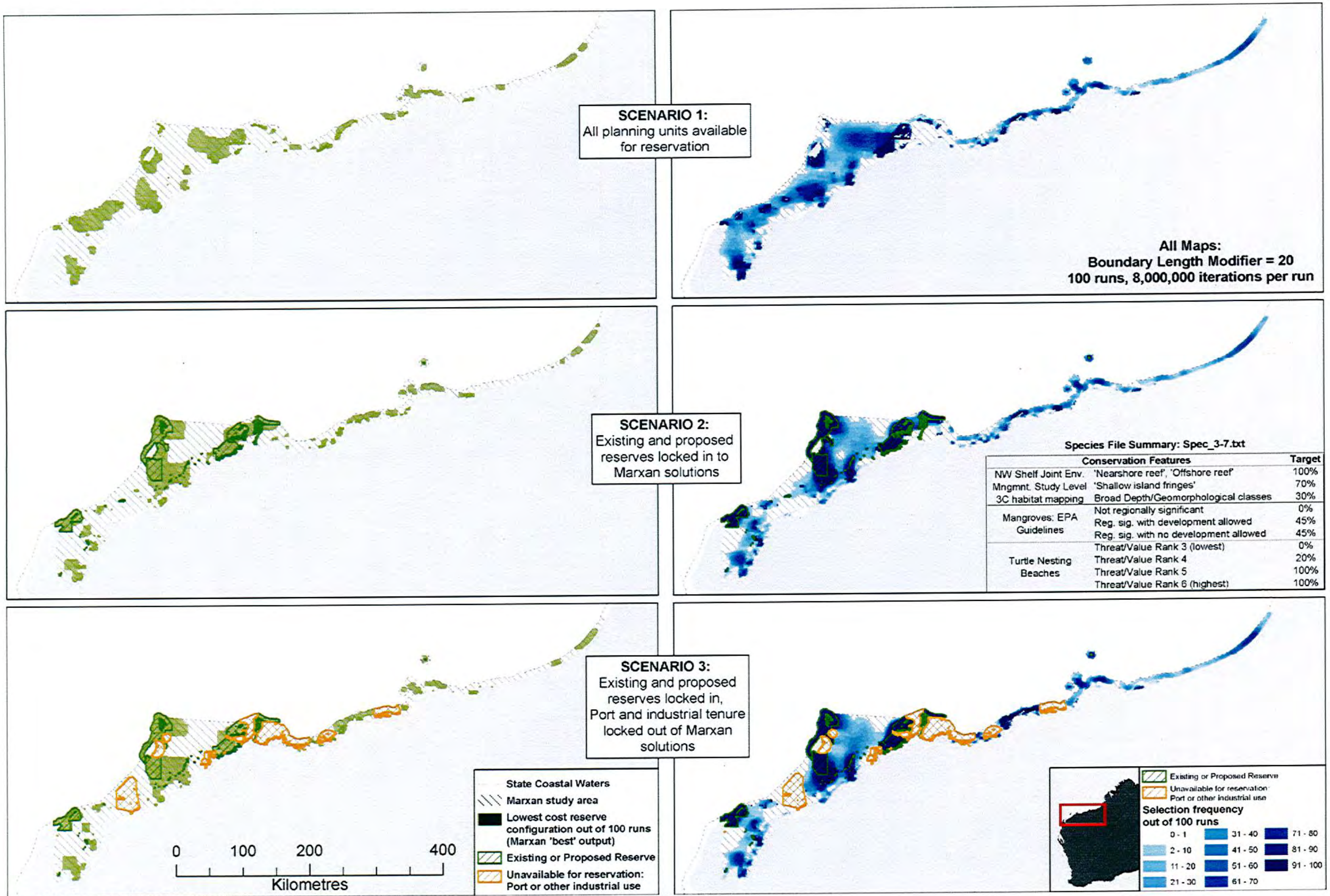

Figure 12: Summed solutions and 'best' results for Scenarios 1, 2 and 3, using Targeting Option 7: *specT3_3_7.dat*

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4.4 Analysis of proposed reserve design using Marxan

A draft proposed reserve design was completed in June 2009, through consultation with stakeholders and using the Marxan results presented in this report as a guide to irreplaceable areas required to satisfy the core goals of the planning process. This reserve configuration was analysed for the extent to which it satisfied the numerical targets used in the Marxan run. Figure 13 shows the proposed reserves set against a Marxan analysis that modified Scenario 3 to include the proposed reserve boundaries as 'locked in' areas. Table 16 provides an analysis of the extent to which the draft proposed marine network, and the existing reserves and proposed reserves contribute towards achievement of the targets. Also shown is the extent to which existing ports and industrial tenure exclude some features from reservation.

It can be seen from these analyses that the draft proposed reserve network achieves most of the targets for conservation features, where they are not excluded from total achievement by 'locked out' areas. Deeper water areas in the Barrow coastal compartment, and conservation features in Exmouth Gulf and Roebourne coastal compartment are the only set of features that were not achieved, due to reserve design decisions rather than exclusion by existing tenure.

Also of note is the extent to which many features are over-achieved by the reserve design (blue figures in Table 16).

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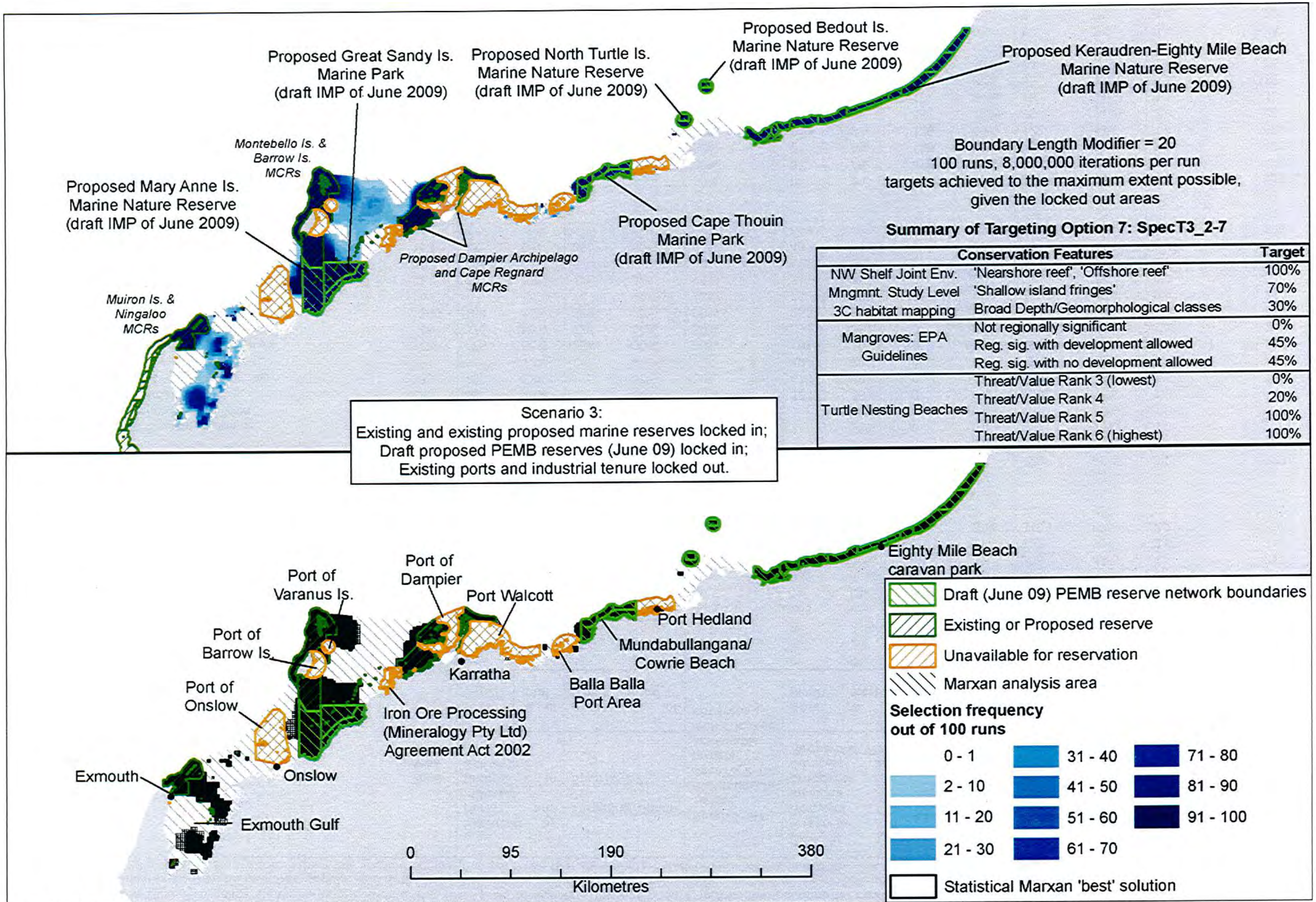

Figure 13: Results of the analysis of the draft proposed outer boundaries of the Pilbara and Eighty Mile Beach marine reserve network.

Table 16: Results of the analysis of the achievement of targets, the extent to which targets are already achieved by existing reserves or proposals, excluded by existing port and industrial tenure, and the draft proposed outer boundaries as at June 2009. Red italics show the modification of the 'final' suite of targets – Target Option 7, to take into account the maximum amounts of reservation achievable given the locked out areas. Figures in blue show features that have more than double their targets held in the proposed marine conservation reserve network, whilst figures in red (non-italics) are features that fall below their target representation. Note: some obsolete conservation features have been removed from this table, greyed out features are those that were not targeted, or were not assigned Species Penalty Factors and thus are included purely for reporting purposes.

ID	Conservation feature name	Total Area (km2)	Excluded by ports and industry tenure in Scenario 3		Targeting Option 7: SpecT3_2-7		SpecT3_5-7 Target : maximum of specT3_2-7 targets achievable with locked out areas	Existing Reserves in Scenario 3: *includes proposed Dampier and Regnard MCRs*		Added by draft proposed PEMB reserves		Combined existing Scenario 3 + PEMB Reserves		Proportion of specT3_2-7 target held in Existing + proposed PEMB reserves	Amount Held in Marxan 'best' solution (Figure 13)	
			Area (km2)	% of total	Area (km2)	% of total		Area (km2)	% of total	Area (km2)	% of total	Area (km2)	% of total	proportion	Area (km2)	% of total
1	Barrow_Mud and tidal flats	144	24	17%	43	30%	30%	0	0%	85	59%	85	59%	2.0	86	59%
2	Barrow_Nearshore Waters lt 5 metres	1181	113	10%	354	30%	30%	18	2%	481	41%	500	42%	1.4	529	45%
3	Barrow_Nearshore reef	10	*2*	*19%*	*10*	*100%*	*81%*	8	81%	0	0%	8	81%	0.8	8	81%
4	Barrow_Offshore Waters 10 20 metres	4216	959	23%	1265	30%	30%	258	6%	376	9%	635	15%	0.5	1266	30%
5	Barrow_Offshore Waters 5 10 metres	1492	230	15%	448	30%	30%	1	0%	429	29%	430	29%	1.0	518	35%
6	Barrow_Offshore Waters gt 20 metres	3137	74	2%	941	30%	30%	332	11%	0	0%	332	11%	0.4	941	30%
7	Barrow_Offshore waters 510 metres island, shoal	598	161	27%	179	30%	30%	240	40%	18	3%	258	43%	1.4	277	46%
8	Barrow_Offshore waters lt 5 metres island, shoal	917	118	13%	275	30%	30%	702	76%	21	2%	722	79%	2.6	742	81%
9	Barrow_Salt flats	519	12	2%	156	30%	30%	0	0%	349	67%	349	67%	2.2	357	69%
10	Barrow_Shallow island fringe	452	99	22%	0	0%	0%	253	56%	79	17%	332	73%	-	340	75%
11	Barrow_UNKNOWN	18	1	6%	5	30%	30%	6	35%	7	38%	13	72%	2.4	13	75%
12	Dampier_Channel Deep 10 20 metres	0	0	0%	0	0%	0%	0	100%	0	0%	0	100%	-	0	100%
13	Dampier_Channel Moderate 5 10 metres	135	6	5%	41	30%	30%	129	95%	0	0%	129	95%	3.2	129	95%
14	Dampier_Channel Moderate Inshore 5 10 metre	85	*66*	*79%*	*25*	*30%*	*21%*	18	21%	0	0%	18	21%	0.7	18	21%
15	Dampier_Channel Shallow lt5 metres	7	5	75%	2	30%	30%	2	25%	0	0%	2	25%	0.8	2	25%
16	Dampier_Embayment Subtidal Zone	3	2	60%	1	30%	30%	1	40%	0	0%	1	40%	1.3	1	40%
17	Dampier_Mud and tidal flats	223	89	40%	67	30%	30%	125	56%	0	0%	125	56%	1.9	126	56%
18	Dampier_Nearshore Waters lt 5 metres	383	199	52%	115	30%	30%	176	46%	0	0%	176	46%	1.5	180	47%
19	Dampier_Nearshore reef	24	*5*	*22%*	*24*	*100%*	*78%*	19	78%	0	0%	19	78%	0.8	19	78%
20	Dampier_Offshore Waters 10 20 metres	848	475	56%	255	30%	30%	165	19%	0	0%	165	19%	0.6	257	30%
21	Dampier_Offshore Waters 5 10 metres	576	376	65%	173	30%	30%	200	35%	0	0%	200	35%	1.2	200	35%
22	Dampier_Offshore Waters gt 20 metres	1298	164	13%	389	30%	30%	253	20%	0	0%	253	20%	0.7	390	30%
23	Dampier_Offshore reef	74	*1*	*1%*	*74*	*100%*	*99%*	70	95%	0	0%	70	95%	0.9	73	99%
24	Dampier_Offshore waters 510 metres island, shoal	38	*34*	*88%*	*11*	*30%*	*12%*	3	7%	0	0%	3	7%	0.2	5	12%
25	Dampier_Offshore waters lt 5 metres island, shoal	17	*13*	*77%*	*5*	*30%*	*23%*	1	8%	0	0%	1	8%	0.3	4	23%
26	Dampier_Salt flats	118	11	9%	35	30%	30%	48	41%	0	0%	48	41%	1.4	48	41%
27	Dampier_Shallow island fringe	241	31	13%	0	0%	0%	209	87%	0	0%	209	87%	-	209	87%
28	Dampier_Tidal channel subtidal	6	3	56%	0	0%	0%	2	40%	0	0%	2	40%	-	2	40%
29	Dampier_UNKNOWN	5	3	54%	2	30%	30%	2	32%	0	0%	2	32%	1.1	2	33%
30	De Grey_Mud and tidal flats	290	1	0%	87	30%	30%	0	0%	115	40%	115	40%	1.3	115	40%
31	De Grey_Nearshore Waters lt 5 metres	990	13	1%	297	30%	30%	0	0%	410	41%	410	41%	1.4	410	41%
32	De Grey_Offshore Waters 10 20 metres	264	0	0%	79	30%	30%	0	0%	155	59%	155	59%	2.0	163	62%
33	De Grey_Offshore Waters 5 10 metres	303	7	2%	91	30%	30%	0	0%	129	43%	129	43%	1.4	129	43%
34	De Grey_Offshore Waters gt 20 metres	66	0	0%	20	30%	30%	0	0%	66	100%	66	100%	3.3	66	100%
35	De Grey_Offshore waters 5 10 metres island, shoal	16	0	0%	5	30%	30%	0	0%	15	94%	15	94%	3.1	15	94%
36	De Grey_Offshore waters lt 5 metres island, shoal	32	0	0%	10	30%	30%	4	13%	28	87%	32	100%	3.3	32	100%
37	De Grey_Salt flats	221	1	0%	66	30%	30%	0	0%	74	33%	74	33%	1.1	76	34%
38	De Grey_UNKNOWN	1	0	0%	0	30%	30%	0	0%	0	33%	0	33%	1.1	0	33%
39	Exmouth_Mud and tidal flats	246	0	0%	74	30%	30%	5	2%	0	0%	5	2%	0.1	74	30%
40	Exmouth_Nearshore Waters lt 5 metres	747	0	0%	224	30%	30%	3	0%	0	0%	3	0%	0.0	224	30%

ID	Conservation feature name	Total Area (km2)	Excluded by ports and industry tenure in Scenario 3		Targeting Option 7: SpecT3_2-7		SpecT3_5-7 Target : maximum of specT3_2-7 targets achievable with locked out areas	Existing Reserves in Scenario 3: *includes proposed Dampier and Regnard MCRs*		Added by draft proposed PEMB reserves		Combined existing Scenario 3 + PEMB Reserves		Proportion of specT3_2-7 target held in Existing + proposed PEMB reserves	Amount Held in Marxan 'best' solution (Figure 13)	
			Area (km2)	% of total	Area (km2)	% of total		Area (km2)	% of total	Area (km2)	% of total	Area (km2)	% of total	proportion	Area (km2)	% of total
41	Exmouth_Nearshore reef	8	0	0%	8	100%	100%	6	74%	0	0%	6	74%	0.7	8	100%
42	Exmouth_Offshore Waters 10 20 metres	1911	0	0%	573	30%	30%	471	25%	0	0%	471	25%	0.8	575	30%
43	Exmouth_Offshore Waters 5 10 metres	882	0	0%	265	30%	30%	10	1%	0	0%	10	1%	0.0	265	30%
44	Exmouth_Offshore Waters gt 20 metres	154	0	0%	46	30%	30%	94	61%	0	0%	94	61%	2.0	95	62%
45	Exmouth_Offshore waters 510 metres island, shoal	29	0	0%	9	30%	30%	12	40%	0	0%	12	40%	1.3	15	50%
46	Exmouth_Offshore waters lt 5 metres island, shoal	23	0	0%	7	30%	30%	11	47%	0	0%	11	47%	1.6	13	59%
47	Exmouth_Salt flats	996	0	0%	299	30%	30%	8	1%	0	0%	8	1%	0.0	299	30%
48	Exmouth_Shallow island fringe	18	0	0%	0	0%	0%	6	34%	0	0%	6	34%	-	14	80%
49	Exmouth_UNKNOWN	12	0	0%	3	30%	30%	4	38%	0	0%	4	38%	1.3	4	38%
50	Roebourne_Mud and tidal flats	438	256	58%	131	30%	30%	0	0%	115	26%	115	26%	0.9	132	30%
51	Roebourne_Nearshore Waters lt 5 metres	688	443	64%	207	30%	30%	0	0%	165	24%	165	24%	0.8	208	30%
52	Roebourne_Nearshore reef	0	0	100%	0	0%	0%	0	0%	0	0%	0	0%	-	0	0%
53	Roebourne_Offshore Waters 10 20 metres	55	55	100%	16	30%	0%	0	0%	0	0%	0	0%	0.0	0	0%
54	Roebourne_Offshore Waters 5 10 metres	574	261	45%	172	30%	30%	0	0%	190	33%	190	33%	1.1	202	35%
55	Roebourne_Offshore waters 510 metres island, sho	0	0	100%	0	30%	30%	0	0%	0	0%	0	0%	0.0	0	0%
56	Roebourne_Offshore waters lt 5 metres island, shoa	6	2	40%	2	30%	30%	0	0%	0	1%	0	1%	0.0	2	31%
57	Roebourne_Salt flats	556	33	6%	167	30%	30%	0	0%	138	25%	138	25%	0.8	167	30%
58	Roebourne_Tidal channel subtidal	1	0	0%	0	0%	0%	0	0%	1	100%	1	100%	-	1	100%
59	Roebourne_UNKNOWN	7	1	8%	2	30%	30%	0	0%	1	15%	1	15%	0.5	1	19%
60	Wallal_Mud and tidal flats	182	0	0%	54	30%	30%	0	0%	182	100%	182	100%	3.3	182	100%
61	Wallal_Nearshore Waters lt 5 metres	752	0	0%	226	30%	30%	0	0%	751	100%	751	100%	3.3	751	100%
62	Wallal_Offshore Waters 5 10 metres	465	0	0%	139	30%	30%	0	0%	457	98%	457	98%	3.3	457	98%
63	Barrow_Mangroves not regionally significant	27	1	4%	0	0%	0%	0	1%	22	82%	22	84%		23	84%
64	Barrow_Regionally significant mangroves with development allowed with conditions	8	1	15%	0	0%	0%	0	0%	0	0%	0	0%	-	0	0%
65	Barrow_Regionally significant mangroves with no development	71	2	3%	0	0%	0%	0	1%	64	91%	65	92%	-	65	92%
66	Dampier_mangroves not regionally significant	21	3	15%	0	0%	0%	15	70%	0	0%	15	70%	-	15	70%
67	Dampier_Regionally significant mangroves with development allowed with conditions	22	2	9%	0	0%	0%	16	73%	0	0%	16	73%	-	16	73%
68	Dampier_Regionally significant mangroves with no development	21	6	27%	0	0%	0%	5	24%	0	0%	5	24%	-	5	24%
69	De Grey_mangroves not regionally significant	31	1	2%	0	0%	0%	0	0%	18	58%	18	58%	-	19	60%
70	De Grey_Regionally significant mangroves with no development	15	0	0%	0	0%	0%	0	0%	0	0%	0	0%	-	0	0%
71	Exmouth_mangroves not regionally significant	20	0	0%	0	0%	0%	0	2%	0	0%	0	2%	-	1	5%
72	Exmouth_Regionally significant mangroves with no development	133	0	0%	0	0%	0%	7	5%	0	0%	7	5%	-	41	31%
73	Roebourne_mangroves not regionally significant	95	31	33%	0	0%	0%	0	0%	2	2%	2	2%	-	2	2%
74	Roebourne_Regionally significant mangroves with no development	113	15	14%	0	0%	0%	0	0%	56	50%	56	50%	-	57	50%
75	Wallal_mangroves not regionally significant															
76	turt_internesting	3515	347	10%	1055	30%	30%	1075	31%	720	20%	1795	51%	1.7	2237	64%
77	turt_foraging	2738	211	8%	0	0%	0%	95	3%	608	22%	702	26%	-	1239	45%
78	mangals_not regionally_significant	194	36	19%	0	0%	0%	16	8%	42	21%	57	30%	-	59	31%
79	mangals_regionally significant no_development allowed	352	23	7%	158	45%	45%	13	4%	121	34%	133	38%	0.8	168	48%

ID	Conservation feature name	Total Area (km2)	Excluded by ports and industry tenure in Scenario 3		Targeting Option 7: SpecT3_2-7		SpecT3_5-7 Target : maximum of specT3_2-7 targets achievable with locked out areas	Existing Reserves in Scenario 3: *includes proposed Dampier and Regnard MCRs*		Added by draft proposed PEMB reserves		Combined existing Scenario 3 + PEMB Reserves		Proportion of specT3_2-7 target held in Existing + proposed PEMB reserves	Amount Held in Marxan 'best' solution (Figure 13)	
			Area (km2)	% of total	Area (km2)	% of total		Area (km2)	% of total	Area (km2)	% of total	Area (km2)	% of total	proportion	Area (km2)	% of total
80	mangals_ regionally significant development_allowed	31	3	11%	14	45%	45%	16	53%	0	0%	16	53%	1.2	16	53%
81	turt_beaches_all	142	13	9%	71	50%	50%	46	32%	55	38%	100	70%	1.4	109	76%
87	IMCRA_EMB	1771	0	0%	531	30%	30%	0	0%	1724	97%	1724	97%	3.2	1724	97%
88	IMCRA_PIO	10002	1263	13%	3001	30%	30%	2208	22%	569	6%	2777	28%	0.9	3974	40%
89	IMCRA_PIN	16327	3109	19%	4898	30%	30%	1651	10%	2679	16%	4330	27%	0.9	5886	36%
90	Mangroves in EMB IMCRA	0	0	0%	0	30%	30%	0	0%	0	6%	0	6%	0.2	0	6%
91	Mangroves in PIN IMCRA	576	62	11%	173	30%	30%	44	8%	162	28%	206	36%	1.2	243	42%
92	Mangrove in PIO IMCRA	1	0	0%	1	100%	100%	1	46%	0	1%	1	47%	0.5	1	100%
93	mangrove_all	577	62	11%	173	30%	30%	45	8%	162	28%	207	36%	1.2	244	42%
94	PIN_Barrow_Shallow island fringe	93	2	2%	65	70%	70%	8	9%	79	85%	87	93%	1.3	88	95%
95	PIN_Dampier_Shallow island fringe	241	31	13%	168	70%	70%	209	87%	0	0%	209	87%	1.2	209	87%
96	PIN_Exmouth_Shallow island fringe	12	0	0%	8	70%	70%	0	0%	0	0%	0	0%	0.0	8	70%
97	PIO_Barrow_Shallow island fringe	359	97	27%	251	70%	70%	245	68%	0	0%	245	68%	1.0	251	70%
98	PIO_Exmouth_Shallow island fringe	6	0	0%	4	70%	70%	6	97%	0	0%	6	97%	1.4	6	99%
103	Turtle nest final Threat/Value rank 3	15	2	13%	0	0%	0%	1	7%	1	7%	2	14%	-	2	14%
104	Turtle nest final Threat/Value rank 4	68	4	6%	14	20%	20%	5	8%	46	68%	51	76%	3.8	54	80%
105	Turtle nest final Threat/Value rank 5	31	*3*	*8%*	*31*	*100%*	*92%*	17	56%	6	20%	24	76%	0.8	29	92%
106	Turtle nest final Threat/Value rank 6	27	*5*	*17%*	*27*	*100%*	*83%*	23	83%	0	0%	23	83%	0.8	23	83%

5 Discussion

Overall, the broad aims of using Marxan as a decision support tool for the Pilbara and Eighty Mile Beach marine reserve planning process to investigate the application of Marxan in the WA MCR planning context, and to assist with PEMB reserve design, were achieved.

The potential for Marxan to take a central role in this multiple-objective planning process involving a variety of stakeholders was not fully realised, mainly due to a lack of readily available suitable spatial information to represent stakeholders' interests, and limited resources to create new data as would be required. However, early in the planning process when these limitations were realised, the planning team adapted the role that Marxan would have in the process and remained a useful tool for the design of reserve outer boundaries, as described further below.

The end result was a thorough understanding of the Marxan methodology and its potential for use in a range of planning applications to suit available resourcing, documented in this report. The results of the Marxan trial provided a useful summary of areas that were important for the suite of environmental values analysed through the Marxan conservation feature set and targeting options, but it did not address socio-economic or cultural values, other than the exclusion of existing port and industrial tenure from reserve configurations.

Another outcome was an informal workshop was run on 16th June 2010 with Department of Environment and Conservation staff in other work areas, who were using Marxan for planning at the time, were planning to in the future, or had in the past. This workshop provided the opportunity to share experiences and to discuss the benefits and limitations of Marxan as a reserve planning tool in WA, and these discussions informed the Conclusions of this report.

5.1 Marxan as a tool for PEMB reserve and/or management zoning design

Outcomes:

- ***Marxan was not used as the primary method of reserve design. Reserves were designed using GIS methods incorporating data from a range of sources, which included Marxan results of ecologically important areas, and other stakeholder and scientific advice.***
- ***Marxan provided important information and analyses for the identification of ecologically important areas, for a regional assessment of reserve outer boundary designs.***
- ***Information about user groups other than port or industrial tenure or administration areas could not be included in the Marxan analyses, and stakeholders did not contribute significantly to the target development and results analysis process.***
- ***Management zoning design was undertaken outside of the Marxan analysis.***

The Pilbara and Eighty Mile Beach marine reserve planning process was set up as a systematic, regional assessment of conservation and socio-economic values, with a primary purpose of securing conservation outcomes for flatback turtle nesting, a representative marine reserve network, and minimal impact on existing uses. Like other marine reserve planning processes conducted in WA, it was a multi-stakeholder process with multiple objectives. Outcomes were considered a Government priority, with an indicative management plan to be delivered within 2 ½ years (December 2006 to June 2009).

Marxan can be the main conduit for gathering and including stakeholder information and objectives as well as the underlying environmental information and conservation objectives that drive a marine reserve planning process. Having clearly defined and easily communicable objectives (as numerical targets), based on validated research agreed to by all stakeholders, analysed against accurate and scientifically robust information by an objective 'black box' such as Marxan has the potential to streamline planning processes (see examples and methods in Ardron *et al.* 2008). By achieving agreed conservation objectives at the minimal cost to other stakeholders in such as way that can be clearly and objectively communicated, stakeholder agreement can potentially be secured with minimised negotiation processes that can often be lengthy and result in reduced conservation outcomes. For these reasons, Marxan was viewed as having the potential to take a central role in the PEMB planning process.

The Marxan system was set up and trialled in early stages of the PEMB process (Trial 1 – see Section 3.1.1 'Trial 1' (Aug/Sept 2008), and the requirement for high-quality data and spatially comprehensive data, able to address at least the most important of the 21 reserve design criteria was quickly established. The procedure for undertaking a Marxan-based planning process requires conservation goals and planning unit costs to be objectively set and based on well-accepted research. The input spatial information thus also needs to be accepted by stakeholders, and accurately represent the conservation features or costs that make up the Marxan problem set, to an accepted scale and with comprehensive coverage across the planning area.

5.1.1 Data limitations

The ability to use Marxan as the primary tool for reserve design was compromised by a lack of high-quality data upon which to base the analysis of targets. Results of Marxan analyses were added to a suite of other information sources including stakeholder advice, scientific advice and MPRA guidance. The resultant draft proposed reserve network of June 2009 was designed partly on the information and targets of the Marxan analyses, as well as other information and objectives not captured within the Marxan system. Thus not all Marxan conservation feature targets were achieved by the resultant draft proposed reserve network of June 2009, and some were substantially over-represented (see Section 4.4 Analysis of proposed reserve design using Marxan).

The Pilbara and Eighty Mile Beach region of Western Australia is sparsely populated and ecologically diverse, with little available scientific data to describe environmental values comprehensively across its extent. Human usage values are similarly poorly mapped, with little suitable spatial information readily available to accurately describe key uses such as commercial, recreational or customary fishing, marine tourism, indigenous cultural importance, resource prospectivity or potential for future developments.

Through the resource assessment, community information sessions, indigenous engagement program and consultations with scientific and industry experts, it was evident that the local communities, traditional owners, scientists and industry had an extensive and detailed understanding of the area and its environmental, socio-economic and cultural values; however at the time of planning, this information was generally not captured or documented in suitable spatial form to use as Marxan inputs without considerable investment in new data capture/creation. This was not possible within the time and resource constraints of the project.

Thus the available socio-economic information was limited to data describing areas that were not available for reservation due to the existence of incompatible existing tenure or administration arrangements. These were the regional ports of Onslow, Barrow Island, Varanus Island, Dampier, Port Walcott, Balla Balla and Port Hedland, and the State Agreement Act area at Cape Regnard (Figure 2). Other methods of including socio-economic data into a Marxan system, such as including in the cost of planning units (see Section 2.1.3 Planning Unit Cost - ∑PUsCost), could not be achieved within time and resource constraints.

This limited the potential for engagement of marine user groups in the development of Marxan analysis options, as their usage values would have no representation in the Marxan analytical system. Once this limitation was established, the role of Marxan was re-adjusted to being largely an in-house tool for identifying priority areas for the achievement of ecological targets only. Stakeholders were kept informed of the development of the Marxan analyses, but did not contribute significantly to targeting; however, scientific advice was sought in the setting of ecological targets and the creation of input data.

The available environmental data was assessed to be most suited to a regional Marxan assessment of priority areas for outer boundary location, based on regionalisations (IMCRA), sub-regionalisation (coastal compartments) and broad geomorphologic and depth-based habitat/habitat surrogate classifications (NWSJEMS level 3C), distribution of regionally important mangals and turtle nesting beaches.

This regional level of analysis of potential outer boundary configurations based solely on existing tenure and the best available conservation features mapping also addressed the lack of socio-economic data, as human usages within marine reserves are generally managed through the negotiation and design of management zones within parks, once outer boundaries have been designed.

5.1.2 Management zoning outside of the Marxan process

Management zoning (including no-take sanctuary areas) using Marxan (or MarZone) was not supported by the scale of available habitat mapping data, but would later be undertaken with advice from scientific experts and stakeholders, and informed by results of the rapid-assessment PEMB habitat groundtruthing survey (Zuideveld *et al.* 2010).

This approach increases the risk that, at the time of management zoning design, negotiations to reduce impacts on existing users may result in those features being under-represented in no-take sanctuary zones, or not represented at all. This works against one of the key features of Marxan, in that it can ensure achievement of representation targets, given the appropriate data and opportunity to avoid impacting existing users.

The planning units in a viable Marxan reserve configuration solution are selected for their complementarity – that is, the extent to which they add to the rest of the planning units' achievement of targets. Removing some selected areas after a Marxan analysis not only reduces the extent to which targets are achieved by the remaining reserved PUs, but also changes the relative importance of all PUs in the solution. This potentially makes the result less efficient and less viable than if the excluded area could have been factored in from the beginning of the process.

Despite the management zoning process being undertaken outside of an objective process such as Marxan, the reserve design criteria still required "adequate no-take areas within marine reserves", regardless of the method used to select them (see Table 1). The resultant draft proposed sanctuary zones included between 16% and 34% of proposed reserve areas, and included the range of habitat types present in each reserve area. They were considered generally representative of the major marine benthic habitats within the proposed marine parks, achieved by placing sanctuary zones over a variety of depth classifications and habitat types. For more information on the biodiversity values represented in each sanctuary zone refer to Section 7.1 of the draft indicative management plan (June 2009, IMP version 5).

Table 17: The size and percentage area of sanctuary zones in the draft proposed Pilbara and Eighty Mile Beach marine conservation reserves. Taken from draft indicative management plan of June 2009 (draft IMP version 5).

	Sanctuary Zone (ha)(%)
Proposed Great Sandy Island Marine Park	
Mary Anne Island SZ	28,430
Mangrove Islands SZ	22,745
Total	**51,175 (26%)**
Proposed Cape Thouin Marine Park	
Cowrie Beach SZ	**10,858 (16%)**
Proposed Bedout & North Turtle Islands Marine Park	
Bedout Island SZ	6,073
North Turtle Island SZ	5,285
Total	**11,358 (34%)**
Proposed Eighty Mile Beach Marine Park	
Anna Plains SZ	40,080
Cape Keraudren SZ	1,030
Pardoo SZ	13,706
Total	**54,817 (26%)**
TOTAL	**128,208**

5.2 Marxan and stakeholder consultation in PEMB

Outcomes:

- ***The opportunity for stakeholder engagement in the Marxan analysis was limited by the time and resource constraints of the broader planning process.***
- ***Manipulation of Marxan parameters and setting of various targeting options was done solely outside of planning sessions. Marine usage group stakeholders did not contribute to detailed Marxan target setting***
- ***Stakeholder aspirations were captured in the reserve design criteria, several of which were addressed by Marxan.***
- ***Government and industry stakeholders were shown the development of targets, input data and preliminary Marxan analysis results at every opportunity.***
- ***Scientific stakeholders contributed to setting of targets and the creation and assessment of input data.***
- ***The demonstration of systematic planning methods using Marxan encouraged the provision of sensitive data by some commercial fishing stakeholders, but this data was not an eventual input into Marxan.***
- ***Government, community and industry stakeholders strongly supported the use of systematic planning with Marxan, despite the limitations within this project to fully represent their interests in the input data or targeting.***

It was intended that Marxan would assist in the creation of a demonstrably transparent, objective, systematic assessment of the information and planning goals, that it would complement the important role that GIS has in assisting planning negotiations and decisions. One of the uses of Marxan is to be able to clearly demonstrate to stakeholders the effect of adding or removing a piece of information, or changing planning targets. Importantly for many stakeholders, the objective nature of Marxan analysis demonstrates that their provision of accurate and detailed data representing their interests is highly beneficial in ensuring good outcomes of the process.

For example, if information about an important commercial fishing area was provided and input as a cost to the Marxan system, the selection of planning units covering that area will cost the system more and so the Marxan algorithm would work to avoid such high-cost areas, if conservation outcomes can be achieved without them (e.g. Stewart and Possingham 2005). Without the accurate fishing area information, this would not be possible in an objective analysis. Achieving the same result by negotiation can be a highly complex task, as a change in reserve design to accommodate one socio-economic objective can lead to non-achievement of conservation targets, resulting in the need to redesign boundaries. This can lead to impacts on other stakeholders, requiring another change of boundary, and so on. The end result can potentially be that conservation outcomes are compromised by the multiple objectives of socio-economic stakeholders, or that resultant boundary designs are relatively inefficient (Mangel *et al.* 1996, Stewart and Possingham 2005).

In the PEMB process, consultation was undertaken with stakeholders via the government agency Interdepartmental Working Group (IWG), the Fishing Consultation Group, native title groups and Aboriginal Corporations through the Indigenous Engagement Program, and contact directly with other industry representatives, local pastoralists, individuals and scientific experts. Information from these sources, the resource assessment and the Marxan analyses was then considered by the planning team who, with advice from the Marine Parks and Reserves Authority (MPRA) and the IWG, produced a draft proposed reserve design. Public stakeholder engagement would then take place once a reserve design was submitted to Government for their approval to release for pubic comment.

5.2.1 Information collection from stakeholders

It was envisaged that Marxan would play an important role in synthesising the various information sets and desired outcomes received from this suite of stakeholder groups, to be analysed against a scientifically robust set of operational targets and ecological information. Socio-economic and cultural values, whether to be viewed as a cost in the Marxan system (for example, the potential financial cost of excluding commercial fishing extraction from an area) or as a target (for example, the inclusion of an important nature-based recreational area or cultural area), were generally unmapped or poorly mapped at the start of the process (see Section 2.1.3 Planning Unit Cost - ∑PUsCost).

The collection of such information from industry and the community is a difficult process due to the potentially large numbers of people involved in a diverse array of uses, across a large geographic area. In addition, particularly for extractive uses such as fishing, there can often be a perception amongst the community that the information they provide may be used to restrict their activities, which further limits the amount and/or quality of information to be collected through reserve planning processes. This can be mitigated by extensive stakeholder consultation and engagement in a process building education, trust and ownership of the process, its methods and outcomes (e.g. Pomeroy and Douvere 2008). In rapid planning processes with limited opportunity for stakeholder engagement, the opportunity to build ownership is reduced, and so is the willingness to provide detailed information.

Methodologies have been developed by the Marine Policy and Planning Branch to deal with these issues. South Coast Regional Marine Planning, a regional strategic planning process led by DEC in 2007-2009 undertook extensive public and industry stakeholder consultation through 10 public workshops in towns across the south coast region (van Schoubroeck & Herford, 2008). At these workshops, and through direct distribution via key marine user contact points, a survey was run to gather spatial information of the types and distribution of marine recreational activities undertaken by the south coast community, from Eucla to Augusta, a geographical area of comparable extent and diversity to the PEMB process, with similar issues of limited data availability.

The survey took approximately 9 months, to develop (3 months), run (6 months), and process the results (2 months), and cost approximately $4,500. The result was 262 returned surveys, yielding indicative (i.e. not statistically robust, but likely to be broadly representative) information to show which areas are used most, for the range of marine recreational uses. Overwhelmingly, the number of surveys received and the quality of information contained in them was highest for those surveys returned after a community workshop session that conveyed the goals of the planning process and invited stakeholder input into it (Buckley 2008).

The potential to replicate this kind of survey for recreational user groups in the Pilbara and Eighty Mile Beach region was assessed, but was not considered viable to produce results within the time and resourcing constraints of the PEMB project. Furthermore, if such data were acquired, a potentially complex task of assigning different uses as either costs or targets, and then the relative costs/targets between uses would require extensive and focussed consultation with user groups.

Industry groups, particularly fishing and other extractive industries can have similar issues as the recreational sectors, where perceptions may exist that the provision of information describing their activities is likely to result in restriction of those activities. Furthermore, in the case of official fishing industry catch and effort data gathered from fishers via compulsory logbook reporting to the Department of Fisheries, there are commercial sensitivities regarding the identification of individual fishers' key fishing areas. This situation can apply also to other resource industry data such as mineral or energy prospectivity or future potential for development investment. The WA Department of Fisheries does not release information outside of use for departmental fishery management, for areas where 3 or less fishers operate, under a memorandum of understanding with the fishing industry.

Through the Fishing Consultation Group, the WA Fishing Industry Council and WA Pearl Producers Association facilitated the engagement of commercial fishers and pearl producers in the area to provide information regarding their activities in the region. Marxan was used as a communication tool to demonstrate the need for accurate spatial information if the systematic assessment of reserve areas or no-take zones was to include these commercial activities as a cost. Both stakeholder groups and the individual operators that were consulted enthusiastically supported the usage of systematic planning methods, and the usage of the Marxan software. Subsequently, detailed and high quality information was provided by several fishers in particular. This detailed information wasn't ultimately used in the Marxan system due to time and resourcing constraints as previously discussed; however, it was used in eventual reserve and zoning design with the same result, avoiding impacting existing users whilst still achieving conservation outcomes.

Spatial indigenous cultural information was gathered from traditional owner groups consulted through the Indigenous Engagement Program, relating mostly to culturally important areas and traditional ecological knowledge. This information was restricted spatially to several areas of interest (Cowrie Beach, and De Grey River area to Eighty Mile Beach) and it was also restricted in its content, in respect to culturally sensitive information. The information gathered was thus not considered to be suitable for inclusion into the Marxan analyses, but would be most useful for use in future consultations and negotiations with traditional owners, regarding management zoning and tenure through an Indigenous Land Use Agreement process.

DEC Marine Science Program scientific staff (Dr Chris Simpson, Kevin Bancroft, Dr Bob Prince), and marine turtle scientific experts (Dr Fran Stanley, DEC and Dr Kellie Pendoley, Pendoley Environmental) were regularly consulted for advice and review regarding the suitability of input ecological data, and the development of conservation feature targets that would adequately represent the conservation features.

5.2.2 Target setting

In order to achieve stakeholder acceptance and support of a systematic reserve planning process, stakeholders need to fully understand and accept the rationale behind the choice of representation targets. They may also contribute to target setting; however, it is important that targets are scientifically sound and will achieve the broader biodiversity conservation aims of a representative marine reserve system, such as the long-term viability of species and communities, connectivity between habitats, etc.

Ideally, where resources and/or information is available, target setting should be done with specific reference to the ecological characteristics of the region being planned for, its key species and habitats to be protected. A range of measures can be used to provide information required to fine-tune the targets that Marxan provides for: target areas, minimum clump sizes, separation distance of clumps, or the number of occurrences of a feature. Species-area curves can be used to approximate the number of dependent species likely to be contained within habitat areas of a certain size (Neigel 2003), and measures of dispersal can inform the optimal minimum size of protected areas, and the separation distance between reserves required to ensure the viability of a target species (Johnson *et al.* 2008). Minimum viable population sizes can further inform the minimum areas of required critical habitats for important species (e.g. Shaffer 1981, Ferrar & Lotter 2007, discussed in Ardron *et al.* 2008).

This level of detail was not available for PEMB conservation features other than expert scientific knowledge of turtle nesting beach ecological values and risks, which were captured and input into the data and targets as a ranking of mapped beaches in the region. Given the high conservation status of marine turtles found in the Pilbara, and the clear objective of the planning process to focus on turtle conservation, turtle nesting beaches had high targets for representation of 50% of all beaches, to be made up of the highest ranked for value and threat. That the target was not higher than 50% was reflection of the protected status of marine turtles, and the existence of various non-spatial measures for their protection, such as the development of a Recovery Plan to manage turtle populations across the state (*DEC Marine Turtle Recovery Plan*, in prep.), feral predator eradication measures (DEC cat and fox eradication or control programs on offshore islands and mainland), environmental regulation of development impacts on turtles (e.g. Gorgon Gas project offset measures) and education and monitoring programs run by DEC and as part of environmental monitoring by resource development companies (e.g. turtle tagging program on Barrow Island, via Pendoley Environmental on behalf of Chevron).

For other conservation features in the PEMB project, target setting was undertaken by the DEC Marine Policy and Planning Branch planning team based on recommended representative target ranges described in marine planning literature such as those established for the Marxan-based Great Barrier Reef Representative Areas Program (GBR Biophysical Operational Principles of minimum 20% – 40% of habitat areas in no-take areas), and 2003 International Union for the Conservation of Nature World Parks Congress (20%-30% of each habitat in no-take areas). It is important to note that the PEMB targets were set in reference to these values, but were for outer boundaries of reserves, not for no-take areas. These generalised targets were modified as described in Section 2.6 PEMB Conservation feature target setting, to provide a range of targeting options, in consultation with scientific experts including the DEC Marine Science Program and members of the Marine Parks and Reserves Authority. Different targeting options and their effect on output reserve designs were demonstrated and their rationale explained to other stakeholder groups as required, but there was no process established to engage the range of stakeholders in the detailed process of Marxan target setting.

Although detailed input into Marxan target setting was not a part of the stakeholder consultation for the PEMB process, aspirations for the protection of the environment and minimisation of impact on existing users was a common outcome of community information sessions, indigenous engagement, and engagement with industry stakeholders. These aspirations formed the basis of the PEMB reserve design criteria and operational targets that informed the target setting process.

5.3 Marxan's potential to increase reserve PEMB efficiency

Outcomes:

- ***Marxan reserve configurations for Scenario 1, where no existing tenure was included, tended to be smaller (more efficient) than when existing reserves were included (locked in) to reserve design options.***

- ***Existing reserves and reserve proposals were developed independently, and have different sets of environmental and socio-economic values, making comparisons of 'efficiency' or 'success' difficult using the broad information and objectives of the PEMB Marxan analysis.***

- ***Resourcing/data limitations meant that the Marxan analyses were a subset of the broader PEMB planning process, and could not replicate the processes that led to the development of existing reserves or reserve proposals in the region.***

- ***Given appropriate input data and targeting to reflect the broader planning process, the use of Marxan systematic planning software would likely result in more efficient reserve design.***

- ***Existing reserves and reserve proposals contributed significantly to the achievement of Marxan targets.***

One of the major advantages of a Marxan-based process is the potential to reduce the size and increase the efficiency of reserves required to achieve stated conservation goals, when compared to reserves designed *ad hoc*, opportunistically or through negotiation (Stewart *et al.* 2003, Stewart *et al.* 2007). Smaller reserves that still achieve conservation targets are generally considered to be better, as they have lower management costs (patrolling, monitoring, signage etc), and are likely to impact fewer existing user groups.

This was considered to be especially important in the Pilbara region, where fishing, aquaculture, ports and resources industries that are potentially incompatible with some biodiversity conservation objectives (such as no-take zoning) contribute significantly to the local, state and federal economy. Impacts (real or perceived) on the continuing development of these and other industries due to management strategies of proposed new reserves could have caused significant delays in the PEMB planning process, and/or resulted in reduced conservation outcomes through extra negotiation processes potentially required to achieve stakeholder and Government acceptance.

Consultation and negotiation to resolve potential conflicts is always a part of successful marine reserve planning processes, and Marxan was considered a planning tool with the potential to streamline such negotiation processes through the setting of clear measureable objectives that are easily communicated, discussed and analysed by all stakeholders. The choice of adding or subtracting a planning unit to a reserve configuration is made based on that area's contribution to all targets, and how much it costs the system to do so. Thus Marxan can include multiple stakeholder objectives each time that an analysis is re-run, potentially minimising the time taken to reach a result from the inputs of many different stakeholder groups.

5.3.1 Objective vs subjective planning processes

Historically, marine reserve planning processes in the region (marine conservation reserves at Muiron Islands, Barrow Is., Montebello Is., and proposed MCRs at Cape Regnard and Dampier Archipelago) have used community-based planning processes, where public consultation and input via an Advisory Group is used to guide planning and design of reserves. In these forums a wide range of experience and information is able to be discussed and negotiated towards a final outcome, which is then available for the government and general pubic to comment on before being finalised. This allows the full spectrum of information available to be discussed and potentially included in the process, from rigorous scientifically based spatial information, to undocumented anecdotal information; however, it also makes the process potentially vulnerable to politics (e.g. better outcomes for the 'loudest voice' or sectors with the most information), or to be pushed towards lesser conservation outcomes through avoiding impact on user groups (Mangel *et al.* 1996). This can be mitigated by the selection of representatives who recognise the conservation objectives, and who have experience in a multiple-objective planning situation (i.e. work towards the 'greater good').

This is in contrast to the Marxan methodology, which provides an objective computationally-based analysis, but which requires high quality data in spatial formats accompanied by a set of numerical targets and costs. These targets and costs need to be scientifically robust, and accurately reflect the conservation and socio-economic objectives of the process. It should be noted that accepted anecdotal information can still be included in a Marxan analysis, but would need to go through extra data capture, interpretation and verification processes to translate into spatial form which can be very time and resource consuming. Both objective (i.e. Marxan) or subjective (i.e. negotiation) methods can result in well-accepted marine conservation reserves that achieve good conservation outcomes, but the differences between the methods and their inputs makes simple comparisons of measures of 'efficiency' or 'success' problematic.

In both methods, their respective key strengths are also their greatest limitations. The fundamental dependency on high quality and scientifically robust data of a Marxan analysis that truly replicates the real world gives it the objective analytical power that is potentially lacking in planning processes by negotiation. If high quality data are not available then a potentially time- or budget-consuming data creation phase is required, or the Marxan analysis proceeds based on low-quality information, and therefore will have lower-quality outputs.

Conversely, a group of community experts can draw on and process low quality information through a negotiation process more effectively than a software program, and thus potentially have more information to base planning decisions on. Ideally, acceptance for the eventual reserve design is built through the negotiation process, and the risks of using low-quality information are dealt with and accepted by the planning group. However, the subjective nature of reserve planning through negotiation can potentially result in the acceptance of lesser conservation outcomes, or can result in real or perceived political interference.

5.3.2 Measures of 'efficiency'

Stewart *et al.* 2003 calculated reserve efficiency by comparing the number of planning units in a successful reserve design against the total number available:

$$E = 1 - X/T$$

where E is efficiency, X is the number of planning units in a reserve solution, and T is the total number of planning units in the problem set.

Comparing the results of the average number of planning units in reserve solutions for a number of comparable analyses showed that output reserves for Scenario 1 runs (no existing tenure) were consistently more efficient than for Scenarios 2 and 3, where no existing tenure was included (Table 18).

Table 18: Measures of efficiency $E = 1 - X/T$ where X is the average number of planning units in a set of viable solutions of a given targeting option analysis, and T is the total number of planning units in the problem set. Scenario 1 produced more efficient reserve designs than Scenarios 2 or 3.

	Target options (species files)								
	3-7	**3-4**	**3-1**	**2-19**	**2-6exTM**	**2-6**	**2-5exTurt**	**Mean**	**Std.Dev.**
Scenario 1	0.73	0.85	0.75	0.75	0.72	0.71	0.73	0.75	0.05
Scenario 2	0.65	0.73	0.65					0.67	0.05
Scenario 3	0.67	0.76	0.67	0.67	0.63	0.65	0.62	0.67	0.05

Unless considerable time and resources are spent in ensuring that all reserve design criteria and their related operational targets can be represented by information in the Marxan problem set (whether as features for targeting, or as costs to be minimised), then a Marxan analysis is in effect a coarse model of the 'real world' process. The greater the representation of the reserve design criteria in the problem set, the closer the fit of the model, and the more useful it may be for reserve design. For example, the PEMB analysis documented in this report and the South Australian example presented in Stewart *et al.* 2003 contained limited or no socio-economic information other than existing tenure boundaries. Minimising impacts on existing or future users, and including socio-economic or cultural objectives is a highly important part of most marine planning processes. Human usage values can influence on the size and location of reserve boundaries, potentially making them less efficient under such objective measurements of 'efficiency', if they are not able to be included in the Marxan problem set.

However, for those reserve design criteria and objectives that *can* be captured within a Marxan problem set, these analyses of reserve design efficiency clearly demonstrate the capability of Marxan to reduce reserve sizes, thus minimising impacts on existing users whilst achieving conservation targets. The guiding principle of 'complementarity' in a Marxan analysis ensures that sites are selected based on their contribution to the whole range of input targets.

5.4 Notes on PEMB Marxan results

5.4.1 Island Nature Reserves to Low Water Mark

In Scenarios 2 and 3, where the intertidal areas of several island groups gazetted as Nature Reserves were included as 'existing reserves', the effect can be seen that planning unit choice clumped around these islands, as the algorithm sought to reduce the higher boundary length costs associated with having numerous small and widely distributed reserves (Figures 10, 11, 12). Whilst these reserves are gazetted to Low Water Mark, and therefore include intertidal areas around the islands, in practice they are not managed as marine reserves. The interpretation of the level of protection of intertidal habitats, or the amount of turtle nesting beaches protected by existing reserves should take this into account. For these measures to count towards target achievement, either the marine areas surrounding these island reserves should be reserved as MPAs and managed to High Water Mark, or the management of the terrestrial areas would need to be adapted to recognise and manage the intertidal marine values. As Nature Reserves gazetted under the *Conservation and Land Management Act* 1984, extractive activities or disturbance of habitat is not allowed, and so this would need to apply to marine uses such as fishing, anchoring, shell collection, etc.

Additionally, the mapping of Low Water Mark is an ongoing issue, where methodologies used to capture Low Water Marks are unlikely to capture their true extent, or biological influence. For example, an intertidal area – nominally the area between Low and High Water Marks – is in ecological terms, the area affected by inundation and drying cycles that are driven by sea level fluctuations resulting from the combination of tidal cycles, wind and wave action, barometric pressure, and long-period waves such as shelf waves. The regularity and length of exposure to the wetting/drying cycle determines the biological assemblage that can survive in the intertidal area, with a gradient from organisms that can survive long periods of drying towards the shore, and towards hose that can tolerate only short periods of air exposure towards the ocean.

Low-water mark mapping methods usually involve desktop interpretation from aerial photography, and as such represent an interpreted line at the time of capture. This methodology is likely to under-estimate the true extent of low-water marks, unless aerial photography was specifically scheduled for low-water. It is especially unlikely to capture areas that are only exposed to air under unusually low water levels resulting from combinations of high barometric pressure, persistent offshore winds, low wave action, low spring tides and troughs of long-period waves. Thus the capture of sensitive intertidal areas by mapped Low Water Marks should be interpreted with caution.

5.4.2 Exmouth Gulf

Exmouth Gulf holds many regionally important environmental values (Figures 3 and 4), and at the time of planning, was not represented in any marine conservation reserves. As shown in Figures 10-13 and Table 16, reservation of areas in Exmouth Gulf was important in any viable Marxan solution that achieved targets. Marxan was used in the PEMB process to provide an objective regional assessment of broad ecological targets, using information appropriate to the regional scale of planning. As such it shows the importance of Exmouth Gulf to a regional network of marine reserves. Exmouth Gulf is also identified in the Marine Parks and Reserves Selection Working Group's 1994 report which identified candidate areas and areas warranting further investigation as marine protected areas (the 'Wilson Report').

Exmouth Gulf was outside of the initial scope for the planning process provided by the 2006 Cabinet decision to progress marine reservation in the region, and so was not included in the June 2009 draft indicative management plan reserve proposals.

5.4.3 Environmental management by ports and industry

In the PEMB Marxan analyses, port and industrial area tenure was not considered to contribute to the achievement of conservation targets, as their primary purpose is for industrial use. Port and industrial marine areas pose some environmental impacts, such as habitat loss due to land reclamation or dredging, as well as the potential for pollution from industrial activities. These risks are managed through environmental regulatory mechanisms (*Environmental Protection Act* 1986) and usually require industrial operators to implement risk reduction strategies and environmental management plans. Thus some environmental values can be the focus of significant environmental management action by industry, for example feral species quarantine and turtle nesting monitoring funded by the resources industry at Barrow Island.

Marxan allows only for 'in' or 'out' of protected areas, and cannot deal with varying degrees of protection or management. Marxan with Zones (MarZone, Watts *et al.* 2009) deals with this limitation, by allowing different zones to be created or locked in, which contribute to targets differently. For example, a 'ports' zone could include the management strategies employed by a particular port, or by industry environmental regulations in general. Using MarZone may allow for more flexibility in reserve designs, as targets are addressed in varying degrees by different zones.

5.4.4 Effect of existing tenure on planning unit selection

The effect of existing tenure on Marxan reserve solutions is clearly evident in Scenario 3 runs, where existing ports and industrial areas restrict the area available for reservation (Figures 10-13). In the Roebourne and Dampier coastal compartments (Figure 3), port areas at Port Hedland, Balla Balla, Port Walcott and Dampier cover much of State Waters (Figure 2). The achievement of habitat features based on coastal compartment mapping therefore required much of the remainder of the area to be selected in every output solution, reflected in very high selection frequency of (up to 100%) the areas between ports tenure in this region. Thus, the high selection frequency for these planning units reflects the unavailability of the remainder of the area as well as the environmental values contained in these planning units.

5.4.5 The State Waters limit

Based on the extent of offshore waters in the state's jurisdiction available for reservation under the WA *Conservation and Land Management Act* 1984, the PEMB planning area could be divided into two subregions, one from Exmouth Gulf to Karratha, and another from Karratha east to the northern end of Eighty Mile Beach. The WA State Waters limit is a line nominally 3 nautical miles offshore of the mainland, or islands under WA jurisdiction. Thus the numerous offshore islands from the Dampier Archipelago to North-West Cape (Exmouth) cause the state waters boundary to extend up to ~100 km offshore (northern Montebello Islands), encompassing relatively deeper and more oceanic marine habitats, compared to the Eighty Mile Beach area where the 3 nautical mile limit is nearly all intertidal habitat in some parts (Figure 3).

The variety of habitats in these different sub-regions was represented by dividing the original depth and geomorphology based NWSJEMS level 3C habitat features by primary coastal compartments (Figure 3). Thus within the Marxan problem set, targeting would achieve adequate representation of the different habitats found within state waters; however, many of the depth and geomorphology based conservation features targeted in the Barrow coastal compartment for example, would not be targeted offshore of the Wallal compartment (Eighty Mile Beach). This was not because they are not present in the region, but because the state waters boundary did not extend far enough offshore to capture them. This reduces the number of conservation features available to differentiate areas for reserve selection along the Eighty Mile Beach region, as shown by the relatively low selection frequencies of planning units in the area (Figures 10-13). Representation of habitat targets can be built around a random 'seed' starting point almost anywhere in the region – though the northern end of Eighty Mile Beach tended to have higher selection frequencies due to having slightly greater areas of the three depth classes present in the coastal compartment.

The availability of deeper offshore waters provided by the extended state waters boundary around offshore islands between Karratha and Exmouth makes these areas relatively rare and important for representation in the State's conservation estate, where the nominal 3 nautical mile limit restricts the areas available for reservation generally to relatively shallow inshore waters.

6 CONCLUSION/RECOMMENDATIONS

The PEMB Marxan project described in this report successfully used available broadscale habitat mapping data, and data on turtle nesting beaches and regionally significant mangrove areas for a regional assessment of these ecologically important areas in the region. Socio-economic and cultural information was not included, other than the inclusion of existing or existing proposals for marine conservation reserves and the exclusion of existing ports and industrial marine tenure. Conservation feature targets were determined based on broad guidelines of representation required for marine habitats and species available in the literature, and modified upon review and consultation with marine science experts.

A Marxan problem set is essentially a model of a reserve planning process and is highly dependent on the input data. As such, it follows that analyses that include more representation of reserve design criteria and operational objectives and with higher quality and more detailed information to support targeting and costing will represent the real world situation more closely. Therefore the results of those analyses would be more instructive in eventual reserve design.

The set-up and implementation of a Marxan analysis is technically challenging and requires a relatively high degree of GIS skill and computer literacy. There is much support amongst the international Marxan user community via a mailing list that acts as a general forum for questions and problem solving, and the Marxan development team based at the University of Queensland provide excellent training and support for the software. However, the technical glitches, complex geoprocessing tasks and high requirement for documentation of data processing and results analyses that are a normal part of GIS require extra resourcing when combined with a Marxan analysis.

Marxan is a highly valuable tool for objective analysis of the multiple objectives in marine planning, and if properly implemented should lead to more efficient reserve design that minimises impacts on existing users whilst ensuring the achievement of conservation objectives. It captures the key elements of marine planning processes within an objective mathematical function that can deal with multiple objectives and supply many planning options rapidly. However, the success of a Marxan-based planning process, including the suitability of the output reserve solution options, and their acceptance by stakeholders and government relies on adequate resourcing of data development, data management and stakeholder consultation throughout the process. If structured carefully, a Marxan-based planning process may not necessarily require significantly more resources than other planning methods, but would certainly not require less. It is not a 'magic bullet' for the complex task of marine protected areas planning, and it does not provide 'the answer' but if properly implemented, has the capacity to add to the scientific rigour and stakeholder acceptance of reserves, and to ensure the achievement of conservation objectives in a multiple-stakeholder situation.

6.1 Recommendation 1: interpret PEMB Marxan results in the context of the limited input data

Results of the PEMB Marxan analyses should be viewed and interpreted in the context of the limited information and targeting detail able to be included. The results are a valid regional assessment of the distribution of some broadscale marine habitats and depth and geomorphologic proxies for habitats, regionally significant mangroves and turtle nesting beaches, at the representation targets described in this report. The results are not a definitive analysis of the region's ecological values, but highlight the objective power of the Marxan algorithm, and the potential for future usage with more data inputs.

6.2 Recommendation 2: recognise that some important ecological information was not used in PEMB Marxan

Whilst the PEMB Marxan results presented in this report are a valid assessment of some ecological values, they do not include other significant environmental variables such as regional oceanography, rivers, threatened or priority species other than marine turtles, key species dispersal and migration behaviours and other information sets that are important for the design of a network of marine protected areas. Whilst not an objective analysis, existing work done by the Marine Parks and Reserve Selection Working Group (MPRSWG 1994) was a systematic analysis of regional environmental values that included many more information sets than were used in the PEMB Marxan project.

6.3 Recommendation 3: recognise that the PEMB Marxan results did not include human usage values

The PEMB Marxan analyses do not include human usage information important to marine reserve planning, such as commercial, recreational and customary fishing, marine tourism, mineral and resource prospectivity, marine recreation, aquaculture, pearl and specimen collection, indigenous culture and other socio-economic and cultural values of the region, and so represent only a basic set of ecological objectives that could guide outer boundary design.

6.4 Recommendation 4: recognise that PEMB Marxan was for the analysis of IUCN Category IV areas – outer boundaries of reserves

Whilst guidance on target setting came from recommendation in marine planning literature for MPA no-take reservation (IUCN Category 1a), these targets were applied in the PEMB case as a selection of IUCN Category 4 areas, where the primary focus in on biodiversity conservation, but some level of extraction and human usage is allowed that does not impact significantly on conservation objectives, i.e. outer boundaries of multiple-use marine reserves.

6.5 Recommendation 5: review data requirements and availability before implementing Marxan

Before implementing Marxan as a reserve planning tool, a thorough review of available data to represent the reserve design criteria and their operational targets is essential. Following this, a detailed review of data gaps, potential sources of information to fill those gaps and the resources required for that work should be undertaken. The extent to which reserve design criteria and operational objectives can or can not be matched by the available information should determine the role that Marxan would have in the process.

6.6 Recommendation 6: provide for extra resourcing of data management and GIS

If limited data are available to represent values and objectives of the planning process, significant time and resources are required to create new data, whether using desktop mapping methods or field-based information collection. The objective reliance of Marxan on information inputs means that high-quality and comprehensive data are required for high-quality results. The data management, creation and interpretation requirements of Marxan are greater than for other GIS-based planning methods.

6.7 Recommendation 7: Marxan may not benefit a process if sufficient data are not available

If data can not be acquired to represent at least the major ecological objectives with sufficient spatial and attribute detail, and comprehensively covering the planning area, then the usage of Marxan is likely to be of little value. For the full benefit of Marxan's objective analysis power, human usage values also need to be included in the system as costs or target features. If human usage values are not able to be input into a Marxan problem set through a lack of data or ability to consult with stakeholders, stakeholders will have little ability or incentive to engage with the Marxan analysis. This means that a key benefit of Marxan, the ability to minimise impacts on non-conservation stakeholders, will not be realised.

6.8 Recommendation 8: have sufficient scientific expertise available for target setting

For best conservation outcomes and stakeholder acceptance, ecological targets should be based on the best available scientific information, specific to the region of interest and the key species present in the area. Where such information is not readily available, expert scientific opinion should be sought to create a range of targeting options that are based on scientific assessments of, for example: representation targets; viable population sizes; species-area curves; minimum critical habitat sizes; minimum and maximum separation distances between habitat or species population clumps; larval dispersal; species foraging and migration.

6.9 Recommendation 9: provide time and resourcing for adequate stakeholder engagement with Marxan

To gain maximum benefit of the objective analytical power of Marxan, stakeholders need to be involved in data capture/provision, allocation of costs in the system, and targeting, in order to be represented within the Marxan system, and thus to have ownership of and trust in the outcomes. This is no different to other planning methods, where stakeholder engagement is important in maximising the amount and quality of information available, and in the eventual acceptance of final reserve designs and management strategies. Marxan should not be viewed as a method to reduce the need for adequate stakeholder consultation.

6.10 Recommendation 10: combine the Advisory Group model with Marxan objective analysis model

For Marxan analyses that can include the full suite of socio-economic and ecological information, the formation of an Advisory Group of marine stakeholders would be highly beneficial to assist in information gathering, target selection and cost allocation to planning units. Engaging such a group in the Marxan analysis would take the best aspects of both a subjective Advisory Group process, and objective Marxan analysis. An Advisory Group can synthesise a wide range of information types, and provide a wide range of experiences to the setting of costs and targets. Anecdotal or subjective information gathered and processed through an Advisory Group and converted into spatial formats could fill important gaps in knowledge that would otherwise limit a Marxan objective analysis. The requirement to make source information, costs and targets highly explicit for a Marxan analysis, and the objectivity and repeatability of output results can demonstrate fairness and impartiality of planning and promote wider acceptance of final proposed reserve design and management strategies. Additionally, the objective function of Marxan should result in the most efficient reserve designs possible that achieve targets and minimise impacts.

6.11 Recommendation 11: implementation of Marxan should be done within the DEC Planning/Marine Information Section group

Marxan implementation requires a high degree of GIS skill, and thorough understanding of the Marxan analytical methodology. This may lead to a conclusion that a GIS specialist or outside contractor with Marxan experience may be best suited to implementation of a Marxan analysis. Under certain circumstances this may be the case; however, it is highly important that the origins of the input data, and the context of the development of target options is well understood by the Marxan operator/s. For this reason, it is recommended that if Marxan is implemented in the future, the Marxan operator/s should be based in the Marine Policy and Planning group, whether within the Planning, or Marine Information Section. Regular contact between the Planning team and Marxan operator/s is essential for the efficient and accurate implementation of Marxan.

6.12 Recommendation 12: review the application of Marxan/MarZone to Regional Marine Planning

The ability of Marxan to include a wide range of objectives and input data make it highly suitable for large-scale multiple-stakeholder Regional Marine Planning processes, where priority uses or strategies may be assigned for marine areas across a wide geographical area. In addition to use for the identification of priority conservation areas, the objective function of Marxan may be applied to non-conservation uses such as resource infrastructure developments. For example, the identification of new port areas could be input as a Marxan problem set where avoidance of environmentally or culturally significant areas, proximity to resource development projects, road/rail, deep water, and suitable geomorphology and weather protection are input as a set of conservation features or costs. The usage of systematic planning software such as Marxan would also focus the capture of information at an appropriate regional scale, resulting in a spatially and thematically comprehensive database of information covering all planning sectors at comparable scales, which would have further usage in the regional planning process and other subsequent planning.

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7 APPENDIX A – RESERVE DESIGN CRITERIA, OPERATIONAL TARGETS AND SUPPORTING DATA.

Design criteria	Principle & explanation	Draft operational target NOTE: a range of percentage values were used in different iterations of Marxan analyses	Supporting Data layers	Usage in PEMB Marxan
Biophysical				
1. Represent examples of each ecosystem within each bioregion in marine parks and reserves*.	**Comprehensiveness.** The full range of ecosystems at an appropriate scale within and across the marine bioregions should be included in marine parks and reserves. The bioregions described by the *Interim Marine and Coastal Regionalisation for Australia* (IMCRA) are the recognised classification units within which marine parks and reserves should be established, with ecosystems used as the basis for determining comprehensiveness.	30% of each bioregion (State waters only) in marine parks and reserves. Penalty high. 30% of each ecosystem (State waters only) in marine parks and reserves. Penalty high.	IMCRA Bioregions – Pilbara Nearshore, Pilbara Offshore and Eighty Mile Beach. NWSJEMS level 3A classification of 'subregions'. Extended by DEC from De Grey to Cape Missiessy. NWSJEMS level 3B classification of 'coastal zone units'. Extended by DEC from De Grey to Cape Missiessy. NWSJEMS level 3C classification of 'habitat surrogates', essentially depth classes or basic substrate (reef, mud flats, salt flats, tidal flats. Primary Coastal Compartments – sub-regional geomorphologic units derived from assessments of 1:500,000 scale geology, coastal aspect and major coastal processes driving geomorphology and therefore broadscale habitat distributions (Eliot et al. 2010 in prep.). These provide a longitudinal sub-regionalisation of the study area.	**IMCRA Bioregions** targeted in Marxan **Ecosystems** were inferred from a union of Primary Coastal Compartments, and the NWJEMS 3C habitat surrogates, targeted in Marxan. NWSJEMS 3A and 3B were used in the interpretation of Primary Coastal Compartments. See text for rationale.
2. Represent examples of the main marine habitats, flora and fauna of each bioregion in marine parks and reserves.	**Representativeness.** The marine flora and fauna of each IMCRA bioregion should be represented in marine parks and reserves. Marine parks and reserves should reasonably reflect the biotic diversity of the marine ecosystems from which they are derived i.e. local marine habitats, flora and fauna.	30-100% of each habitat type (State waters only) in marine parks and reserves. Penalty high. **Habitats to be captured:** Coral reef, mangrove, macroalgae, seagrass, soft sediment communities (subtidal & intertidal), filter feeder communities, cyanobacterial mats. **Geomorphological features to be captured:** islands, islets, headlands, beaches, mudflat, subtidal soft sediments, rocky shores, subtidal reef platforms, reef, lagoons, embayments, creeks, estuaries.	Data on specific habitat types and distribution i.e. subtidal coral reef, macroalgae, seagrass, soft sediment (subtidal), filter feeding communities or coastal habitat types were limited to the area of the Dampier Archipelago (except mangal, mudflats and salt flats which are generally well defined spatially across the region, in the NWSJEMS classification). Mangrove mapping and mangrove conservation priority status (Semeniuk 1997, EPA 2001).	Limited data on habitat types. '**Habitat surrogates**' of the union of Primary Coastal Compartments, and the NWJEMS 3C habitat surrogates, which included 'nearshore reefs', 'mud flats', 'tidal flats', 'salt flats', mangal systems, 'island fringes' and 'shoals' – targeted in Marxan. **Regionally significant mangroves** in each bioregion were targeted in Marxan.
3. Represent longitudinal and cross-shelf (where necessary) diversity in marine parks and reserves.	**Comprehensiveness and representativeness.** Recognising the length and width (predominately intertidal in some areas) of the study area, representative examples of the longitudinal and cross-shelf diversity should be included in marine parks and reserves. This reserve design criteria recognises the nature of population dynamics that not all habitats are equal across the study area (e.g. seagrass diversity in the east and west may be very different).	30% of each depth range in marine parks and reserves. Penalty high. 30% of each 'longitudinal subregions' in marine parks and reserves. Penalty high.	NWSJEMS 3C depth classes. Primary Coastal Compartments	Unioning the Primary Coastal Compartments with the NWSJEMS 3C depth classes provided both offshore and longshore classification, tagetted in Marxan.
4. Have 'adequate' no-take areas** in all marine parks and reserves.	**Adequacy and no-take areas.** Adequacy means having the required level of reservation to ensure the ecological viability and integrity of populations, species and communities. No-take areas are integral for biodiversity conservation in marine parks and reserves. No-take areas assist with resilience, persistence, minimum viable population, connectivity and risk management. No-take areas also provide relatively undisturbed areas to monitor and assess the performance of the marine parks and reserves system as well as areas for nature appreciation and low impact recreation and tourism activities. Adequacy refers not only to size and representativeness of no-take areas but also their replication and configuration across the region.	30% of each habitat type within the reserves in no-take zones. Penalty high.	NWSJEMS level 3C classification of 'habitat surrogates' (essentially substrate and/or depth classes). Data on specific habitat types and distribution i.e. subtidal coral reef, macroalgae, seagrass, soft sediment (subtidal), filter feeding communities or coastal habitat types were limited to the area of the Dampier Archipelago (except mangal, mudflats and salt flats which are generally well defined spatially across the region, in the NWSJEMS classification). Field work (Oct-Nov 2008) to gather groundtruthing and baseline information on habitat distributions.	Used in zoning planning through stakeholder consultation outside of Marxan process, once outer boundaries had been proposed.
5. Have a preference for larger versus smaller no-take areas, however flexibility will need to	**Adequacy.** The long term integrity of an area increases with increased size. As such, increased reserve size is likely to produce increased conservation benefits. Larger no-take areas minimise edge effects, the influence of external impacts, and the risk of failing to implement a comprehensive, adequate and representative reserve system. However, in marine conservation planning, flexibility is required to allow for limitations (such as costs/benefits where available	No take areas with a minimum size of 10km in diameter. Penalty high.		

Design criteria	Principle & explanation	Draft operational target NOTE: a range of percentage values were used in different iterations of Marxan analyses	Supporting Data layers	Usage in PEMB Marxan
be maintained.	conservation area is small).			
6. Maximise replication of no-take areas within marine parks and reserves	**Replication and precautionary principle.** Replication of no-take areas within marine parks and reserves minimises the risks that reserves may not represent important components of biodiversity or fail to provide adequate protection to ensure long-term viability. Such risks are generally associated with inadequate knowledge of biodiversity and data deficiencies. Replication adds a measure of insurance. The precautionary principle means that the absence of scientific certainty should not be a reason for postponing measures to establish marine parks and reserves to protect ecosystems and decision making should proceed in a manner that provides safeguards for marine ecosystems.	Minimum of 2 samples of each habitat type in no-take areas. Penalty high.		
7. Have a preference for including 'whole systems' rather than 'part systems' in no-take areas.	**Adequacy and representativeness.** Ecological function and integrity is more likely to be maintained by including whole systems (e.g. reefs, mangrove communities) rather than parts of systems within no-take areas. Adequacy and representativeness are maximised.			Addressed by selecting Boundary Length Modifier values that result in large areas that contain a range of adjacent ecosystem/habitat surrogates.
8. Represent examples of outstanding naturalness and preferentially include undisturbed ecosystems and habitats in marine parks and reserves.	**Naturalness and scientific interest.** Marine parks and reserves should include areas that display outstanding naturalness, amenity or cultural landscape values. Representing undisturbed areas generally assists with maintaining ecosystem integrity. Undisturbed areas are required to monitor and assess the performance and adequacy of the marine parks and reserves system.	30% of all areas of outstanding naturalness in marine parks and reserves. Penalty low.	No distinguishing data layer for areas of outstanding naturalness. Heritage Council data of 'natural', 'indigenous' and 'historic' areas could be used, however 'natural' areas cover much of the coast and therefore do not distinguish specific areas.	Not specifically targeted in Marxan. Given the remoteness of the region, with its nodes of development and usage focussed around Port areas, it can be assumed that by avoiding reservation of port areas, 'natural' areas will be captured in reserve solutions.
9. Represent biophysically special and/or unique areas and rare and/or endemic species in marine parks and reserves.	**Uniqueness, productivity and scientific interest.** Inclusion of special, unique, rare and endemics will ensure that comprehensiveness and adequacy principles are maximised to protect biodiversity. This includes areas and habitats with unusually high levels of biodiversity (i.e. species richness), rarity (i.e. numbers of rare species), and uniqueness (i.e. endemism richness).	100% of 'special' areas in marine parks and reserves. Penalty high. **Special areas:** Anchialine habitat, endemics, regionally significant mangroves, De Grey areas for several species of turtles, male turtle aggregations in Mangrove islands, EMB bird populations, dugong aggregations near Cape Keraudren.	<u>Regionally significant mangroves</u>. As outlined by EPA guidance statement (2001) and Semeniuk (1997) No distinguishing data layer representing biophysically special areas. No data on distribution of endemic species or areas of unusually high biodiversity or species richness or distribution of rare species. <u>Turtle foraging and internesting areas</u> - Expert advice about hawksbill, green and flatback turtle distributions from Dr Kelly Pendoley (Pendoley Environmental), based on sparse satellite tagging data of 31 turtles tagged whilst nesting on Barrow Is, and expert observational data. This included a representation of the Mangrove islands area as a significant male turtle aggregation area.	Regionally significant mangroves were highly targeted in Marxan Turtle internesting areas were targeted but with no penalty for non-achievement, due to a lack of reliable data across the region. Turtles are sighted in large numbers across the whole region, and their collective varied diets mean that all areas/habitats are likely foraging areas. Thus, it was presumed that reservation of large areas of congruent habitats would secure foraging areas.
10. Represent habitats or areas on which species or other systems depend in marine parks and reserves.	**Ecological importance and productivity.** Marine parks and reserves should aim to protect habitats or areas on which other species or systems depend to ensure integrity of the ecosystem as a whole. This can include important areas for migratory species or economically important species (e.g. nursery, spawning, feeding, breeding and resting areas) as well as habitats that contribute to the productivity of the system without which other species would not persist (e.g. mangrove, seagrass, macroalgae and coral communities).	% of benthic primary producer habitat (seagrass, macroalgae, mangrove, coral reef) in marine parks and reserves. Penalty high. % of 'important' areas (nursery, spawning, feeding, breeding, nesting, resting, aggregation areas) for migratory or economically important species in marine parks and reserves. High penalty.	<u>Turtle nesting beaches</u> – expert assessment (Dr Kelly Pendoley (Pendoley Environmental), Dr Bob Prince DEC, Dr Fran Stanley DEC) of the importance of various beaches for flatback turtle nesting. Beaches were given an importance ranking based on their ecological value (numbers/density of nesting females) and threats to their viability (developmental, human usage, feral or natural predator threats). <u>Eighty Mile Beach Ramsar migratory bird distributions</u> – seasonal bird observations made along a transect of Eighty Mile Beach. **Limited to EMB** No data layer for the distribution of benthic primary producer habitat (seagrass, macroalgae and coral reef) except mangal and intertidal coral reef surrounding islands where there is some data. No comprehensive data layer of important areas for migratory or economically important species including fish, invertebrates, cetaceans, dugong, turtles and migratory birds.	Turtle nesting beaches were highly targeted in Marxan, with up to 100% of highest ranking beaches being targeted. Bird observations were limited to EMB, thus not used in Marxan analysis. However, the importance of EMB as migratory bird refuge was noted throughout the planning process.
11. Represent critical habitat for turtles and other vulnerable, threatened, rare or endangered species in marine parks and reserves.	**Ecological importance.** Marine parks and reserves should provide for the needs of vulnerable, threatened, rare or endangered species. This can include feeding, nesting, resting and aggregation areas.	% of turtle rookeries in marine parks and reserves. Penalty high. % of turtle feeding, aggregating and internesting areas in marine parks and reserves. Penalty low or none.	No data layer available for vulnerable, threatened or rare bird or fish species distributions Australian Customs (Coastwatch) aerial sightings of dugong, Dr Bob Prince (DEC) and Dave Holley (DEC) expert opinion on aggregation areas. Single aerial survey of dugong distributions. No data layer.	

Design criteria	Principle & explanation	Draft operational target **NOTE: a range of percentage values were used in different iterations of Marxan analyses**	Supporting Data layers	Usage in PEMB Marxan
		% of vulnerable, threatened and rare bird habitat in marine parks and reserves. Penalty medium. % of vulnerable, threatened and rare fish habitat in marine parks and reserves. Penalty medium. % of dugong feeding and aggregation areas in marine parks and reserves. Penalty low. % of cetacean feeding and aggregation areas in marine parks and reserves. Penalty low.		
12. Provide for ecological connectivity in the configuration of marine parks and reserves.	**Adequacy and connectivity.** Providing for ecological connectivity helps to maintain the integrity and resilience of ecosystems and minimises the risks of failing to protect important relationships for maintaining biodiversity. This criteria provides for the complex connectivity between the land and sea as well as connectivity between State and Commonwealth waters. Connectivity is particularly important in areas with large tidal ranges where species move in and out of Commonwealth waters on a daily basis.	No operational target.	No data and limited knowledge of how to implement in marine parks and reserve design.	
13. Recognise the contribution of existing marine parks and reserves in the region the other criteria and attempt to create an effective and compact reserve system.	**Efficiency and complementarity.** One of the distinctive characteristics of systematic planning is that it recognises the extent to which conservation goals have been met in existing reserves. This results in 'efficient' marine parks and reserves. The biodiversity values represented in existing and proposed marine parks and reserves in the regions (i.e. Montebello/Barrow islands and Dampier Archipelago/Regnard) should be considered in the selection of new marine parks and reserves in the region and the reserve design process should aim for effective and compact reserves.	% of existing marine parks and reserves 'locked in' (i.e. contribution to all operational targets considered). **Existing reserves:** Montebello Islands Marine Park, Barrow Island Marine Park, Barrow Island Marine Management Area, Muiron Islands Marine Management Area.	Boundary data layers for existing reserves. Consider how to implement contribution of existing reserves to the operational targets.	Existing reserves and reserve proposals were included as 'locked in' areas of Scenarios 2 and 3.
Socio-economic				
14. Maximise complementarity of marine parks and reserves to Indigenous and broader community access, activities, values and aspirations.	**Social and Indigenous importance and practicality/feasibility.** Marine parks and reserves should aim to complement existing community **access, activities,** values and aspirations. Complementarity can be achieved through no-take area configuration and other types of zones as well as agreement of strategies with the community. Best achieved through a participatory planning approach, complementarity can greatly assist with creating community support and ownership which can later result in self-enforcement. Indigenous **access, activities,** values and aspirations should be considered specifically and in a manner that recognises Native Title rights, past and future use, contemporary Aboriginality and caring for country aspirations.	No operational target.	Consultation on reserve type, vision and strategies as well as zoning will ensure the proposed reserves complement existing indigenous and broader community values and aspirations. This section only deals with Indigenous and community values and aspirations. All access and activities to be dealt with in criteria 15, 16 and 17. Indigenous joint management and participation is dealt with in criteria 19.	
15. Provide opportunities for Indigenous use within marine parks and reserves (where appropriate).	**Indigenous importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes indigenous uses and interests which should be considered specifically and in a manner that recognises Native Title rights, past and future use and contemporary Aboriginality. Providing opportunities could include specific zones or strategies that recognise Indigenous use.	**Operational targets to be developed in liaison with native title working groups, local Indigenous people and the Department of Indigenous Affairs.** Examples could include: % of the indigenous sites protected within marine parks and reserves. % of important areas 'locked out' of marine parks and reserves. % of the customary hunting and fishing areas included in appropriate zones of marine parks and reserves. % of important species habitat protected in marine parks and reserves. **Indigenous sites, features, uses and activities:** customary fishing & hunting, use of sacred sites,	Consult with native title working groups and local indigenous people on the sites, features and activities they would like considered in marine parks and reserves. Very limited data on important areas for indigenous hunting, fishing and significant sites. Very limited knowledge on 'vision' and what indigenous people want for these areas.	

Design criteria	Principle & explanation	Draft operational target **NOTE: a range of percentage values were used in different iterations of Marxan analyses**	Supporting Data layers	Usage in PEMB Marxan
		species of shared concern.		
16. Provide opportunities for commercial use within marine parks and reserves (where appropriate).	**Social importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes commercial uses and interests. Providing opportunities could include specific zones or strategies that recognise commercial use.	% of existing major industrial areas 'locked out' of marine parks and reserves.	No data layer. Considered not necessary as existing port areas overlap major industrial areas (i.e. Cape Preston, Mt Anketell, Onslow, Port Hedland and Dampier). State Agreement Act areas deal with in criteria 20.	
		% of future major industrial expansion areas 'locked out' of marine parks and reserves.	No data layer. Confirm prospective proposed ports with DPI. Section 19 areas from DoIR.	
		Proposed future ports – no operational target.		
		% of the 'section 19 areas' 'locked out' of marine parks and reserves.	Pipelines data layer from DoIR. Consider how to implement in Marxan with Zones***	
		% of petroleum pipelines not in no take zones.	Confirm implications of open wells for marine parks and reserves (in particular no take areas) and develop appropriate target.	
		Petroleum wells – no operational target.	No data layer.	
		% existing marinas 'locked out' of marine parks and reserves.	No data layer.	
		% of jetties not in no take zones.	No data layer. Old principal fishing data is out of date and doesn't reflect the true areas.	
		% of the principal commercial prawn trawl (Onslow and Nickol Bay) areas not in reserves.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial mackerel fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial wetline fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF, WAFIC and the PPA.	
		% of the principal commercial pearl oyster fishing areas not in no take zones.	Pearl lease and license areas. Data layer to be updated by Department of Fisheries.	
		% of the pearling lease and license areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial bech-de-mer fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial marine aquarium fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial specimen shell fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	
		% of the principal commercial blue swimmer crab fishing areas not in no take zones.	No data layer. 60nm grid fishing areas and principle fishing areas from Department of Fisheries. Develop a mechanism to collate a finer scale data in liaison with DoF and WAFIC.	

Design criteria	Principle & explanation	Draft operational target **NOTE: a range of percentage values were used in different iterations of Marxan analyses**	Supporting Data layers	Usage in PEMB Marxan
		% of the principal charter fishing areas not in no take zones.	Charter fishing data layer. To be updated by Department of Fisheries. Clarification to be given on 'principal' areas (i.e. > 1.5 boats per block).	
		Commercial uses: fishing, aquaculture, pearling, tourism, petroleum/gas, mining, shipping, marinas/infrastructure.	For all of the above fishing uses, develop operational targets for other lower usage areas i.e. not principal areas. Such that they are included in general use zones.	
17. Provide opportunities for recreational use within marine parks and reserves (where appropriate).	**Social importance.** Marine parks and reserves allow that level of recreational and commercial use which is consistent with the purposes of the reserve. This includes recreational uses and interests. Providing opportunities could include specific zones or strategies that recognise recreational use.	% of the high usage boat-based recreational fishing areas not in marine parks and reserves.	Boat-based recreational fishing creel survey data. Liaise with Neil DoF in respect to other information behind this data and trends over time. Consider the relevancy of the Coastwatch data in identifying other important areas.	
		% of the medium usage boat-based recreational fishing areas not in no take areas.	As above.	
		% of the high usage shore-based recreational fishing areas not in marine parks and reserves.	No data layer. Department of Fisheries creel survey data collated information of shore-based fishing. Arrange to meet with Neil Sumner and Laurie Caporn regarding this data.	
		% of the medium usage shore-based recreational fishing areas not in no take areas.	No data layer. As above.	
		% of the mangrove creeks used for recreational fishing and mudcrabbing not in no take zones.	No data layer. Consider developing a spatial layer of all mangrove creeks, in liaison with Stephen Newman and the Department of Fisheries. Time permitting.	
		% of offshore islands used for recreational fishing not in no take zones.	No data layer. Consider developing a spatial layer of all offshore islands in the region. Time permitting.	
		% of coral reefs used for recreational fishing not in no take zones.	No data layer. Consider developing a spatial layer of all coral reefs for recreational fishing in the region, in liaison with Department of Fisheries. Time permitting.	
		% of the continental shelf waters used for recreational fishing not in no take zones.	No data layer. Consider developing a spatial layer of all continental shelf recreational fishing areas in the region. Time permitting.	
		Recreational uses: fishing, boating, four-wheel driving, collecting, diving/snorkelling, swimming, nature appreciation.		
18. Provide for the preservation of any feature of archaeological, historic or scientific interest within marine parks and reserves.	**Social and indigenous importance.** Consistent with the purposes in the CALM Act, marine parks and reserves should provide protecton for features of archaeological, historic or scientific interest.	% of archaeological features in marine parks and reserves. Penalty high.	No new data layer. Archaeological features consider in criteria 14 and 15.	
		% of historic shipwrecks in no take zones. Penalty medium.	Historic shipwrecks data layer. Heritage council data layer on 'historical' areas. Check if this layer is useful? No data layers on European settlement sites, pearling industry sites, military history etc. Consider developing a historic features layer in liaison with Alistair Paterson from UWA and Ross Anderson from WA Museum.	
		% of the scientific features in no take zones. Penalty high.	No data layers. Turtle nesting beaches and Ramsar habitat considered in other criteria. As above, consider developing a data layer representing the anchialine habitat, in liaison with Bill Humphreys at the WA Museum. Time permitting. Identify other features of scientific interest.	
		Archaeological features: indigenous artefacts, middens, burials, art. **Historic features:** shipwrecks, European settlement sites and artefacts, pearling industry artefacts, rabbit proof fence, military history, North Turtle island exploration site of John Lort Stokes		

Design criteria	Principle & explanation	Draft operational target **NOTE: a range of percentage values were used in different iterations of Marxan analyses**	Supporting Data layers	Usage in PEMB Marxan
		1841. **Scientific features:** anchialine habitat, turtle nesting beaches, EMB ramsar habitat, others?		
19. Provide for Indigenous participation and joint management.	**Indigenous importance.** Marine parks and reserves should create opportunities for Indigenous uses and values (criteria 15) and maximise complementarity to Indigenous access, activities, values and aspirations (criteria 14). Marine parks and reserves should also provide opportunities for Indigenous people to participate in management of country and receive benefit from management (e.g. protection of important sites, economic development, capacity-building, training and employment). Indigenous participation is crucial to success and effectiveness of marine parks and reserves. Joint management options should be explored and options developed with Indigenous people.	No operational target.	All indigenous access and site data is consider in criteria 14 and 15. This section should deal only with the mechanisms to provide for indigenous participation and joint management.	
20. Maximise complementarity of marine parks and reserves management with adjacent tenure and management arrangements (both existing and future).	**Economic and social importance and practicality/feasibility.** Where possible and appropriate, marine parks and reserves should complement other tenure and management arrangement within and adjacent to the marine parks and reserves. In particular, within WA Government (e.g. Department of Fisheries, Department of Industry and Resources, Department for Planning and Infrastructure, WA Tourism) and cross-jurisdictional (e.g. Northern Territory and Commonwealth). Complementary management arrangements should assist in providing an integrated approach.	% of the Ramsar habitat in marine parks and reserves. Penalty low. % of the CALM Act tenure in marine parks and reserves. Penalty high. % of the existing ports 'locked out' of marine parks and reserves. 100% of the State Agreement Act areas 'locked out' of marine parks and reserves.	EMB Ramsar boundary data layer. CALM Act tenure data layer. Consideration needs to be given to tenure types (i.e. all or only nature reserves) and whether the target is inclusion in no take areas or just marine parks and reserves. Marine & Harbours Act data layer. Shipping & Pilotage Act data layer. DoIR State Agreement Act data layer. Other management priorities (e.g. future industrial expansion areas, future ports) are considered in other criteria.	Existing tenure of marine and island nature reserves to Low Water Mark (including proposed marine reserves), and existing port and industrial administration boundaries were included in various planning scenarios as 'locked in' or 'locked out'.
21. Zoning should be simple for people to understand and easily enforceable.	**Practicality/feasibility.** Marine parks and reserves zoning should be simple for people to understand and easily enforceable. This could include: a preference for straight boundaries along definable latitudes/longitudes; using headlands, reefs and other definable sites as boundary markers; including whole physical structures (i.e. reefs, creeks etc). Practicality of implementing the zoning scheme is an important factor in the success of marine parks and reserves. Consideration should also be given to remoteness of proposed reserves and existing nodes of management in respect to ease of enforcement and management.	No operational target. **Type of zones/permitted activities:** ensure consistency with other types of zones and where possible reduce the number of different types of zones. **Boundaries:** align with easily identifiable landmarks, lat and longs.	Consider using BLM to ensure compact reserves. First draft reserve boundary and zoning scheme must be reviewed to ensure it is simple for people to understand and easily enforceable (as specified).	

8 APPENDIX B – MARXAN TRIAL 3 INPUT FILES

Table 19: Trial 3 input planning unit files.

Input file	Description
pu_3_1.dat	Planning unit file for Trial 3, Scenario 1: all planning units status set to "0" (Available)
pu_3_2_IUCN1a.dat	Planning unit file for Trial 3, Scenario 2: planning units within existing no-take sanctuary zones (i.e. IUCN Category IV) set to "2" (Locked in)
pu_3_2_IUCN4.dat	Planning unit file for Trial 3, Scenario 2: planning units within existing marine reserve outer boundaries (i.e. IUCN Category IV) set to "2" (Locked in)
pu_3_2_plwk-resIUCN-IV.dat	
pu_3_3.dat	Planning unit file for Trial 3, Scenario 3: planning units within existing reserve outer boundaries have status set to "2" (Locked in), planning units within ports and industrial tenure status set to "3" (Locked out), all other planning units status set to "0" (Available)
pu_3_3_plwk-resIUCN-IV.dat	
pu_3_3_pmcr20090406.dat	Potential final proposed reserve network, which included Exmouth Gulf and separate northern and southern reserves of Eighty Mile Beach
pu_3_4_pmcr_20090407.dat	Final proposed Pilbara and Eighty Mile Beach marine reserve network included as 'locked in'
pu_20081124-2_1_1.dat	
pu_20081124-2_3_1_excl-DeGrey.dat	the same as *pu_3_3.dat*, but with the De Grey coast 'locked out'. This area originally though to be of lesser biodiversity value to to extremely high sediment movements.
pu_20081124-2_3_1_excl-DeGrey_res-munda.dat	the same as *pu_3_3.dat*, but with the Mundabullangana coast locked in as a hypothetical reserve, due to very high conservation values for turtle nesting, and with the De Grey coast 'locked out'. This area originally though to be of lesser biodiversity value to to extremely high sediment movements.
pu_20081124-2_3_1_res--munda.dat	the same as *pu_3_3.dat*, but with the Mundabullangana coast locked in as a hypothetical reserve

Trial 3 Targeting Option (See Table 14)	Marxan 'species file' reference	Description
-	specT3_1-1 to specT3_1-7	Did not include the full final set of conservation features
1	specT3_2-1	See Section PEMB Conservation feature target setting
	specT3_2-1exTurt	Same as 2-1 but without targeting turtle conservation features, for sensitivity testing of the effect of turtle fine feature targets on the resultant solutions
2	specT3_2-2	See Section PEMB Conservation feature target setting
	specT3_2-2exTurt	Same as 2-2 but without targeting turtle conservation features, for sensitivity testing of the effect of turtle fine feature targets on the resultant solutions
3	specT3_2-3	See Section PEMB Conservation feature target setting
	specT3_2-3 exTurt	Same as 2-3 but without targeting turtle conservation features, for sensitivity testing of the effect of turtle fine feature targets on the resultant solutions
4	specT3_2-4	See Section PEMB Conservation feature target setting
5	specT3_2-5	See Section PEMB Conservation feature target setting
	specT3_2-5 exTurt	Same as 2-5 but without targeting turtle conservation features, for sensitivity testing of the effect of turtle fine feature targets on the resultant solutions
	specT3_2-5exTurtMang	Same as 2-5 but without targeting turtle conservation features, of mangrove features, for sensitivity testing of the effect of turtle and mangrove fine feature targets on the resultant solutions
6	specT3_2-6	See Section PEMB Conservation feature target setting
	specT3_2-6exTurtMang	Same as 2-6 but without targeting turtle conservation features, of mangrove features, for sensitivity testing of the effect of turtle and mangrove fine feature targets on the resultant solutions
7	specT3_2-7	See Section PEMB Conservation feature target setting
	specT3_2-7exTurt	Same as 2-7 but without targeting turtle conservation features, for sensitivity testing of the effect of turtle fine feature targets on the resultant solutions
	specT3_2-7exTurtMang	Same as 2-7 but without targeting turtle conservation features, of mangrove features, for sensitivity testing of the effect of turtle and mangrove fine feature targets on the resultant solutions

Trial 3 Targeting Option (See Table 14)	Marxan 'species file' reference	Description
Files below were produced and analysed for the re-runs in Feb 2010, as part of producing this report		
8	specT3_2-8	See Section PEMB Conservation feature target setting
4	specT3_2-9	Targets modified from specT3_2-4, to reflect what is achievable given the locked out areas - to reduce unavoidable system penalties and increase the influence of the BLM. See Section PEMB Conservation feature target setting
1	specT3_2-10	Targets modified as above, from specT3_2-1
8	specT3_2-11	Same as specT3_2-8, but with SPF's modified to 80% of the original settings
8	specT3_2-12	Same as specT3_2-8, but with SPF's modified to 50% of the original settings
8	specT3_2-13	Same as specT3_2-8, but with SPF's modified to 10% of the original settings
8	specT3_2-15	Same as specT3_2-8, but with SPF's set to zero, and non-targeted features deleted from species file, to improve Marxan analysis processing
8	specT3_2-16	Same as specT3_2-8, but with non-targeted features deleted from species file, to improve Marxan analysis processing
4	specT3_2-17	Same as specT3_2-9, but with non-targeted features deleted from species file, to improve Marxan analysis processing
1	specT3_2-19	Same as specT3_2-10, but with non-targeted features removed from species file to improve Marxan analysis processing
1	SpecT3_3_1	Modified from 2-1 to remove non-targets, for easier processing, for analysis of Scenarios 1 & 2 using targeting option 1
1	SpecT3_4_1	Modified from 2-1 to remove non-targets, for easier processing; also modified to reflect what is achievable given the locked out areas - to reduce system penalties and increase the influence of the BLM. For analysis of Scenario3, as a direct comparison with SpecT3_3_1 without the influence of extremely high species penalties in the locked out areas.
4	SpecT3_3_4	Modified from 2-4 to remove non-targets, for easier processing, for analysis of Scenarios 1 & 2 using targeting option 4
4	SpecT3_4_4	Modified from 2-4 to remove non-targets, for easier processing; also modified to reflect what is achievable given the locked out areas - to reduce system penalties and increase the influence of the BLM. For analysis of Scenario3 using targeting option 4, as a direct comparison with SpecT3_3_1 without the influence of extremely high species penalties in the locked out areas.
5	SpecT3_3_5	Modified from 2-5 to remove non-targets, for easier processing, for analysis of Scenarios 1 & 2 using targeting option 5
5	SpecT3_4_5	Modified from 2-5 to remove non-targets, for easier processing; also modified to reflect what is achievable given the locked out areas - to reduce system penalties and increase the influence of the BLM into play. For analysis of Scenario3 using targeting option 5, as a direct comparison with SpecT3_3_5 without the influence of extremely high species penalties in the locked out areas.
7	SpecT3_3_7	Modified from 2-7 to remove non-targets, for easier processing, for analysis of Scenarios 1 & 2 using targeting option 7
7	SpecT3_4_7 SpecT3_5_7	Modified from 2-7 to remove non-targets, for easier processing; also modified to reflect what is achievable given the locked out areas - to reduce system penalties and increase the influence of the BLM. For analysis of Scenario3, using targeting option 7 as a direct comparison with SpecT3_3_7 without the influence of extremely high species penalties in the locked out areas.