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Marine Spatial Planning: Ecosystem-based zoning methodology for marine management in South Australia

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ABSTRACT: Marine spatial planning, for the purpose of ocean zoning, is a relatively new concept that is being explored by different countries to better manage development and use in marine ecosystems. The state of South Australia has introduced the first ecosystem-based zoning model for near shore waters with the release of the Marine Planning Framework for South Australia. A large database of habitat and species diversity was collected for the Spencer Gulf, South Australia. These data were analysed using GIS to produce a graphical depiction of the Gulf in which 5x5 km planning units (PUs) were assigned an ecological rating depending on the amount of habitats and species within those units. Multivariate analysis, uncertainty analysis and sensitivity analyses were then used to confirm the robustness of the GIS-based model. The strength of this zoning model is the simplicity with which ratings can be applied to PUs representing small geographic areas. However, there are limitations to this model related to available spatial data within the marine environment, method for distributing zones, and the inclusion of information on dynamic processes. The marine plans, which will be produced based on this model, will guide decision-making authorities on appropriate levels of development and use in the marine ecosystems of South Australia without comprising whole ecosystem functioning.

Keywords: marine spatial planning, ecologically sustainable development, zoning, GIS, ecologically rated zones, multivariate analysis, sensitivity and certainty analysis

INTRODUCTION

Protection of marine resources from over exploitation and degradation is fundamentally important to ensuring their sustainability. The need for management of marine ecosystems at the large seascape scale is increasingly recognised. Prudent management to ensure ecological sustainability has long been recognised for land-based systems. Cities and states commonly plan for development of commercial, residential, and agricultural activities through municipal zoning systems. Only in recent years has the application of zoning models for the marine environment been recognized.

Planning for human activities at large seascape scales through marine spatial planning and ocean zoning is in varying stages of development in the United Kingdom (GHK Consulting, 2004; Marine Spatial Planning Consortium, 2006), Belgium (Douvere *et al*., 2007), USA (Pew Oceans Commission, 2003; Russ and Zeller, 2003; Sanchirico, 2004; Norse, 2005), Scotland (Tyldesley, 2004), Canada (Fisheries and Oceans Canada, 2005; Rutherford *et al*., 2005), New Zealand (Ministry for the Environment, 2005), China (Chinese Government, 2001), the Baltic Sea (Helsinki Commission, 2006), and South Africa (O'Toole *et al*., 2001). These planning strategies encompass a multitude of objectives for particular regions, and have an economic focus with emphasis on sustainable development and protection of the marine environment whilst minimising conflicts between users of the resource.

In Australia, regional marine planning is the key delivery mechanism for the Commonwealth Government to implement the Australia's Oceans Policy (Environment Australia, 1998). Regional marine plans enable the integration of management to ensure ecologically sustainable use, and the conservation of ecologically important areas, whilst maintaining economic, social and cultural values. Other national initiatives include Integrated Coastal Zone Management (Natural Resource Management Ministerial Council, 2006) and Integrated Oceans Management (Australian Government, Department of the Environment and Heritage, 2006). The South Australian Government is a partner in developing these programs.

MARINE PLANNING IN SOUTH AUSTRALIA

Background

The State Government of South Australia has approximately 59,800 km^2 of territorial waters in its jurisdiction that are used for a range of purposes, including shipping, tourism, recreational activities, industry, aquaculture and fisheries. Historically, there have been few coordinating mechanisms for these activities across Government agencies and communities. There are numerous separate pieces of legislation, many that have been produced *ad hoc*. This same situation is documented in many other parts of the world (Crowder *et al*., 2006; Douvere and Ehler, 2007).

South Australia's marine, coastal and estuarine environment is under pressure from development and use, pollution and the introduction of pest species. Many of these issues will be addressed by the recently developed *Marine Planning Framework for South Australia* (the Framework) (Government of SA, 2006a) and associated *Performance Assessment System* (Ward *et al*., 2006a, b). The development of the Framework establishes the policy direction to conserve and protect South Australia's marine, coastal and estuarine environment. The Framework delivers six marine plans spanning the whole of South Australia's waters.

Marine planning is a management tool which will guide development and use in the marine environment to reduce impacts to marine ecosystems which often result from these activities. Marine planning in South Australia is underpinned by three key principles: ecologically sustainable development, ecosystem-based management and adaptive management. Ecologically sustainable development (ESD) in this context is defined as using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be improved (Australian Government, Department of the Environment and Heritage, 1992). The ESD principle also incorporates the precautionary principle, in which, if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

The principle of ecosystem-based management is based on the importance of recognizing ecosystem structures and functions and then responding to signals from the ecosystem in order to manage anthropogenic activities and uses. Adaptive management is described for use in this paper as a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. These principles will be applied through the development, implementation and review processes of the marine plans (Australian Government, Department of the Environment and Heritage, 2006).

These principles interact in two ways in a marine plan. Firstly, by driving the development of a simple zoning model that groups amounts of known habitats and species into four ecologically rated (ER) zones for all South Australian marine ecosystems and secondly, by linking a set of goals, objectives and strategies to each of these zones (see Government of SA, 2006a). Each goal has an impact threshold. For example, in an ER1 zone the impact threshold is *negligible* and states, 'not to exceed negligible impacts to habitats or populations and is unlikely to be measurable against background variability e.g. interactions may be occurring but it is unlikely that there would be any change outside of natural variation. Recovery is measured in days and not to exceed one month' (Government of SA, 2006a). These impact thresholds are based on measures of recovery and guide development and use in particular areas as to the degree of impact they may incur.

Marine Planning in South Australia endeavors to create strategic integrated management using a whole of Government approach. Therefore management for each of the ER zones will occur through Government Agencies, Local Governments, Councils, and Natural Resources Management Boards using the ER zone goals, objectives, strategies and impact thresholds as guidelines to manage their own activities. This will also occur through the subsequent development of strategies, plans and policies on issues related to the sustainable development and use of South Australia's marine, coastal and estuarine resources. Monitoring of these activities will occur through the implementation of the Performance Assessment System.

Marine planning will also complement the Marine Parks process in South Australia by reducing impacts to the marine environment outside of marine parks established by the State. Marine protected areas (MPAs) are one tool for the protection of marine resources and are an increasingly common means of protecting specific habitats and/or species (see Committee on the Evaluation, Design and Monitoring of Marine Reserves and Protected Areas in the United States, 2002). Despite the benefits of MPAs (see Sobel and Dahlgren, 2004), their generally small geographic extent often leaves large areas of habitat and species unprotected. MPAs are not isolated from diffuse impacts such as poor water quality, and the scales of ecological processes, such as species dispersal and recruitment into populations, are generally much larger than the scale of MPAs (Allison *et al*., 1998). Consequently, without adequate protection of species and ecosystems lying outside of MPAs, their effectiveness at protecting marine systems as a whole is limited (Allison *et al*., 1998). Therefore, one way in which managers can limit impacts outside of MPAs is to integrate them with coastal zone, ecosystem, or broader ocean zoning management plans (Sobel and Dahlgren, 2004).

Management for sustainable development recognises that most problems in the sea start on land (Environment Australia, 2002). Marine planning will integrate the practices onshore and in the air that impact on water quality, life cycles of marine species and the vulnerability of coastal communities to marine hazards. This will require the integration of land use practices within catchment areas of rivers and streams that feed estuaries and coastal waters.

Marine planning does not attempt to resolve all of the competing and occasionally conflicting uses within the planning area. There may be some resolution of conflicts between different activities but this would occur as a defacto outcome of marine planning.

At the time of development of the marine planning model in South Australia, there were no marine planning models available worldwide that were suitable for use in an in-shore environment. The marine planning process involved pre-consultation with the public (through a Statewide issues analysis, regional briefings, surveys, and workshops with communities); boundary selection; consultation during the development of the methodology through a Regional Consultative Committee, Scientific Working Group and Steering Committee; data collection; data analysis and zoning; and development of goals, objectives and strategies that link with each of the zones developed. The products produced from this process included: the *Marine Planning Framework for South Australia*; six regional reports, one for each of the six marine planning areas for South Australia six regional marine plans; the *Marine Planning Framework for South Australia - Performance Assessment System* (PAS) (Ward et al., 2006a, b); and six regional performance assessment systems. The PAS outlines an approach which will measure the success of the Marine Plans. These documents are available at: www.environment.sa.gov.au/coasts/.

This paper describes the GIS based, zoning methodology for the development of marine planning in South Australia. The zoning approach was selected for the South Australian marine planning process, as it was deemed robust, objective and repeatable compared to industry-based approaches (see Government of South Australia, 2007). The aim of the ecosystem-based approach was to create a zoning system based on the amount of habitats and species that occur within the marine environment, and identify and define the spatial boundaries of the zones.

METHODS

The assumptions behind the model were developed based on managing activities within the assimilative capability of the ecosystem. The key assumptions were that the data available should reasonably reflect the correct spatial distribution of the ecological parameters fundamental to the function of the ecosystem and its biological diversity.

Study Area

The State waters of South Australia have been divided into six marine planning areas based on national bioregions from the Interim Marine and Coastal Regionalisation for Australia Technical Group (1998) (Figure 1, page 41). Marine plan boundaries extend from the highest astronomical tide to 3 nautical miles offshore, including all bays, gulfs and offshore islands. This boundary was set in order to include a major proportion of the saltmarsh and stranded saltmarsh areas found in South Australia. These habitats are usually inundated by seawater at least once a year and were deemed important for inclusion as they serve as nursery and feeding habitats for wader birds, sea birds, fish and invertebrates. Some of these habitats are classified as nationally and/or internationally important wetlands.

The Spencer Gulf marine planning area was selected as the pilot area to trial the model for the *Marine Planning Framework for South Australia*, due to the broad and complex range of marine uses and habitats in the region (Figure 2, page 42).

The steps in the development of the marine planning zoning model, within a Geographic Information Systems (GIS) environment, are described next.

FIGURE 1 Map of the marine planning areas and bioregions in South Australia.

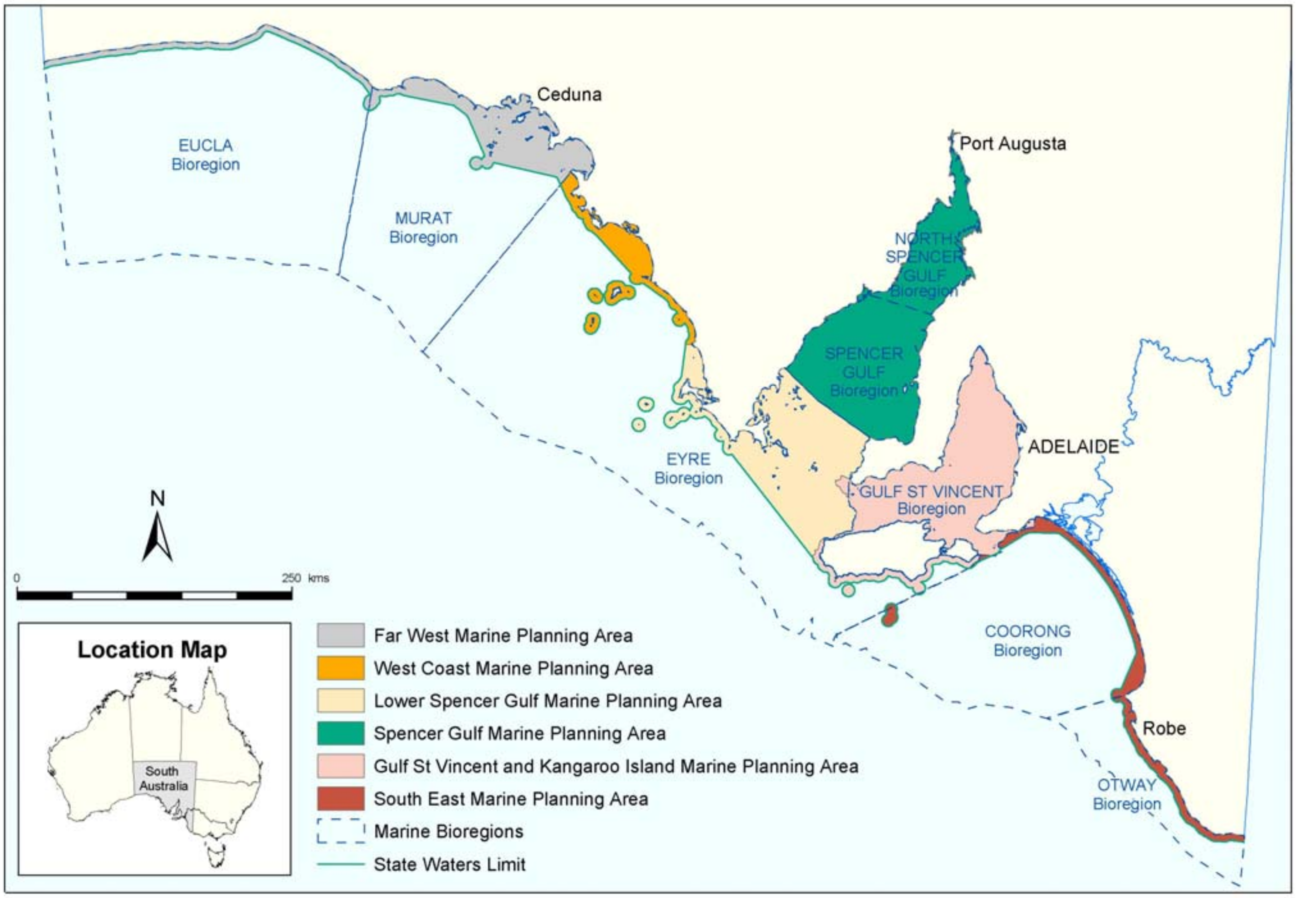
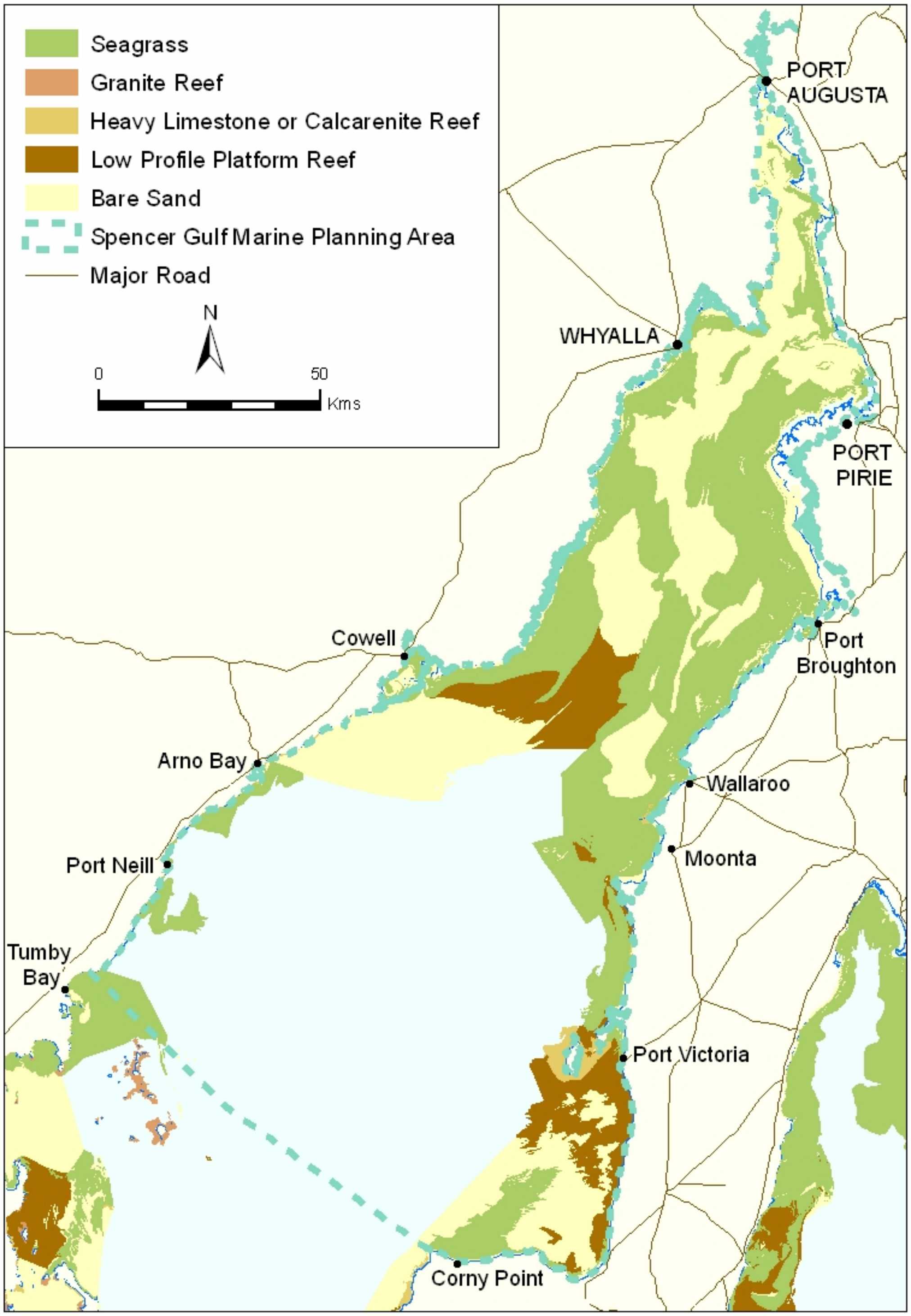


FIGURE 2 Spencer Gulf marine planning area and 5x5 km PUs.



DATA COLLECTION

Geographic Information Systems (GIS) are computer-based systems used for the manipulation and analysis of spatially distributed data. GIS is useful in an array of natural resource management applications (Johnson, 1990) including fisheries management (Nishida and Booth, 2001), gap analysis (Scott *et al.,* 1993), coastal resource management (Welch *et al.,* 1992, 2002), water resource management (Tsihrintzis *et al.,* 1996), habitat assessment and management (Stanbury and Starr, 1999) and traditional (Clamia, 1999) and non-traditional (Indigenous) marine reserve planning (Mumby *et al.,* 1995; Palumbi *et al.,* 2003). In developing the marine planning zones, GIS software (ArcGIS) was used to store, display and analyze the collected data.

Data were collected on the environmental, economic, social and cultural values of the marine ecosystems of South Australia from a variety of sources including published literature, information from community members and groups, private businesses and Government agencies (fisheries, heritage, transport and environmental departments). This resulted in approximately 70 GIS spatial layers. The environmental data were used for the development of the marine planning model with the social, economic and cultural/ heritage data used to support it. For the pilot Spencer Gulf marine planning area, 18 layers of environmental data, were selected for use in developing the zoning model and were grouped as either 'habitats' or 'uniqueness' (Table 1, page 44). The environmental layers in the marine plans contain information on habitats and uniqueness of the area. Habitat layers include data on the presence of reef, seagrass meadows, soft sediment communities, mangrove forests, and saltmarsh. Uniqueness layers include information on migratory wader birds and shorebird breeding/roosting sites, fish spawning and nursery areas, endemic species, and rare and endangered species. Each environmental layer created is referred to as an ecological variable.

Planning Units

To simplify the collation of the extensive amount of data that were collected, the Spencer Gulf marine planning area was divided into grid cells of equal size (5x5 km), termed PUs (Figure 3, page 45). This size was considered practical for natural resource management purposes. Each PU had a known location and a unique numerical identifier. Many of the coastal PUs were not of equal size as they had been clipped to the coastal boundary of the planning area (Figure 3, page 45). The PU system simplified the use of a large planning area as well as decreasing spatial errors by taking into account the range of capture scales and styles in the data (benthic habitats were mapped at 1:100,000, saltmarsh habitats were mapped at 1:10,000 (Figure 2, page 42) and seabird breeding sites were identified as a point).

Grouping Data

Several methods are available for grouping the data into zones within ArcGIS. As the data were not normally distributed, a non-parametric approach was necessary. The ArcGIS default classification method, the natural breaks method (Jenks, 1977), was chosen as it is a non-parametric, robust scheme of grouping variables based on natural groupings inherent in the data (ESRI, 1996). This method uses a statistical formula (Jenks optimisation) that identifies break points in the data by picking the class breaks that best group similar values and maximise the differences between classes.

GIS analysis, using the natural breaks method, group grid cells (PUs) into four zones (Figure 4, page 46), based on rating areas according to number of ecological factors (habitats and uniqueness) found in the PU. There are four categories of ER zones with ''cascading'' ecological importance, with one type of zone (E4) developed for areas with little or no information. Each cell is categorised according to the data it contained, distinguished by the relative importance of the contribution made by species, habitats and ecological processes to the healthy functioning of the ecosystem. Each ER zone has specific

TABLE 1 Ecological Variables (spatial layers) Used in the Spencer Gulf Marine Plan

Grouping	Spatial Layer	Description/Source	Scale Captured
Habitat			
	Benthic habitats (seagrass meadows and reef)	Marine Habitats mapped as part of a National seagrass / marine habitat mapping program undertaken by CSIRO. Mapping in South Australia was jointly undertaken by CSIRO and SARDI Aquatic Sciences Centre. The resulting mapping is a mixture of biological (seagrass densities) and geomorphic (reefs) cover types. 1:100000 satellite imagery.	1:100000
	Saltmarsh and mangrove habitat	Mapping of individual tidal saltmarsh and mangrove habitats throughout SA, providing landform, lifeform and condition categories.	1:10000 and 1:15000
Uniqueness			
	Australian sea lion breeding and haul-out locations	Australian sea lion locations within South Australian waters, describing population, breeding season and breeding and haul out sites for both the mainland and islands locations. Sea lion data was provided by Dr Anthony Robinson, South Australian Department for Environment and Heritage.	generated from latitude and longitude coordinates
	Wetlands	Contains approximate areas of Wetlands of Importance according to the report by Morelli and de Jong (1995).	1:10000 to 1:50000
	Conservation status of endangered marine algae (COSEMA)	Contains point locations of the known distributions of vulnerable Australian macroalgae. Point locations were obtained with permission from Reef Watch from the COSEMA online database which has been designed to help expand knowledge about vulnerable Australian macroalgae.	generated from latitude and longitude coordinates
	Breeding, nursery and spawning locations	Displays data collected for the Inventory of important coastal fisheries habitats in South Australia (Bryars 2003).	varying scales
	Rhodoliths	This dataset contains information on a unique type of crustose algae bed; data supplied by prawn fisherman from Spencer Gulf.	not applicable
	Seabird nesting locations	Seabird locations within South Australia, describing population and breeding seasons, including mainland and offshore island sites.	unknown
	Significant ecological attributes for the proposed South Australian (SA) Representative System of Marine Protected Areas	Distributions of significant coastal, marine and estuarine species associated with proposed SA Representative System of MPAs, mapped from textual information contained in a technical report (Baker 2004).	1:1000
	Wader Birds	Locations of key areas for wader birds according to the South Australian waders survey (Wilson 2000).	not applicable
	Zostera	Locations where *Zostera murcronata* is found within the Northern Spencer Gulf intertidal zone and is protected under the South Australian *Naional Parks and Wildlife Act 1972*.	not applicable

FIGURE 3 Benthic habitats: including seagrass meadows, mangrove forests and saltmarsh.

goals, objectives and strategies that guide use and development within the environmental capability of that PU. These zones are reviewed as additional information and understanding becomes available. This system is based on nationally recognised definitions that are used for the National Ecologically Sustainable Development Reporting Framework for Australian Fisheries (see Government of South Australia 2006a).

Impact Analysis

To identify potentially impacted areas or areas already experiencing impacts, analysis is undertaken in GIS using known variables. Each variable represents an activity that has a discernible impact on any marine habitat, flora or fauna such as aquaculture, marine pest, and point source pollution. Each variable was assigned a value of one and all activities were viewed as having the same degree of impact. Data were presented to reflect areas of the highest concentration of use and not the degree of impact that each variable may have, either independently or cumulatively. ER zone maps are produced as a result of the analysis and are presented by biounit. Impact analysis using spatial data, provided information on areas of high concentration of use which align closely with the ER1 zones.

Uncertainty analysis

Uncertainty analysis was used to determine and quantify the uncertainty in the model outputs that may be a result from insufficient input data (Crosetto, 1999) by determining the certainty of each variable being present or absent within each of the PUs. Thus, UA was used to determine how gaps in the data might be affecting the grouping of ER zones. The analysis was performed using ESRI ArcInfo and Microsoft Excel software. An uncertainty

FIGURE 4 Ecologically rated zone boundaries formed using Jenk's natural breaks method for the Spencer Gulf marine planning area.

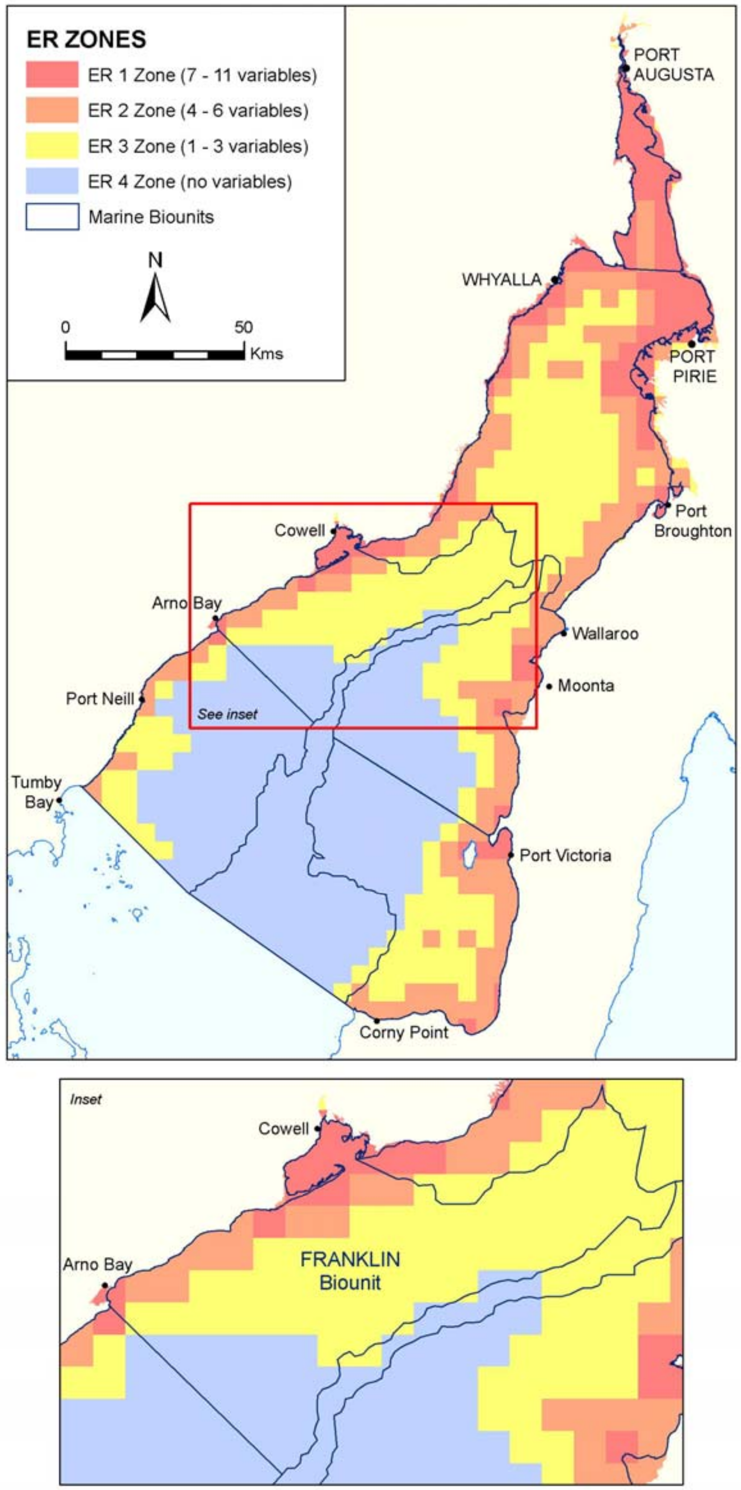


table was created containing the presence, absence, or uncertainty of the variables (18) within the all of the Spencer Gulf PUs. The uncertainty for each variable was removed as much as possible by determining presence or absence values for each PU. Table 2, page 48, outlines the criteria used for each variable being calculated as present, absent or uncertain. The totals from the uncertainty table were linked to the Spencer Gulf Marine Plan planning unit grid for visual display to show uncertainty effects of spatial data (Figure 5, page 49).

Sensitivity Analysis

The associated sensitivity analysis (SA) explored the impacts of individual layers on the groupings of ER zones and determined which variables were causing the most variation (see Marshall, 1999; Kocabas *et al*., 2004). The model was run several times excluding a number of layers at a time and using different themes (*e.g.* habitats only).

Two approaches were used to test the final outcome of the model: optimistic and pessimistic. In an optimistic approach, all uncertain values are considered certain (Marshall, 1999). The result of the uncertainty total plus the frequency for each planning unit was used in the analysis. In the pessimistic approach, entire variables are removed from the analysis to identify how sensitive the model is to certain variable removal. Each of the most uncertain variables was removed from the ER zones analysis one at a time and the analysis was re-run. In addition, the analysis was re-run removing all the variables that had an uncertainty greater than 50%. Finally, the analysis was run with only layers identified in the habitat category in order to explore which grouping was driving the ER zone rating. The results from each run of the model were compared to the original ER zone coverage (Figure 6, page 50) (Wright *et al*., 2007).

Multivariate statistical analysis

We used cluster analysis to test the robustness of the GIS natural breaks analysis and to explore other options for break methods (Biometrics SA, University of Adelaide – Lorimer *et al*., 2003). Cluster analysis partitions a set of objects (PUs) into two or more groups based on the similarity of the objects for a set of specified variables. The habitat and uniqueness variables were identified as present or absent within each PU for the Spencer Gulf planning area. The cluster analysis was performed using the Bray-Curtis similarity matrix and the group average hierarchical agglomerative cluster procedure (PC-ORD v.4). The resulting dendrogram showed possible grouping for the PUs. There is no standard procedure for choosing an appropriate number of groups from the cluster output; therefore, this was done subjectively based on large distance before groups combined with *a priori* criteria. A map was produced from the resulting clusters for comparison to the maps produced from the natural breaks method.

RESULTS

Grouping Data

The natural breaks method resulted in a four-zone system. Three zones represented the difference in abundance of habitats and species found in each PU. The fourth zone was created for PUs that contained inadequate scientific information. The ecologically rated zones (ER zones) were graded as follows:

- ER1 zone - containing the highest amount of marine, coastal and estuarine habitats and species.
- ER2 zone - containing a high amount of marine, coastal and estuarine habitats and species.
- ER3 zone - containing a moderate amount of marine, coastal and estuarine habitats and species.

TABLE 2 Example of Criteria for Assigning Present, Absent or Uncertain Values to Variables for the Uncertainty Analysis

Variable
Seagrass: *Present* - where seagrass was mapped in a PU. *Absent* - where other habitats were mapped to the full extent of the PU. *Absent* - in depths greater than 30m, and *Uncertain*- all other PUs, including those containing less than 1 ha of mapped data.
Reef: *Present* - where data were mapped in a PU. *Absent* - where Saltmarsh and Mangrove habitats were mapped to the full extent of the PU. *Uncertain* - all other PUs. This is because it is certain that there are reef habitats that are unmapped in PUs within the Spencer Gulf (for example False Bay) and there is no depth limitation to reef habitats, including those containing less than 1 ha of mapped data.
Sand (Unvegetated soft sediment): *Present* - where data were mapped in a PU. *Absent* - where all other habitats are mapped to the full extent of the PU. *Uncertain* - all other PUs, including those containing less than 1 ha of mapped data.
Mangrove, Saltmarsh, Wetlands of Importance, all other wetlands: *Present* - where data were mapped in a PU. *Absent* - where data were unmapped in a PU. *No Uncertainty*
Zostera capricorni* - seagrass protected under the *National Parks and Wildlife Act 1972: *Present* - where seagrass was mapped in a PU. *Absent* - where other habitats were mapped to the full extent of the PU. *Absent* - in depths greater than 30m, and *Uncertain*- all other PUs, including those containing less than 1 ha of mapped data.
Rhodoliths — type of marine sponge: *Absent* - where Saltmarsh, Mangrove, Seagrass and Reef habitats are mapped. *Uncertain* - all other PUs (when coordinates are overlayed with the Benthic mapping the rhodoliths are identified in already identified habitats).
Endangered marine macro algae (COSEMA Database), Key Biodiversity Area, Spawning, Nursery, Prawn breeding, Australian Sea lion breeding/haul out sites: *Present* – where it has been identified in a PU. *Uncertain*- all other PUs.
Water bird feeding grounds: *Present* - where data were mapped in PUs. *Absent* - PUs with water depth of greater than 2 metres. *Uncertain* – PUs with tidal flats or mangrove areas.
Seabird nesting locations, Seabird nesting locations (Vulnerable): *Present* - where locations identified in PUs. *Absent* - PUs with wet areas. *Uncertain* - all PUs that intersect the coastline.

FIGURE 5 Uncertainty totals for Spencer Gulf Marine Plan.

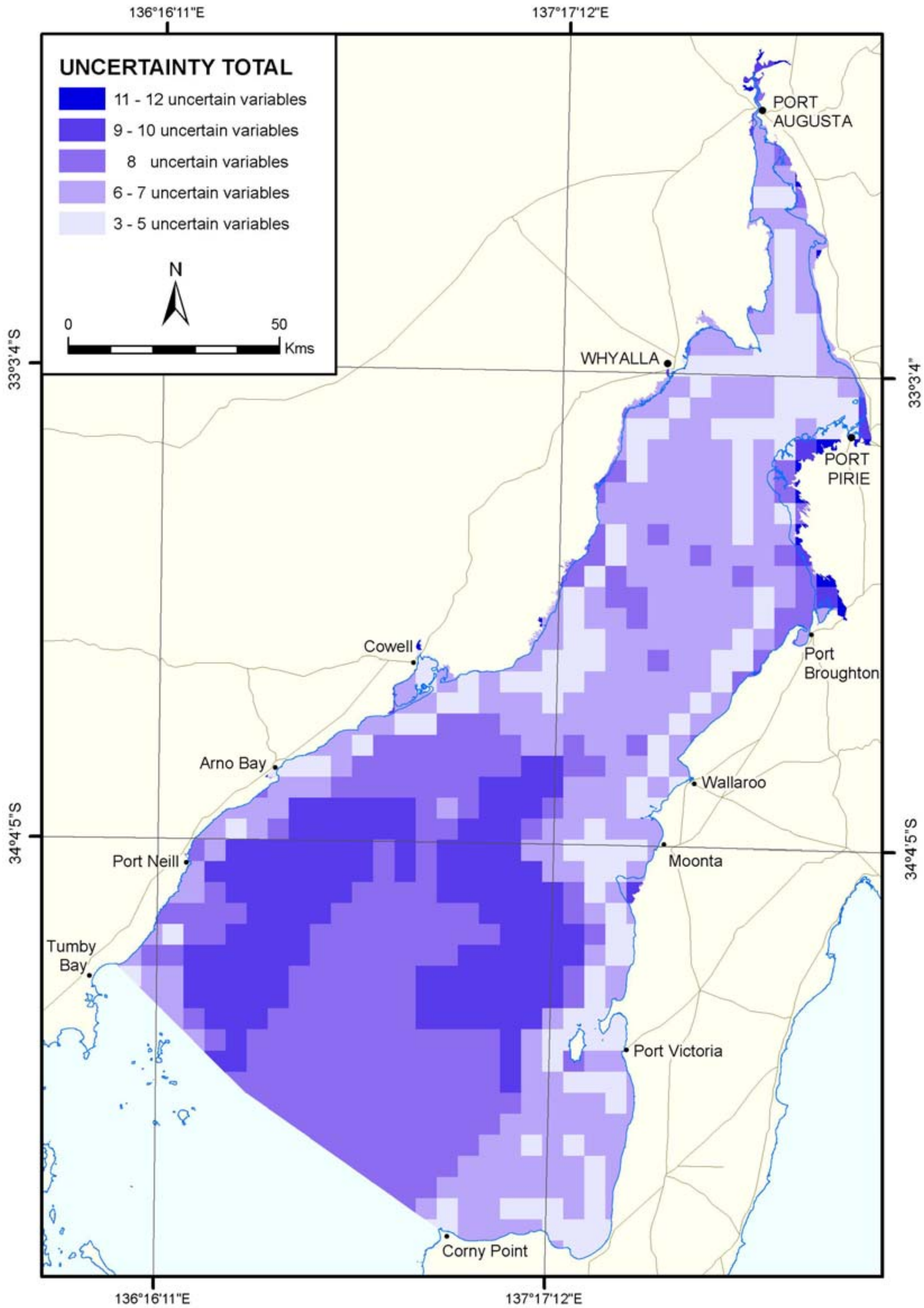
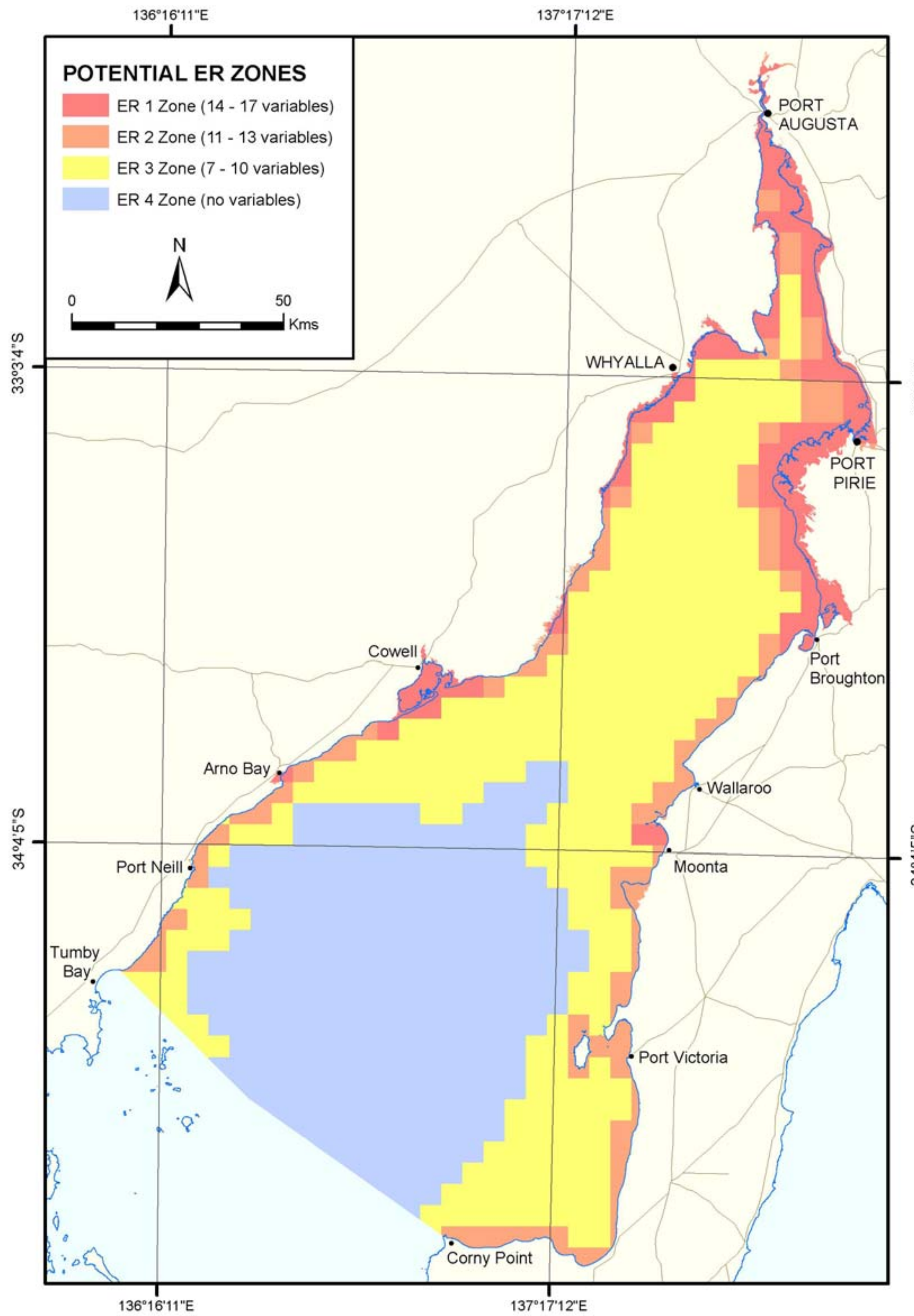


FIGURE 6 Potential ER zoning assessing uncertainty over the Spencer Gulf marine planning area including ER4 zones already identified.



- ER4 zone - areas for which the available scientific data are inadequate to identify their importance to the maintenance of biodiversity, ecological health and productivity of the ecosystem.

The statistics resulting from the ER zones groupings included: ER1 zones that covered an area of 199,239 ha or 15% of Spencer Gulf mostly in shallow coastal areas; ER2 zones covering an area of 223,833 ha or 19% of Spencer Gulf; ER3 zones covering an area of 557,175 ha or 31% of Spencer Gulf; and ER4 zones covering an area of 656,066 ha or 31% of Spencer Gulf mostly in deeper water locations (Figure 6, page 50).

Each ER zone is linked to goals, objectives and strategies, which are described in the *Marine Planning Framework for South Australia* and within each marine plan. These goals, objectives and strategies will guide appropriate levels of development and use of the South Australian marine, coastal and estuarine environment.

Uncertainty Analysis

Results from the UA showed that variables ranged in uncertainty from 0% to 95%. Of the 18 spatial layers used in the analysis, six showed no uncertainty, four variables showed less than 40% uncertainty, and eight variables showed greater than 50% uncertainty, with the two most uncertain variables being greater than 95% uncertainty (Table 3, page 52).

The pattern for the zoning that resulted from the UA was similar to the original ER zones. The majority of the PUs with the highest uncertainty (ranging from 45% to 55%) was prevalent in the middle of the Gulf, many of which were coincident with the ER4 zones. The PUs with the next highest uncertainty totals (ranging from 33% to 45%) were coincident with the ER3 zones and tidal and coastal environs.

Sensitivity Analysis

The potential ER zone based on the ultimate optimistic result was similar to the original ER zone map with the predominant changes being attributed to having no ER 4 zones. Analysis with the ER4 zones included showed only an 8% decrease in ER2 zones and subsequent 8% increase in ER 3 zones compared to the original ER zone model (Figure 6, page 50).

The pessimistic analysis results showed that some variables with high uncertainty, such as presence of Rhodoliths and endangered marine macro algae (COSEMA), had little or no impact on the results if removed (Table 4, page 52). However, the removal of other key ‘uniqueness’ data such as spawning and nursery areas had the most impact on ER zones. For example, when spawning data were removed there was a noticeable 7% increase in the number of ER2 zones and accordingly, ER3 zones decreased by 6% (Table 4, page 52). These changes can be attributed to a change in the zones break (natural breaks method) where the new break was defined between 3 and 5 variables as opposed to 4 and 6. The removal of sand, reef or seagrass had similar results to one another. For example, the removal of the sand habitat variable forced an increase in the ER4 zones by 47%, due to PUs being entirely comprised of a single habitat. The removal of seagrass, showed a decrease in the ER1 zones by 6% and increase in ER3 and 4 zones by 5% and 3%, respectively (Table 4, page 52).

The ER zone model was also run with just the variables from the habitat category, removing all variables classed in the ‘uniqueness’ category, in order to show if habitats were the main driving variables in the model. The results showed a 9% decrease in ER3 zones, a 4% increase in ER2 zones and a 5% increase in ER4 zones. Interestingly, the ER1 zones retained the same cover percentage. However, the number of higher ranked PUs increased in the middle of the gulf due to more than two habitats being present. In this model, the PUs only

TABLE 3 Uncertainty Analysis Based on Uncertainty of a Variable Being Mapped within a Planning Unit

Variable	Uncertainty Total	% of Total PU
Rhodoliths	801	95
Endangered marine macro algae	799	95
Reef	700	83
Zostera mucronata	616	73
Nursery	515	61
Spawning	515	61
Key biodiversity areas	467	55
Unvegetated soft bottom	401	53
Seagrass	310	37
Seabird nesting locations	199	24
Seabird nesting locations (vulnerable)	199	24
Wader/shorebirds - key area	151	18
Prawn breeding	0	0
Australian sea lion	0	0
Mangrove ecosystem	0	0
Saltmarsh ecosystem	0	0
Wetlands	0	0
Wetlands of National Importance	0	0

TABLE 4 Percent Coverage of ER Zones Running Different Iterations of the Model

Analysis Model Runs	ER zones % Cover of Planning Area			
	ER 1	ER2	ER3	ER4
Original zoning Spencer Gulf ER zones (Figure 4)	15	23	31	31
Certainty + Uncertainty	14	15	71	0
Certainty + Uncertainty – inclusive of ER 4 (Figure 6)	14	15	39	32
No spawning	13	30	25	32
No nursery	13	30	25	32
No Rhodolith	15	23	31	31
No endangered marine macro algae	15	23	31	31
No reefs	12	23	33	32
No sand	14	17	24	45
No seagrass	9	21	36	34
No key biodiversity areas	14	25	28	33
Habitat data only	15	27	22	36
No uncertainty layers	8	8	8	77

required two variables to be classed as an ER2, and three variables to be classed as an ER1 zone.

Multivariate Analysis

Eight groups were decided as appropriate based on the cluster analysis (Table 5). In group 1, the PUs have only wetlands present, with one planning unit having a unique variable (wader birds). For group 2, nursery habitats are found in all the PUs with some other variables. In group 3, samphire habitats are present in all PUs and most have wetlands present with one planning unit showing nursery habitats. For group 4, all PUs have sand present, with many having seagrass and some reef habitats. This group also had PUs with prawn breeding areas and spawning areas. Group 5 had all seagrass habitats present within PUs, with some having either deep sea or reef present and only on planning unit with a unique variable (endangered macroalgae). There were only eight PUs in groups 6 and reef habitats were present in all with six out of eight also having deep sea habitats. Group 7 had all deep sea habitats present in the PUs, with only a few PUs with sand and/or seagrass habitats. There were no unique variables in this group. In group 8 all PUs had deep sea, nursery areas, and spawning areas. There were only six PUs within this group, many which contained different unique variables (wader birds and seals) (Lorimer *et al*. 2003).

The map produced from this grouping is similar to the natural breaks method results represented in Figure 4, page 46.

Discussion

This model provides a simple system of grouping ecologically significant criteria into zones. The zones reflect their importance to the health and functioning of the marine ecosystem as a whole rather than on the needs of industry. This four zone model is the basis of a robust marine policy, the Framework (see Government of SA, 2006a). This policy links goals, objectives and strategies to each zone in order to guide development and use in the reduction of impacts to the marine environment, particularly to areas of biological significance such as seagrass, mangrove and saltmarsh areas.

TABLE 5 Description of Similarity Between PUs Within Determined Cluster Groups

Group	Variables Present within PUs
1	All have wetlands and one planning unit with wader birds.
2	All have nursery areas, plus some other variables.
3	All have samphire habitats, some have wetlands. One planning unit has nursery areas.
4	All have sand habitats, many have seagrass and some have reef. All have prawn breeding and some have spawning areas.
5	All have seagrass, some have either deep sea or reef present. One planning unit with endangered macrolagae.
6	Only eight PUs present. All have reefs. Six out of eight have deep sea. No unique variables.
7	All have deep sea present and only a few have sand or seagrass habitats. No unique variables.
8	Only six PUs within this group. All have deep sea, nursery and spawning present. Many different unique variables present.

The advantages demonstrated by this model include repeatability, transparency and robustness with no complicated modeling or programming. It is also highly adaptable so as new information is received, it can be accommodated.

There are; however, limitations to this model related to available spatial data within the marine environment, method for distributing zones, and the inclusion of information on dynamic processes.

Data Layers

The Spencer Gulf marine planning area was examined according to the ecological data available at the time of developing the model during the initial data collection stage. These data did not always give a comprehensive cover of the entire planning area. For example, the mapping of the benthic habitats, although extensive, does not include deep waters (generally deeper than 30 m) and there were limited data on the diversity of organisms across the entire area. Considering the limitations of the data sets used for the planning area, the ecological variables selected were considered indicative of the biodiversity, habitats and important species of each PU.

Another issue that has been discussed is that there is no valuing or weighing of layers. All variables are considered equal in their value within the planning unit when this may not be the case. For example, those PUs with only one habitat (*e.g*. seagrass or reef) and no unique variables will be rated low but in fact, may be an important part of ecosystem functioning.

There is some overlap in the data layers. This occurred where a habitat was also recognised as unique. For example, mangrove forests were in the basic habitat layer but also received recognition for being in a wetland layer, or a wetland of National Importance layer. In this case, a planning unit where mangroves appeared may also have the extra variable of wetlands of national importance. Using the ecosystem-based model avoided the complication of having to value each layer by giving them a weighting but then the outcome of this was the overlap between layers.

There are also issues with the size of the PUs. The 5x5 km grid size poses a dilemma when, for example, the grid boundary cuts through an island and the amount of layers in each of the PUs is different. In this scenario, one half of the island could be an ER1 zone and the other half may be an ER3 zone, yet the whole island has similar values. Also, in many cases, a finer scale of zoning may be important in the future when more point data is available on immobile species of conservation concern or habitats.

Spatial distributions of ecosystem processes, flora and fauna also present a problem. For example in the wader/seabird data layer the areas are represented by point data only; this is anomalous because the birds are spatially more widely spread than at a particular point and the points may change seasonally or yearly. Ecosystem processes such as upwellings or currents are not adequately represented in the marine planning methodology.

Grouping Data

The Jenk's natural breaks method of determining the amount of data layers for each of the ER zones is robust when using it for one marine planning area. However, the natural breaks method is dependent on the amount of data layers it uses. For each subsequent marine planning area the amount of habitats/species in each ER zone will change if the amount of layers used is not exactly the same as in the first zoned marine planning area. This will bias how the ER zones fall out for each marine planning area particularly as some ER zones may have more data layers in them than others.

As data are lacking in many of the marine planning areas the natural breaks method used in the GIS analysis may not present the best distribution of the data and therefore other models may need to be tested.

Sensitivity and Uncertainty Analysis

Data layers with no uncertainty indicate that the information which is available is comprehensively mapped across the Spencer Gulf planning area and is adequate for use in the ER zone analysis. High uncertainty ratings suggest that the relevant variables should be further verified or researched. However, it may be that variables involving endangered organisms, by their very nature, will only be identified in limited areas, therefore for high uncertainty should be considered acceptable.

Most of the PUs with the highest uncertainty were in ER4 zones, and for these PUs, the precautionary principle is already in place. ER1 and ER2 zones contained the lowest variable uncertainty. This finding builds confidence that there is adequate coverage of these environs in those ER zones. PUs with the highest uncertainty values, having a total of 10 or 11 uncertainties, make up <1% of the planning area.

When all variables containing any uncertainty were removed from the ER zone model, the largest difference was a greater number of ER4 zones (*i.e.* PUs with no data). A similar pattern remained for higher-ranking ER zones in the northern gulf, in embayments or around islands. This analysis highlighted that using the uncertain data does provide a greater understanding of the marine environment even though the data may not be comprehensive.

When analysing the removal of some of the variables identified spatially as point information, little to no change occurs suggesting that these types of point data have minor influence over the results of the model. As further research is undertaken and more knowledge is gained, it would be preferable, for point data (site information) to be replaced by polygon data (mapped habitats), thus identifying associated habitats to the already identified point locations (*i.e.* wader bird feeding sites, seabird breeding sites or sea lion/seal haul-out locations).

When the unique layers identifying spawning and nursery were removed from the analysis the number of ER 2 zones increased considerably. This shifted some of the focus of the higher level zoning from coastal regions, that are recognised as 'key habitats' for species such as wader birds and shorebirds and identified nursery, breeding and spawning areas, to more seaward areas. In addition, a greater protection is offered to more areas, restricting development and use in the gulf that may not be necessary. However, it is important to leave these layers in the analysis to identify important processes in the Gulf. Similarly, using only the habitat layers and removing any of the unique layers makes the grouping of the ER zones homogenous, indicating that the use of the 'uniqueness' variables is significantly important in identifying areas of greater ecological significance.

These results identified the importance of having an adequate number of variables to support the natural breaks method of classification. The analysis identified clearly those spatial layers that required further research. It also showed that the removal of layers with high uncertainty did not significantly change the model outcomes, providing confidence in the model itself. Until further information becomes available, the data used in the zoning model for the Spencer Gulf is sufficient to fulfill the objectives and actions of the *Marine Planning Framework*.

Multivariate Analysis

The cluster analysis showed obvious similarities to the Jenk's natural breaks analysis used in the GIS environment (Lorimer *et al.* 2003). It was also evident that many of the groups were clustering due to habitat variables only, with unique variables being split between groups (exception being group 8) (Table 5). This is mostly due to uniqueness data being sparse for many parts of the planning area. This helps identify gaps in data and where future research needs to be focused (*i.e.* habitat mapping).

The binary nature of the data can be a limiting factor with multivariate analysis. Cluster analyses rely upon a distance matrix, which can be hard to detect without continuous measurements. In addition, the assumptions of normality are not met with binary data and limit the use of many multivariate analyses. Arbitrarily choosing the number of clusters is also a limitation, but there is no standard procedure for choosing an appropriate number when using cluster analysis.

The further use of different multivariate analyses for zoning is a likely option for refining the marine planning model. In the future, cross-validation techniques need to be employed to validate clustering. Also, principle components analysis can be utilized to reduce the data set and to reveal what data are driving the grouping patterns with the expectation of modeling these patterns in GIS.

Future Progression

The marine planning model is based on the principle of adaptive management and as new data become available it will be included in the analysis, making the model stronger. Every two and half years the data will be analysed to consider this new information and to refine zoning. Other issues that may be considered in the first round of reviews include: weighing the value of the variables for ER zoning which would involve a comprehensive risk assessment; using multivariate analyses for establishing breaks for zoning to exclude human bias in choosing the breaks; and establishing smaller PUs.

CONCLUSION

Marine spatial planning with the main goal of ocean zoning is an emerging method for many countries around the world to better manage their marine ecosystems. Some approaches attempt to place industry sectors (*e.g.* commercial and recreational fishers) into their own zones reserved purely for their operations (Sanchiro, 2004). This industry-focused approach, however, is overly cumbersome with so many competing uses for the entire marine environment. From an ecosystem approach, Crowder *et al.,* (2006) explain that elements of successful zoning include locating and designating zones based on the underlying topography, oceanography and distribution of biotic communities and designing a system of use-rules within each zone attached to compliance mechanisms and a review and monitoring process. The *Marine Planning Framework for South Australia* (Government of South Australia, 2006a) and resulting *Spencer Gulf Marine Plan* (Government of South Australia, 2006b) have been developed largely encompassing all of these criteria.

This ecosystem-based zoning model is a good first step to integrated large ocean management for near shore waters. By bringing together and displaying marine environmental data in a simple way, the model assists in providing valuable information to all users of the marine environment on what impacts are acceptable for whole marine ecosystem functioning and sustainable use.

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