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Prioritising areas for dugong conservation in a marine protected area using a spatially explicit population model

Alana Grech
School of Earth and Environmental Sciences
James Cook University,
Townsville, QLD 4811, Australia.
alana.grech@jcu.edu.au

Helene Marsh
School of Earth and Environmental Sciences
James Cook University,
Townsville, QLD 4811, Australia.
helene.marsh@jcu.edu.au

Abstract: The Great Barrier Reef World Heritage Area (GBRWHA) covers an area of approximately 348,000km² making it the world's largest World Heritage Area / marine protected area complex. Dugongs (*Dugong dugon*) inhabit the shallow protected waters of the GBRWHA, and were an explicit reason for the region's World Heritage listing. To manage dugongs effectively in the GBRWHA, it is critical to understand their spatial relationship with their environment and the human activities that threaten them. We demonstrate how a spatially explicit dugong population model can be used to prioritise conservation initiatives for dugongs in the GBRWHA. We used information collected from dugong aerial surveys in conjunction with geostatistical techniques, including universal kriging, to develop a model of dugong distribution and abundance. After completing the model, we conducted frequency analyses to categorise relative dugong density and distribution to identify areas of low, medium or high conservation value. As dugongs extend over a wide distributional range, prioritising areas of conservation value has the potential to be an important basis for administering management resources. We conclude that spatially explicit population models are an effective component of species conservation management, particularly for species that range over large, complex and dynamic regions.

Key words: spatial distribution, dugong, *Dugong dugon*, universal kriging, marine protected areas, Great Barrier Reef, World Heritage Area

1. Introduction

Marine protected areas (MPAs) are designed to manage or protect defined areas of sea through legislative arrangements and management infrastructure (Kelleher and Kenchington 1992). The intentions behind designating a MPA differ between regions, but MPAs are usually established to increase the likelihood of sustainable fisheries, biodiversity conservation, species conservation and/or the preservation of cultural values (Kelleher *et al.* 1995). The Great Barrier Reef World Heritage Area (GBRWHA) of Queensland, Australia covers an area of approximately 348,000 km² making it the world's largest World Heritage Area (Figure 1).

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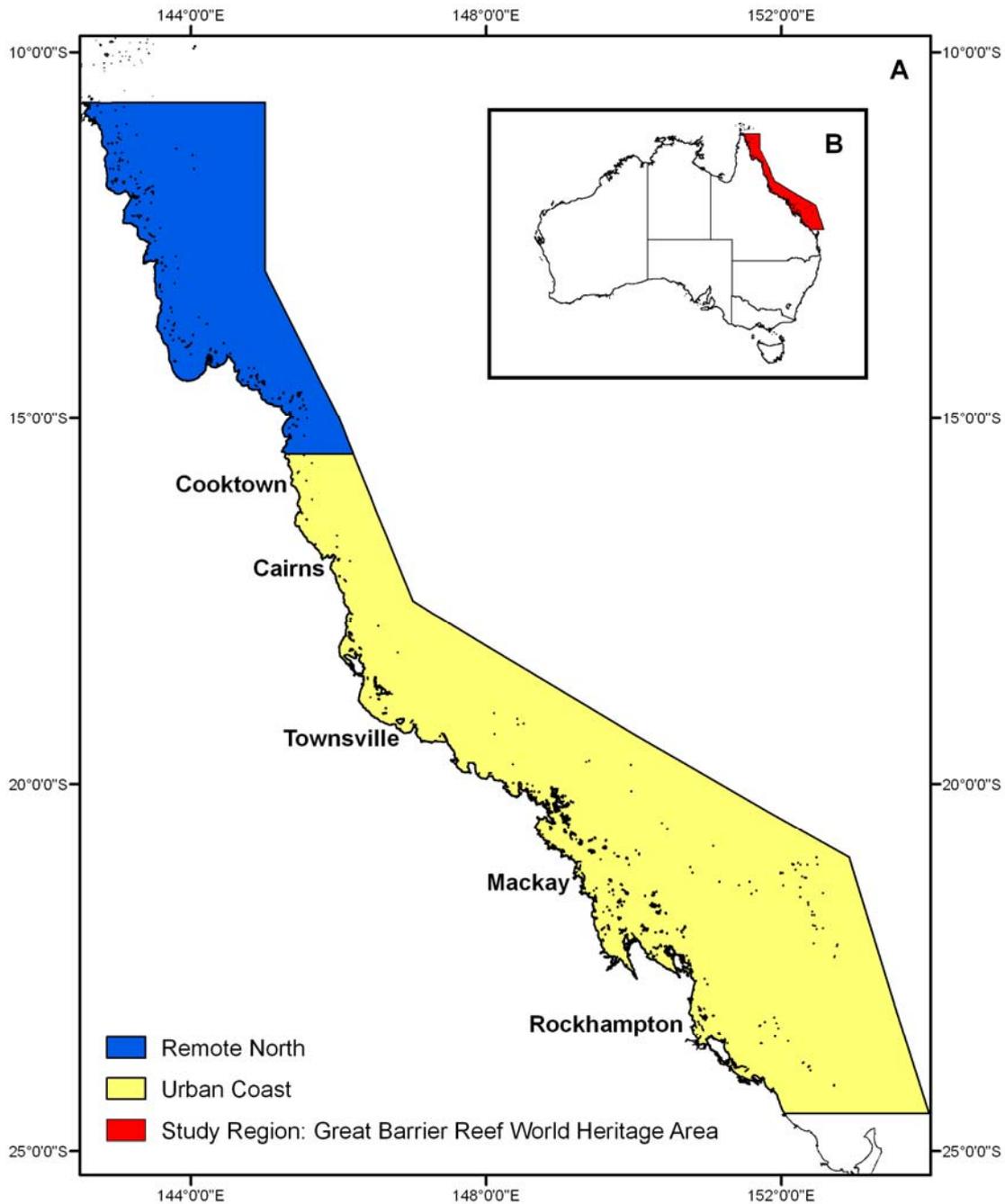


Figure 1 - Extent of the Great Barrier Reef World Heritage Area (GBRWHA) off the coast of Queensland, Australia showing major regional cities. The GBRWHA is divided into the remote north region and the urban coast.

Two large MPAs encompass most (~99%) of the region; the Great Barrier Reef Marine Park (GBRMP), which is administered by the Australian Government's Great Barrier Reef Marine Park Authority (GBRMPA); and the Great Barrier Reef Coast Marine Park (GBRCMP), which is administered by the Queensland State Government's Environmental Protection Agency (EPA). In the early 1990s, the shortcomings of the contemporary zoning regime governing the

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distribution of activities in the region were recognised. Re-zoning of the GBRMP was subsequently initiated to maximise biodiversity protection through a comprehensive and representative multiple-use regime (Day *et al.* 2000; Fernandes *et al.* 2005). Spatial analysis and GIS techniques, including the use of the reserve design software MarXan (Ball and Possingham 2000), were integral to the re-zoning process (Lewis *et al.* 2003). The GBRCMP was subsequently created to mirror the revised zoning in the Queensland waters of the GBRWHA that are not included in the GBRMP.

The dugong (*Dugong dugon*) or sea cow is a threatened species of very high cultural value to Indigenous Australians and high intrinsic value to non-Indigenous Australians (Figure 2). Significant populations of dugongs inhabit the shallow, protected inshore waters of the GBRWHA (Marsh *et al.* 2002) and were an explicit reason for the region's World Heritage listing (GBRMPA 1981). Dugongs are protected under Queensland's *Nature Conservation Act* 1992, and listed as 'vulnerable wildlife' under schedule 3 of the *Nature Conservation (Wildlife) Regulation* 1994. They are also protected under the Australian Governments's *Environment Protection and Biodiversity Conservation Act* 1999 as a 'listed marine' and a 'listed migratory' species.



Figure 2 - A dugong

Dugongs are specialist feeders on seagrass, especially the genera *Halophila* and *Halodule*. The dugong's distribution is highly correlated with the distribution of its food resources in the coastal waters of Queensland. Dugongs are known to undertake large scale movements (defined as moves >15km) between sites of significant seagrass habitat (Gales *et al.* 2004; Marsh *et al.* 2004; Marsh *et al.* 2005; Sheppard *et al.* 2006). Dugongs undertaking large scale movements in coastal waters have been recorded making repeated deep dives rather than traveling at the

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surface (Sheppard *et al.* 2006). In the GBRWHA, dugongs apparently make large scale movements in response to changes in the availability of forage as a result of cyclone and flood events which can destroy seagrass meadows (Preen and Marsh 1995).

In latitudes higher than the GBRWHA such as Moreton Bay (Preen 1992) and Hervey Bay in South East Queensland (Sheppard *et al.* 2006) and Shark Bay in Western Australia (Holley *et al.* 2006), dugongs also undertake large scale movements in response to low water temperatures in winter. Thus these animals exhibit seasonal movements like those of their close relative, the Florida manatee (Deutsch *et al.* 2003). The minimum temperature thresholds triggering such movements are not reached in the GBRWHA and seasonal movements have not been recorded.

In order to manage a MPA effectively, it is necessary to understand the spatial relationships between the resources it is designed to protect and the anthropogenic activities that affect them. As a result of the dugong's extensive range (10°S - 24°S along the GBRWHA coast), its tendency to undertake individualistic movements and the spatial magnitude of the GBRWHA, it is challenging for managers to prioritize areas for dugong conservation. Spatially explicit models incorporating the distribution of species and anthropogenic impacts (Pull and Dunning 1995) have proved valuable to the decision-making process when managers are attempting to ameliorate the impacts of human activities over large, complex and dynamic regions (Turner *et al.* 1995; Rogers-Bennett *et al.* 2002).

We developed a spatially explicit model of dugong density and distribution for the GBRWHA using: (1) information collected from dugong aerial surveys conducted in the GBRWHA since 1986, and (2) geostatistical techniques, including universal kriging. We then conducted a frequency analysis to identify areas that are of low, medium and high conservation value for dugongs in the GBRWHA to inform the conservation management of the species in the region.

2. Methods

Aerial surveys conducted by Marsh and her group at James Cook University have systematically monitored dugong abundance and distribution in the GBRWHA since the mid 1980s, providing empirical data on patterns of dugong distribution and abundance (Marsh and Saalfeld 1989, 1990; Marsh *et al.* 1993, 1996; Marsh and Lawler 2001, 2002). The surveys extended from the southern edge of the GBRWHA (24°30'39''S) into the remote northern regions (11°32'59''S) (Figure 1) and covered ~73,000km² (21%) of the GBRWHA, substantially more than the dugong's recorded range within the region.

2.1 Dugong Aerial Surveys

Aerial surveys were conducted using the strip transect method described by Marsh and Sinclair (1989). The survey region was divided into blocks containing systematic transects of varying length, which were typically perpendicular to the coast across the depth gradient which supports seagrass in the region. Tandem teams with two observers on each side of the aircraft independently recorded sightings of dugongs, including information on group size and calf numbers, and the number at the surface. Transects were 200m wide at the water's surface on either side of the aircraft. These surveys have been used to estimate absolute dugong abundance by correcting sightings for perception bias (animals that are available to but missed by observers) and availability bias (animals that are unavailable to observers because of water turbidity) *sensu* Marsh and Sinclair (1989) and Pollock *et al.* (2006). The corrections for these biases were applied at the spatial scale of entire surveys (thousands of square kilometers), an inappropriate spatial scale for our research. As a result, our model of dugong distribution and abundance is based on relative rather than absolute total density. Nonetheless, the relative densities among regions should be approximately comparable.

In this analysis, dugong relative density was calculated at a grid size of 2km × 2km .This scale was chosen as: (1) it corresponds with the scale of the aerial survey data allowing us to account for: (a) slight changes in altitude of the aircraft (which affects transect width at the surface); and (b) the blind area under the aircraft.; and (2) it is the scale recommended for use by managers of wildlife under Criterion B of the *International Union for Conservation of Nature and Natural Resources Red List* (IUCN 2001). The results of six aerial surveys of the urban coast (Cooktown south) of the GBRWHA are in a digital format (1986, 1987, 1992, 1994, 1999, and 2005) as are the results of three surveys of the remote north (Cooktown north) (1990, 1995, and 2000; see Figure 1). All surveys were conducted in late spring or early summer when weather and sea states provide optimum survey conditions. As explained above, dugongs are unlikely to exhibit a seasonal component in their movements in the GBRWHA, and so conducting multiple surveys in the same season should not confound our relative estimates of dugong distribution and abundance.

The sampling intensity of each survey block was determined by calculating the proportion of area surveyed. There were some (relatively minor) differences in sampling intensity per block and area sampled between surveys. The sampling intensity within surveys varied between survey blocks depending on dugong abundance, ranging from approximately 6% to 40%,

In our analysis, four computations were required within each 2km x 2km grid cell to correct for these differences. Firstly, each dugong observation (u) was multiplied by the reciprocal of the sampling intensity (SI) of its transect:

$$u_n \frac{1}{SI_n}$$

Secondly, the mean sampling intensity of all relevant survey transects was calculated:

$$\frac{\sum_{i=1}^n SI}{N}$$

where N is the number of surveys within the region and 1, 2, ...n is an individual survey identifier. Each value from the first step was then divided by the mean sampling intensity of the relevant transect:

$$\sum_{i=1}^n u_i \frac{1}{SI_i} \bigg/ \frac{\sum_{i=1}^n SI}{N}$$

Lastly, the resulting value was divided by the number of surveys conducted on each transect to obtain a mean index of dugong abundance for each grid cell.

The spatial distribution of dugongs on which our analysis is based takes account of the large scale dugong movements resulting from changes in seagrass habitats (Preen and Marsh 1995; Gales et al. 2004; Marsh et al. 2002, 2004, 2005; Holly et al, 2006) because it is based on integrated data from six aerial surveys spanning 19 years along the urban coast and three surveys of the remote coast from Cooktown north over a decade.

2.2 Geostatistical Analysis

The analyses were conducted in the following sequence.

(1) The spatial autocorrelation of the data was investigated by a variogram analysis using the Geostatistical Analyst extension of ArcGIS® 9.0 (Environmental Systems Research Institute,

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2004). Spatial autocorrelation detects the spatial dependence of the relationship between two samples as a function of their separation distance and estimates the strength of this dependency (Vasiliev 1996).

The variogram analysis used the following circular model to estimate semivariance (Johnston *et al.* 2003):

$$\gamma(h; \theta) = \begin{cases} \frac{2\theta_s}{\pi} \left[\frac{\|h\|}{\theta_r} \sqrt{1 - \left(\frac{\|h\|}{\theta_r}\right)^2} + \arcsin \frac{\|h\|}{\theta_r} \right] & \text{for } 0 \leq \|h\| \leq \theta_r \\ \theta_s & \text{for } \|h\| > \theta_r \end{cases}$$

where $\theta_s \geq 0$ is the partial sill parameter, $\theta_r \geq 0$ is the range parameter and h the separation distance (lag) in metres. Lag h is defined as a vector that separates any two locations and has both distance and directional attributes. The directional effect of h was considered by estimating semivariance at different directions of h (0, 45, 90 and 135 degrees).

(2) Universal kriging was chosen as the most appropriate interpolation technique as it is robust to common attributes of ecological data (McKenney 1998; Ver Hoef 1993). Universal kriging is geostatistical estimation method that returns unbiased linear estimates of point values where trends in data vary and regression coefficients are unknown. The Spatial Analyst© extension of ArcGIS 9.1 (Environmental Systems Research Institute, 2004) was used to spatially interpolate the data to a 2km × 2km grid. Each grid cell in the completed model was regarded as a dugong management unit (DMU).

A re-substitution approach was used to validate the model resulting from the kriging analysis. This approach involved removing a random sub-sample of observations constituting 30% of the total observations and then testing it against dugong distribution predicted from a kriging using the remaining 70% of observations.

2.3 Prioritising Conservation

On completion of the model, a frequency histogram was used to categorise the dugong density of each DMU as of low, medium or high conservation value. This approach makes the assumption that dugong density is a robust index of a region's conservation value for dugongs. This assumption is robust because specialised areas for dugong reproduction and migratory corridors have not been identified and density estimates are regarded as suitable surrogate measurements of habitat utilization (Hooker and Gerber 2004).

As a result of the broad scale of the model, some sections of the coastline were not included within DMUs (~885km² or 2.8% of the distributional range of the dugong). To include those areas within the three levels of dugong conservation value, a spatial join was performed in which each marine region not featured within the model was joined to its nearest DMU ranked with the corresponding conservation value of low, medium or high.

3. Results

Parameters of the variogram analysis are shown in Table 1 and Figure 3 shows the semivariogram. Table 1 indicates that dugong distribution is spatially autocorrelated. Thus, the spatial component inherent within the data explained the sampled variation and is suitable for interpolation. The directional variograms showed an isotropic relationship for dugong spatial distribution (Table 1). Cross-validation of the final kriging (Figures 4, 5 and 6) reported reliable predictions of the model, with a low standard error of 0.046.

Direction	Isotropic	0°	45°	90°	135°
Model fitted	Circular	Circular	Circular	Circular	Circular
Nugget (c_0)	0.262	0.255	0.261	0.255	0.261
Sill	0.465	0.459	0.464	0.455	0.464
Range (a)	437.39	437.39	437.39	358.78	429.24
Mean	0.077	0.076	0.076	0.075	0.076
RMSE	0.872	0.872	0.878	0.872	0.878
SE	0.046	0.015	0.009	0.015	0.009

Table 1 - Isotropic and directional (0°, 45°, 90° & 135°) variogram model parameters for dugongs in the Great Barrier Reef World Heritage Area (GBRWHA). RMSE: root-mean-square error between observed and predicted semivariance; SE: standard error.

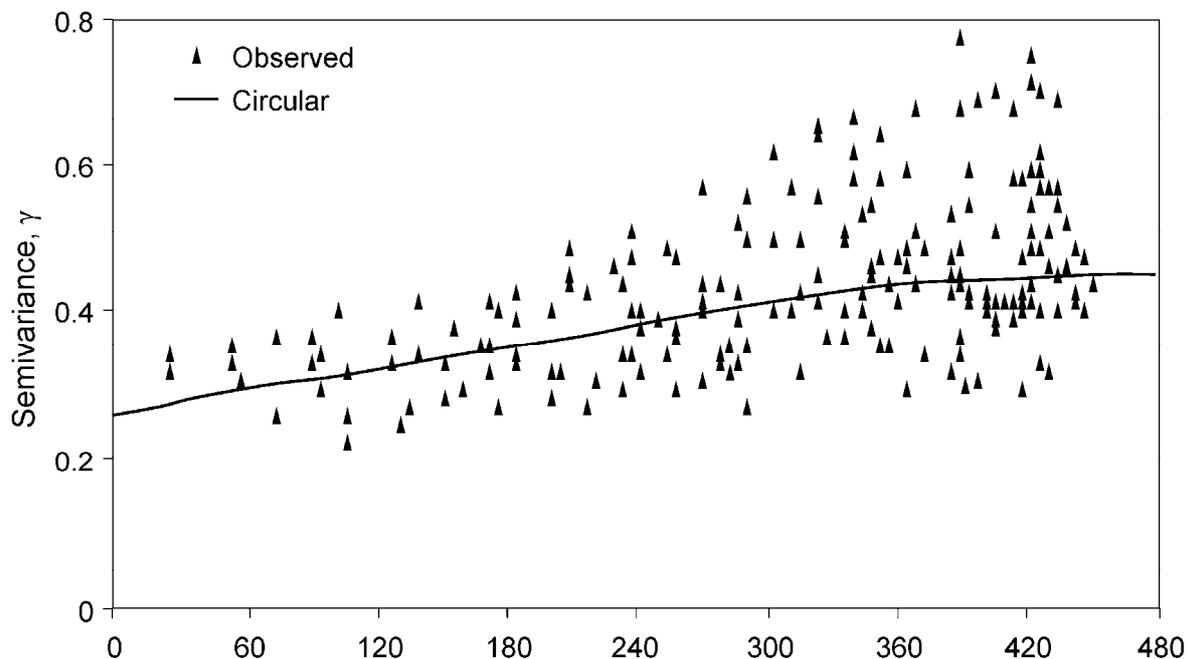


Figure 3 - Dugong semivariogram for the observed data and circular model. Distance is measured in kilometers.

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The index of average relative dugong density in the entire GBRWHA was estimated to be 0.077 dugongs/km²; relative density ranged from 0.0011 to 9.86 dugongs/km². Average dugong relative density in the remote north is seven times higher than the urban coast (0.145 compared with 0.020 dugongs/km²). The highest relative density is also greater in the remote north with a range of 0.0036 to 9.86 dugongs/km² compared with the urban coast range of 0.0011 to 1.92 dugongs/km². The areas of highest relative density (or 'hot spots') in the remote north are in the Friendly Point and Port Stewart regions, and between Lookout Point and Princess Charlotte Bay (Figure 4). 'Hot spots' along the urban coast are north of Hinchinbrook Island, Cleveland Bay (Figure 5), and the Shoalwater Bay region including Port Clinton (Figure 6).

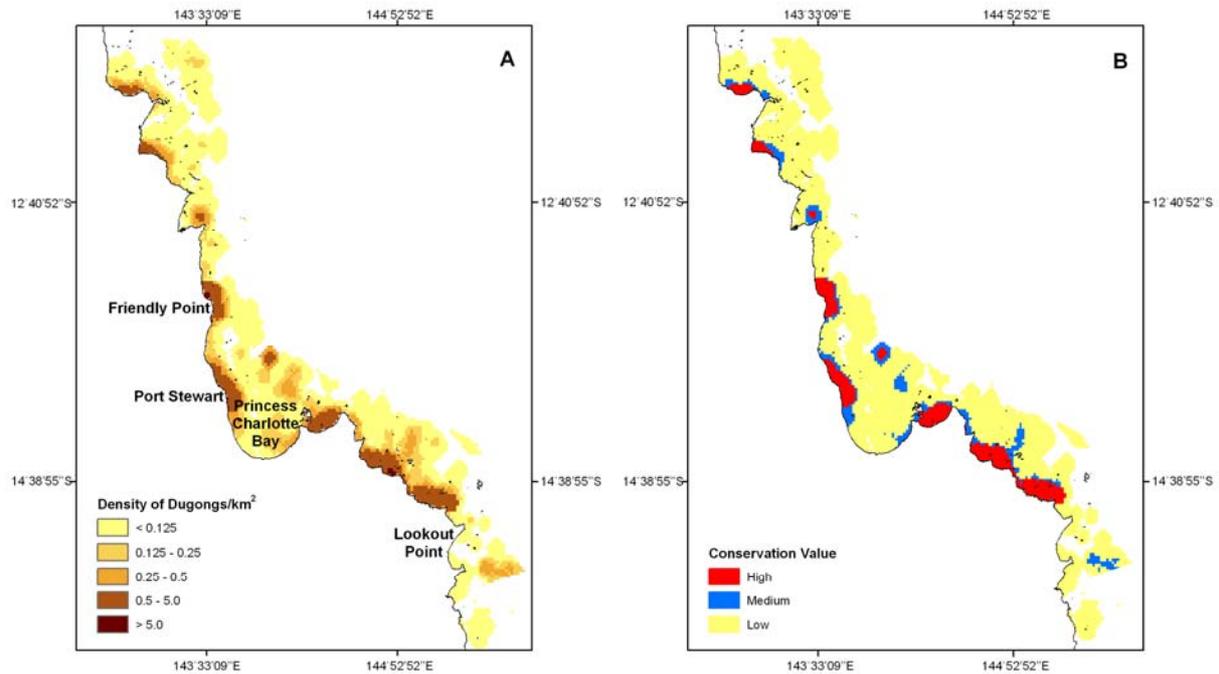


Figure 4 - Model of dugong relative density and distribution (A), and the corresponding levels of dugong conservation value (B) in the remote north.

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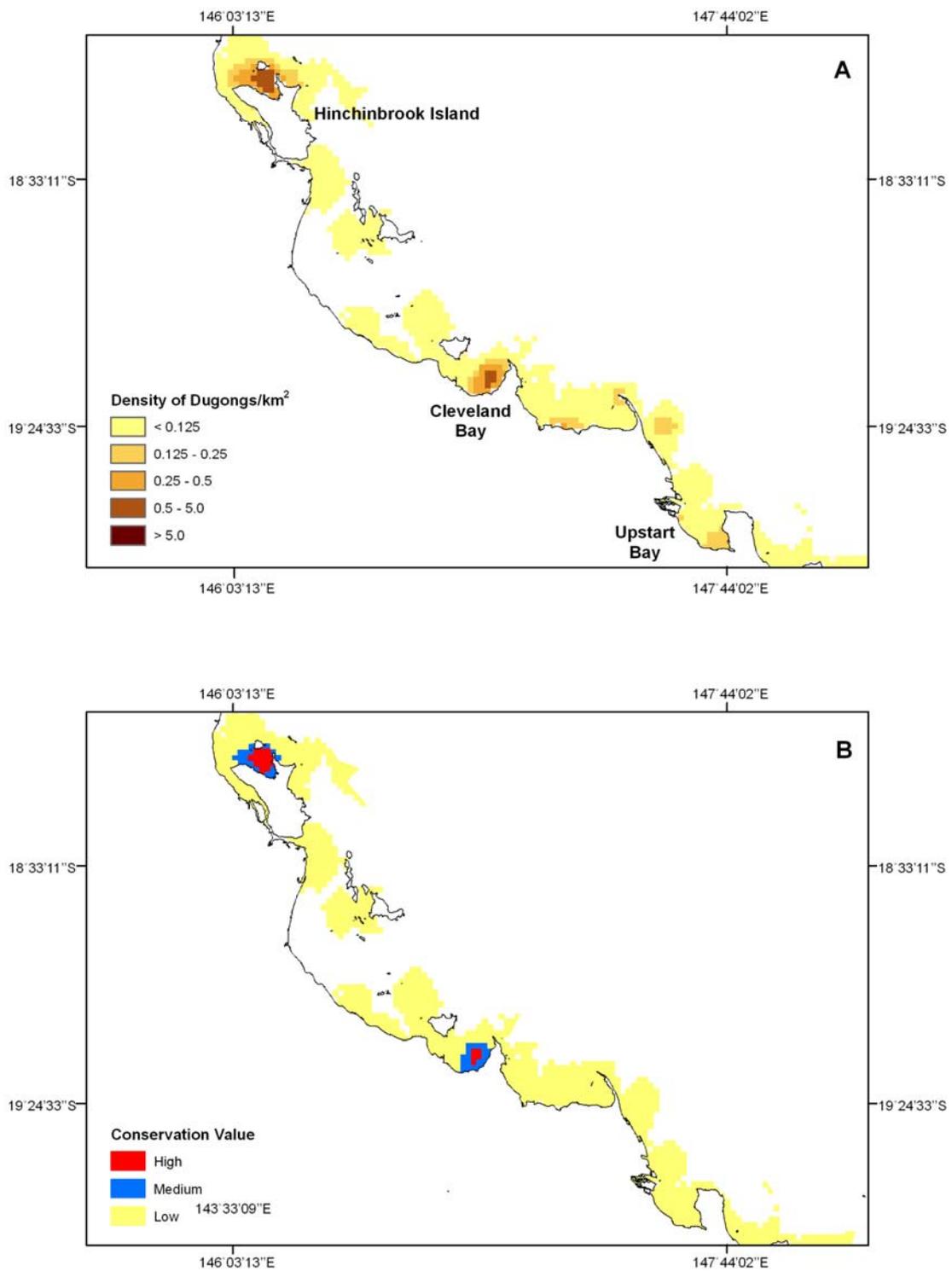


Figure 5 - Dugong relative density and distribution (A), and corresponding levels of dugong conservation value (B) between Hinchinbrook Island and Upstart Bay.

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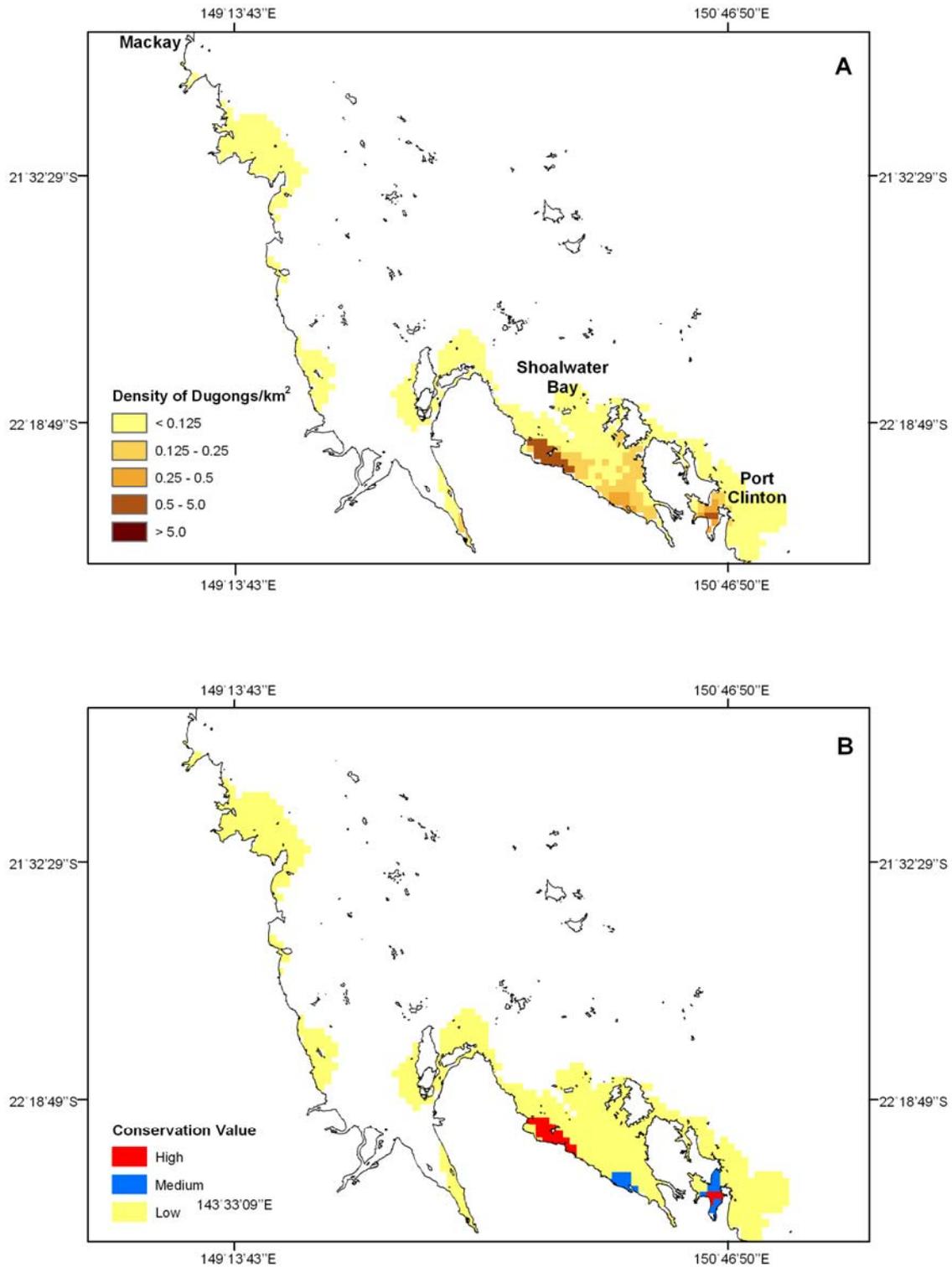


Figure 6 - Model of dugong relative density and distribution (A), and the corresponding levels of dugong conservation value (B) along the urban coast between Mackay and Shoalwater Bay and Port Clinton.

The frequency histogram (Figure 7) revealed relative density thresholds within the dugong population for separation into areas of low, medium and high conservation value. Low conservation value areas had relative dugong densities of between 0.0015 - 0.25 dugongs/km²; medium conservation value 0.25 - 0.5 dugongs/km²; and high conservation value > 0.5 dugongs/km² (Figures 4, 5 and 6).

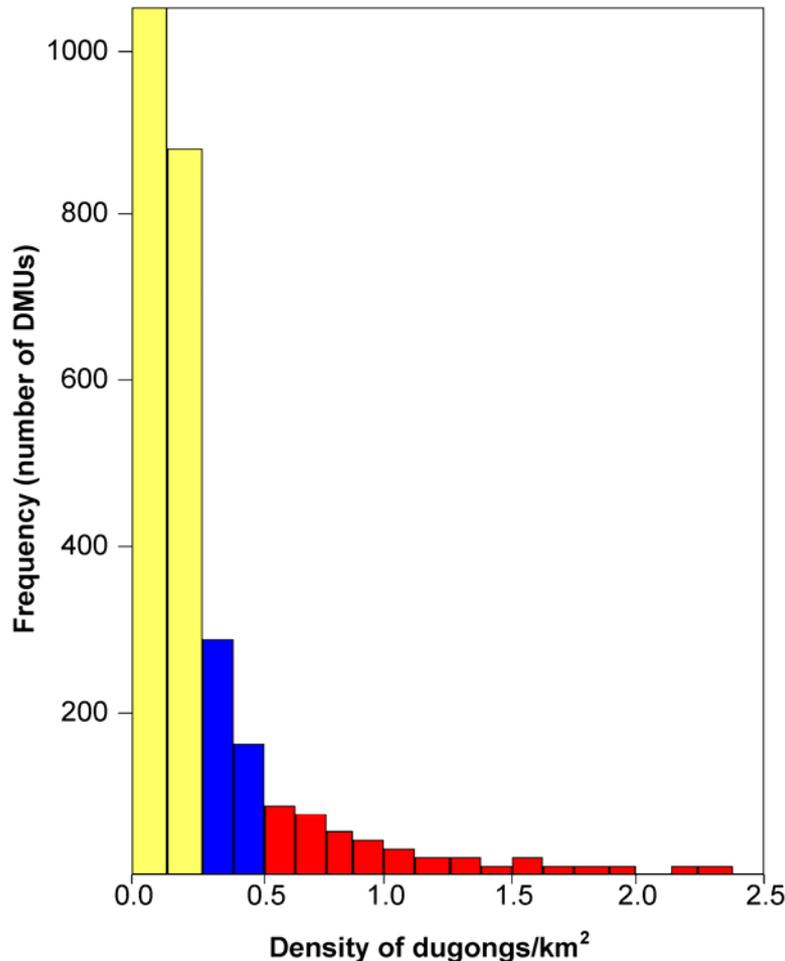


Figure 7 - Frequency diagram of dugong relative density derived from a spatially explicit population model. Low conservation values have dugong densities between 0.0015 - 0.25 dugongs/km² (identified in blue); medium conservation value 0.25 - 0.5 dugongs/km² (orange); and high conservation value > 0.5 dugongs/km² (yellow).

4. Conclusions

We have demonstrated how a spatially explicit population model can be used to prioritise areas of conservation value for a species distributed over a broad spatial scale. Information derived from aerial surveys used in conjunction with geostatistical techniques including universal kriging was used to model dugongs in the GBRWHA, and categorise DMUs as low, medium or high conservation value for the species based upon relative density. As a result, 'hot spots' for dugong conservation in the remote north and urban coast regions of the GBRWHA were identified.

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If additional critical areas for dugongs in the GBRWHA were identified (including breeding locations and migratory pathways), the approach we used to prioritise conservation value would need to be modified. A suitable method would be that implemented in the initial stage of the Great Barrier Reef Marine Park re-zoning process; where special or unique places were identified and included within the network of 'no take' areas, regardless of the impact this approach had on the final model (Day *et al.* 2000; Fernandes *et al.* 2005).

An integral component of the effective management of MPAs is proper understanding of the spatial relationship between what is to be protected and the activities that impact upon them. When this relationship is distributed over a wide geographic extent, prioritising areas of conservation value can be an important tool in distributing the resources that are involved in MPA management. Spatially explicit models, as demonstrated in this study, are an effective component of the decision-making process, and can be used to support the management of dugongs in the GBRWHA.

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