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Systematic Marine Conservation Planning: towards a marine representative areas network in Nanggruh Aceh Darussalam, Indonesia

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Abstract (270). A turbulent history and geographic isolation have prevented systematic surveys of coral reef resources in the Indonesian province of Nanggruh Aceh Darussalam (NAD). Following the Indian Ocean Tsunami (IOT), ecological studies revealed that while most marine habitats where unaffected by the tsunami, many reefs were seriously degraded as a result of decades of destructive fishing and poor coastal development. The recovery of these degraded reefs following dramatic reductions in human activity as a result of the IOT is remarkable. Ironically, socio-economic recovery in NAD is re-introducing anthropogenic threats as fishing pressure and coastal development increase. Some conservation initiatives are in progress, however, these also pose a threat because they lack coordination and integration. A systematic marine conservation plan is required to allow natural recovery processes to continue and to protect marine resources from emerging threats. Here, we present a preliminary analysis using 'Systematic Conservation Planning' guidelines in which the conservation goal was to protect at least 30% of existing coastal ecosystems. Data for the analysis included ecological, socio-economic and reef resilience data collected from 64 sites within NAD. Spatial information for the analysis was derived from satellite imagery due to an extended coast line, habitat complexity and variation in accessibility to sites throughout the region. The optimal approach identified was the establishment of many small marine protected areas (MPA) as opposed to a few large areas. This work provides a solid basis for the establishment of a network of MPAs to achieve these conservation goals for the region and protect and enhance livelihoods.

Key words: coral reefs, MPA, marine conservation, tsunami

Introduction

Sumatra has some of the most diverse coral reefs in western Indonesia where the marine fauna, in particular reef fish, includes a unique mix of species from the Indian and Pacific Oceans (Brown 2007). For example, of the 2057 species of reef fish recorded in Indonesia 60% are found in Sumatra (Allen and Adrim 2003)

The province of Nanggruh Aceh Darussalam (NAD) encompasses the northern third of Sumatra. Coral reefs in the province are concentrated in three areas; Pulah Weh and Pulau Aceh off the northern tip of Sumatra; Simeulue Island and Banyak Islands in the south west of the province; plus extensive fringing reefs along the Sumatran mainland (Fig. 1 and Spalding et al. 2001).

Following the Indian Ocean Tsunami (IOT), ecological studies revealed that while most marine habitats where largely unaffected many reefs in NAD had been seriously degraded as a result of decades of destructive fishing and inappropriate coastal development (Baird et al 2005; Campbell et al 2007, Hagan et al 2007). Subsequent research indicates that these degraded reefs have recovered remarkably well, with up to 5 fold increases in coral abundance since 2005, presumably as a result of the dramatic reduction in human activity caused by the IOT (Ardiwijaya et al 2008). Ironically, as socio-economic activity gains pace in NAD anthropogenic threats to reefs, such as fishing pressure and coastal development, are increasing. While some conservation initiatives are in progress, these also pose a threat because they lack coordination and integration.

The aim of this study was to conduct a systematic marine conservation analysis to provide a framework within which the natural recovery processes of the marine environment could continue, and existing marine resources be protected from these emerging threats. Given the preliminary nature of this analysis the objectives and targets were set following discussions among scientists only. Future spatial analysis will include targets and objectives of all stakeholders.

Material and Methods

Conservation spatial planning analysis was conducted using the GIS based tool, MARXAN, integrated with ARCView 3.3 software. Data sources for the analysis included numerous ecological and socio-economic variables, collected between 2006 and 2008 (Table 1).

Ecological data was collected from 64 coral reef sites throughout NAD. As required for MARXAN, we divided variables into 'habitat' layers and 'cost' layers. Habitat layers are those considered when selecting areas for protection and cost layers are those that are likely to affect the costs of including the area in the final spatial solution (Table 1).

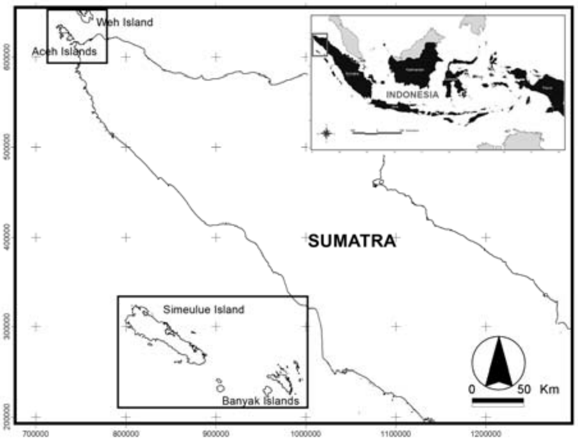

Figure 1. Northern Sumatra with regions of major reef development highlighted by boxes.

Habitat layers	Cost layers
Live coral cover	Distance to village
Coral genera diversity	Distance to port
Coral recruitment	Fishing pressure
Reef fish biomass	Aquaculture
Reef fish abundance	Direct threat (coral mining)
Reef fish species richness	Crown of Thorn Starfish
Clam abundance	
Reef ressilience	
Aggregation sites of Napoleon fish	
Aggregation sites of Bumpedhead parrotfish	
Aggregation sites of Trevaly (*Caranx sp* .)	
Known sites of Manta ray	
Known sites of Whaleshark	
Known sites of Sea Turtle	
Mangrove	

Table 1. A list of the parameters included in MARXAN analysis.

Analysis

For spatial analysis in MARXAN, conservation features were defined by 'bioregion' i.e. a cluster of reefs which have similar characteristics in terms of benthic assemblages and geography (Meerman 2002). This approach was chosen because of the need to analyze many ecological variables (live coral cover, coral diversity, coral recruitment, reef fish biomass and abundance, invertebrate abundance, and reef resilience) based on ranked condition (very good, high, medium, and poor) rather than presence or absence. For the remainder of habitat and cost layers the spatial analysis was performed using presence or absence data.

Spatial data preparation

Quantitative data from the ecological surveys and socio-economic data was converted into four ranked categories (se above). These categories were then incorporated into the previously defined bioregions. Using this approach, each parameter creates four different spatial layers, representing its ranked condition.

Conservation objectives and target

The conservation objectives that we set out to achieve with the analysis were: (i) to conserve 15 to 20% of reef area in total plus (ii) conserve more than 50% of the 'best' habitat. The highest target was set for the best condition for each of the habitat layers representing ecological data and presence or absence of charismatic marine megafauna including Napoleon Wrasse, Bumpedheaded Parrotfish, Trevally, Manta ray, Whale Shark and Sea Turtles. A list of the parameters and targets is presented in Table 2.

Cost Features

Different weightings were given for the four cost values: distance to village, distance to port, fishing pressure (line and net fishing), following the equation:

$$TCF = 2\,P + 8N + 0.5\,L + 2V$$

where:

TCF = Total Cost Value
P = Port
N = Net fishing
L = Line fishing
V = Village

The following parameters were 'locked out' to prevent MARXAN selecting areas with these parameters as priority areas; aquaculture, coral mining, and outbreaks of *Acanthaster planci* (COT). Active outbreak levels of COT were defined as an abundance of adult starfish (>15cm in diameter) of over 30 individuals per ha (IUCN, 2004).

Species Penalty Factor

Once the datasets were assembled we set *Species Penalty Factor* (SPF) values for each conservation target. The SPF parameter is crucial for getting useful results from the analysis. The key point is that SPF values must be chosen so that penalties for missing conservation targets are scaled appropriately relative to each other term in the objective function (Ardron et al 2008). SPF helps MARXAN to define the priority level for each conservation target/feature when selecting priority areas.

We set SPF values to range from 0-100 for all parameters and set a value of 100 for several of the highest biodiversity conditions (Table 2).

Boundary Length Modifier

The Boundary Length Modifier (BLM) is used to improve the clustering and compactness of individual solutions (McDonnell et al. 2005). Higher BLM values mean that selected areas will be more clustered in order to reduce the cost of boundary. In this analysis we set BLM value to 10 to create clustered selected areas.

No.	Parameters	Target	SPF
1	Mangrove	17.00	80.00
2	Live coral cover Low	0.00	10.00
3	Live coral cover Med	72.00	50.00
4	Live coral cover High	100.00	100.00
5	Coral recruit Low	50.00	10.00
6	Coral recruit Med	20.00	50.00
7	Coral recruit High	30.00	50.00
8	Reef fish biomass Very low	0.00	10.00
9	Reef fish biomass Low	0.00	30.00
10	Reef fish biomass Med	80.00	50.00
11	Reef fish biomass High	100.00	100.00
12	Coral diversity Very low	0.00	10.00
13	Coral diversity Low	0.00	10.00
14	Coral diversity Med	53.40	50.00
15	Coral diversity High	70.00	100.00
16	Clam abundance Low	0.00	10.00
17	Clam abundance Med	81.00	50.00
18	Clam abundance High	90.00	80.00
19	Bumpedhead parrotfish	90.00	50.00
20	Trevaly	200.00	50.00
21	Napoleon fish	30.00	75.00
22	Manta ray	50.00	50.00
23	Sea turtle	50.00	75.00
24	Whaleshark	28.80	50.00
25	Village	174.30	50.00
26	Reef fish abundance Very low	0.00	10.00
27	Reef fish abundance Low	10.00	10.00
28	Reef fish abundance Med	73.80	50.00
29	Reef fish abundance High	50.00	100.00
30	Reef resillience Low	0.00	10.00
31	Reef resillience Med	101.10	50.00
32	Reef resillience High	19.20	100.00

Table 2. Target and Species Penalty Factor

Results and Discussion

Reef condition on Pulau Weh was the best in the northern region of NAD giving MARXAN many options for the placement of protected areas indicated in pink in Fig. 2. Dark purple areas were excluded from the analysis ('locked out') because of their proximity to ports and/or dense urban populations. Areas in brown were also excluded because these areas are already under management.

In Pulau Aceh (Fig. 3), MARXAN select only 10% of reef area for protection. Sites in Pulau Aceh generally have much poorer coral reef condition when compared to other areas within the region (Baird et al. 2005; Campbell et al. 2007). In this analysis, MARXAN selected areas with the highest coral generic richness, reef fish abundance and resilience. The purple color indicates areas excluded due to proximity to the port.

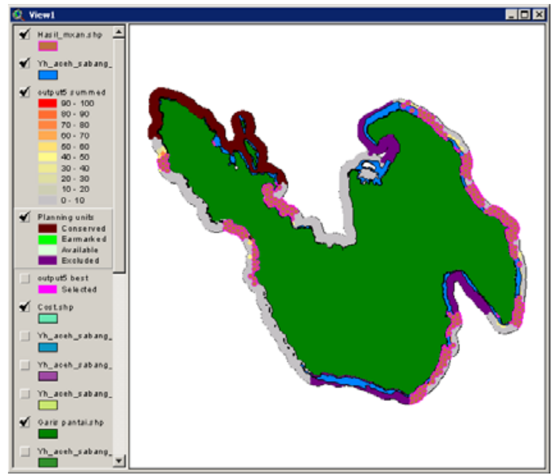

Figure 2. Analysis result of Pulau Weh– northern NAD.

In Pulau Simeulue (Fig. 4), less than 3% of the coastal area was selected by MARXAN. In general, Pulau Simeulue had relatively good reef in some areas, but this result may be affected by limited data. Pulau Simeulue has approximately 300km of coastline and consequently a comprehensive dataset on reef condition is not available.

In Pulau Banyak (Fig. 5), approximately 40% of the coastal area was selected for protection by MARXAN. Areas excluded from the analysis due to proximity to the port or sites of coral harvesting are indicated in red (Fig. 6).

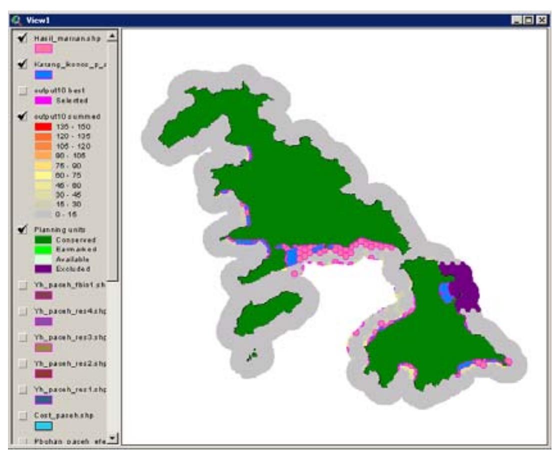

Figure 3. Analysis result of Pulau Aceh– northern NAD.

Conclusion

The analysis identified a ready solution to achieve the limited goals of this preliminary study, i.e. 15 to 20% of reef area conserved in total including more than 50% of the 'best' available habitat. The exclusion of

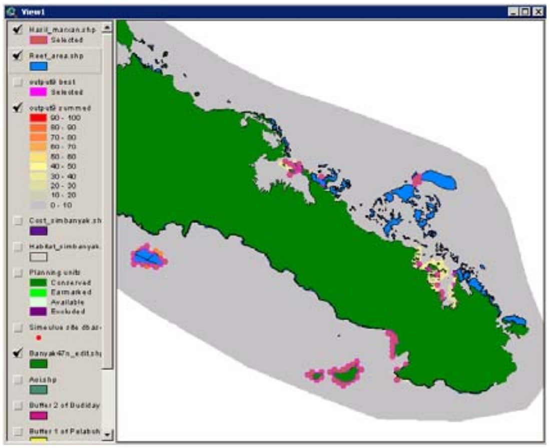

Figure 4. Analysis result of Pulau Simeulue– south-western NAD.

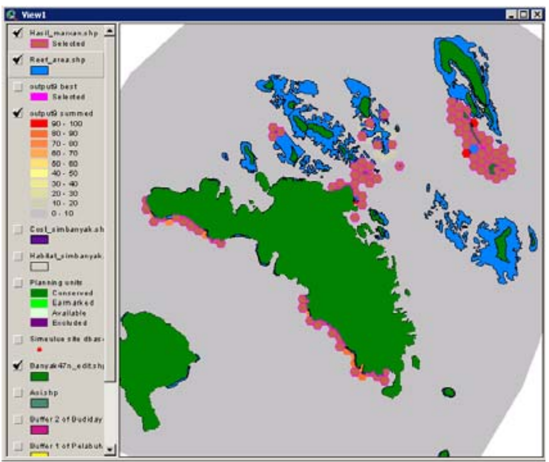

Figure 5. Analysis result of Pulau Banyak– south-western NAD.

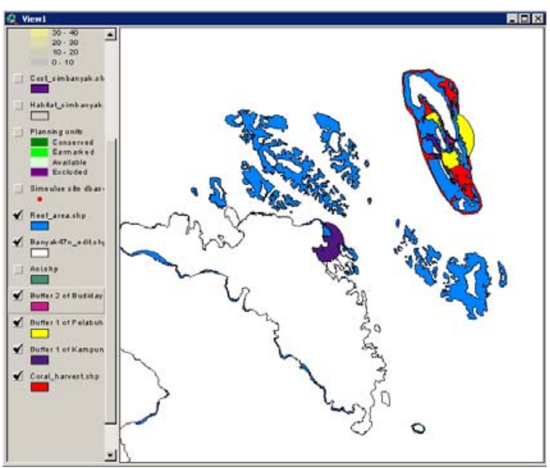

Figure 6. Areas excluded from the MARXAN analysis due to pressure from coral harvesting (indicated by red color).

areas close to ports, high population pressure and conflicting resource use suggests this spatial plan would result in little disruption to other marine resources users and therefore may be a practical solution to the province of NAD's conservation obligations. We must, however, stress that this is a 'first look' conservation plan. Future analyses must seek to consult with other stakeholders to set appropriate targets to achieve a balance between conservation and development in the marine environment in NAD.

Acknowledgements
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