

Zoning Cambodia's First Marine Fisheries Management Area

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ABSTRACT

Zoning of Marine Protected Areas (MPAs) is necessary to spatially designate areas for specific purposes and to resolve conflicts between different activities. A range of methods are available to support decision making processes of MPA design, including scoring and multi-objective analysis using spatial conservation prioritisation tools. The Royal Government of Cambodia is currently working with local stakeholders and NGOs to implement a multiple-use MPA known locally as a Marine Fisheries Management Area (MFMA) around the islands of the Koh Rong Archipelago. Coral reef data collected by Coral Cay Conservation (CCC) in 2010-2012 was used to calculate conservation management values (CMVs) via a preliminary scoring method. However, this does not take into account the full range of biodiversity around the islands nor does it consider the threats to marine habitats. A supplementary analysis was conducted using Marxan with Zones, which used data on coral reef, mangrove and seagrass as well as cost layers derived for sedimentation and fishing impact. The suggested conservation areas derived from Marxan with Zones mostly correspond with areas of high conservation management value identified through the scoring method, with some notable exceptions. We find that while Marxan with Zones provides more comprehensive solutions than the rapid scoring method, it requires multiple quantitative data types which remains a challenge in a data-scarce country like Cambodia. Nonetheless, the resulting solution is an indicative zoning plan that has been useful to inform zoning consultation.

ការកំណត់តំបន់គ្រប់គ្រងក្នុងតំបន់ការពារសមុទ្រ គឺមានសារៈសំខាន់សម្រាប់បែងចែកតំបន់គ្រប់គ្រងគោលបំណងជាក់លាក់នានា និងដើម្បីដោះស្រាយជម្លោះរវាងសកម្មភាពផ្សេងៗគ្នា។ មានវិធីសាស្ត្រជាច្រើន គឺប្រើប្រាស់ដើម្បីគាំទ្រការសម្រាប់ចិត្តនៃដំណើរការរៀបចំតំបន់ការពារសមុទ្រ រួមមានទាំងការដាក់ពិន្ទុ និងវិភាគគោលបំណងច្រើនតាមរយៈការប្រើប្រាស់វិធីសាស្ត្រកំណត់តំបន់អទិភាពសម្រាប់អភិរក្ស។ ថ្មីៗនេះរដ្ឋាភិបាលប្រទេសកម្ពុជាធ្វើការជាមួយអ្នកពាក់ព័ន្ធក្នុងស្រុក និងអង្គការក្រៅរដ្ឋាភិបាលដើម្បីកំណត់តំបន់ប្រើប្រាស់ច្រើនយ៉ាងក្នុងតំបន់ការពារសមុទ្រ ដែលត្រូវបានហៅថាជាតំបន់គ្រប់គ្រងផលសមុទ្រជុំវិញប្រជុំកោះរ៉ុង។ ទិន្នន័យផ្តាច់ដែលប្រមូលដោយអង្គការអភិរក្សផ្តាច់នៅក្នុងឆ្នាំ២០១០ ដល់ឆ្នាំ២០១២ ត្រូវបានប្រើប្រាស់ដើម្បីគណនាតម្លៃនៃការគ្រប់គ្រងការអភិរក្សតាមរយៈវិធីសាស្ត្រដាក់ពិន្ទុដំបូង។ យ៉ាងណាក៏ដោយ ក៏វិធីសាស្ត្រនេះមិនត្រូវបានយកមកប្រើដើម្បីរៀបចំផែនការចម្រុះជុំវិញកោះ ហើយមិនត្រូវបានប្រើប្រាស់សម្រាប់ការពិចារណាទៅលើការគ្រោមគំហែងទីជម្រកសមុទ្រនោះទេ។ ការវិភាគបន្ថែម ត្រូវបានធ្វើឡើងដោយប្រើប្រាស់វិធីសាស្ត្រ Marxan with Zones ដោយប្រើទិន្នន័យផ្តាច់ ព្រៃកោងកាង និងស្មៅសមុទ្រ រួមទាំងកកស្រោចលើដីល្បាប់ និងការប៉ះពាល់ពីការនេសាទ។ តំបន់អភិរក្ស បានស្នើមកពីវិធីសាស្ត្រ Marxan with Zones ដែលត្រូវគ្នាគ្នាច្រើនដែលបានវាយតម្លៃលើការគ្រប់គ្រង ការអភិរក្សខ្ពស់ តាមរយៈការដាក់ពិន្ទុលើកដំបូងដោយមានករណីលើកលែងមួយចំនួនគួរឱ្យកត់សម្គាល់។ យើងរកឃើញថា ក្នុងខណៈពេលដែល Marxan with Zones ផ្តល់នូវដំណោះស្រាយដ៏ទូលំទូលាយជាងវិធីសាស្ត្រក្នុងការដាក់ពិន្ទុបឋម ប៉ុន្តែវាតម្រូវឱ្យមានទិន្នន័យបរិមាណច្រើនប្រភេទ ដែលនៅតែបញ្ហាប្រឈមមួយចំពោះកង្វះខាតទិន្នន័យក្នុងប្រទេស ដូចជាប្រទេសកម្ពុជា។ យ៉ាងណាក៏ការដំណោះស្រាយជាលទ្ធផល គឺជាផែនការកំណត់តំបន់បង្ហាញផ្លូវមួយដែលមានប្រយោជន៍ដើម្បីជូនដំណឹងពិគ្រោះយោបល់ក្នុងការកំណត់តំបន់។

KEY WORDS

Marine management, Marine Protected Area, spatial planning, MARXAN.

INTRODUCTION

Marine ecosystems face mounting threats worldwide (Halpern *et al.*, 2008a) and effectively managed Marine Protected Areas (MPAs) are a means to mitigate threats to marine ecosystems (Veitch *et al.*, 2012). With most of the world's oceans characterised by conflicts between and among users, many of which are contrary to conservation objectives, it is necessary to zone marine space so as to designate areas for specific purposes. There may hence be different levels of protection within an MPA, ranging from areas that allow selective extraction of resources to those that are strictly no-take. Zoning plans allows for the determination of trade-offs when resolving conflicts between human resource uses (Halpern *et al.*, 2008b).

Early systematic planning allows for more effectiveness and cost-efficiency in achieving conservation objectives (Malcolm *et al.*, 2012). A range of methods and tools have been developed to support decision making processes for MPA design. Multi-criteria decision analysis frameworks were the most commonly used previously (Grantham *et al.*, 2012), where information from several different criteria is combined to form a single index of evaluation for each site. While scoring methods are quick and easy, they do not accommodate several key principles in reserve selection (Grantham *et al.*, 2012). Firstly scoring methods are mostly ineffective at providing comprehensive solutions, whereby the full range of biodiversity should be included (Klein *et al.*, 2010). Scoring methods also value sites individually rather than collectively and thus does not take into account complementarity; relationships between sites are not considered (Wilson *et al.*, 2009).

Spatial conservation prioritisation on the other hand, considers comprehensiveness and complementarity. This form of assessment aims to identify the spatial location of actions that will be applied across a landscape or seascape (Ferrier & Wintle, 2009). It involves approaches such as defining a minimum size for priority areas and setting biologically relevant conservation targets, as

well as incorporating other information such as threats (Wilson *et al.*, 2009). A conservation triage approach can be employed, where prioritisation is conducted with the aim of maximising conservation returns at the least possible cost (Bottrill *et al.*, 2008, 2009).

Spatial conservation prioritisation generally involves: 1) setting overall conservation objectives (e.g. biodiversity conservation, threat management, etc.); 2) producing conservation features, which are the habitat types and/or species to be conserved; 3) setting targets for each of these conservation features, by for example, following national or international targets; 4) dividing the planning region into a series of planning units; 5) calculating the amount of each feature found in each planning unit; 6) assigning a cost value to each planning unit; and 7) identifying sets of priority areas for conserving biodiversity that meet the targets, with the constraints of reducing fragmentation of these areas and minimizing planning unit costs (Moilanen *et al.*, 2009).

Numerical optimization tools such as Marxan and Zonation, have been developed as decision making tools for this assessment. However, spatial conservation prioritisation has until recently, focused only on one type of protected area - no-take reserves (Klein *et al.*, 2010). Advances in these tools have allowed for the simultaneous identification of locations for multiple zones with multiple objectives (Watts *et al.*, 2009). Such a multi-objective analysis have thus far only been applied to a few examples in the marine realm (see Klein *et al.*, 2010; Grantham *et al.*, 2012).

Cambodia's 435 km coastline and 69 islands (Touch, 1995) hold a rich diversity of coral reefs, seagrass beds and mangroves (Kim *et al.*, 2004) that are under increasing pressure from unsustainable fishing practices, sedimentation, coastal development and marine based pollution (Ouk *et al.*, 2012). Ninety percent of the coral reefs in Cambodia for example, are estimated to be under high level of risk (Tun *et al.*, 2008) and the overall trend is of increasing overexploitation of the coastal zone (Johnsen & Munford, 2012). Research and monitoring of Cambodia's marine

ecosystems has historically been limited, due in part to the lack of human resources, infrastructure and finance in the Cambodian Government (Kim *et al.*, 2004). Nonetheless, there has been a shift in political will for improved protection and management of marine resources as there is increasing recognition that improvements in marine fisheries management could increase fish catch, family income, ecosystem health and eco-tourism (Ouk *et al.*, 2012).

The Cambodian Law on Fisheries has identified coral reefs, mangroves and seagrass as protection and conservation areas. The Strategic Planning Framework for Fisheries set ambitious national targets of at least 70 km² of seagrass and 8.4 km² of coral reef to be under an appropriate form of sustainable management and 10 km² of mangrove to be rehabilitated by 2019. The National Action Plan for Coral Reef and Seagrass Management aims to put at least 8.4 km² of coral reefs and 90 km² of seagrass under an appropriate form of sustainable management by 2016 (Ouk *et al.*, 2012). International commitments, including Aichi Target 11 of the Convention on Biological Diversity, also require an increase in the proportion of the Cambodia's important marine areas to be brought under effective, equitable and ecologically representative management by 2020.

To contribute to these targets, the Fisheries Administration (FiA) of the Ministry of Agriculture, Forestry and Fisheries of the Royal Government of Cambodia is currently working with a range of national stakeholders and international NGOs, including Coral Cay Conservation (CCC) and Fauna & Flora International (FFI), to develop Cambodia's first Marine Fisheries Management Area (MFMA) around the islands of Koh Rong and Koh Rong Sanloem, Preah Sihanouk Province. The waters of the Koh Rong Archipelago are in part allocated to be managed by three Community Fisheries (CFi) covering 18,672 hectares which were formally established in 2008 (Koh Rong Sanloem CFi, Prek Svay CFi) and 2010 (Deom Thkov CFi). There are now 39 CFis recognised in Cambodia's marine waters (FiA, 2013), and ambitious national targets to both strengthen existing and establish new CFis. However the effectiveness of new and existing marine CFis within the four coastal provinces is not

generally well understood, and is likely variable. The CFI related research in the Koh Rong Archipelago that does exist shed light on relatively small areas (e.g. Savage *et al.*, 2013) and has found that there are no significant differences in reef fish or invertebrate abundance and composition inside and outside of CFI areas (Thuang R., 2013). Additionally, there is a perceived decline in catch amongst small-scale fishers across the archipelago (Ouk V. *et al.*, 2011; Leng P., 2013).

The proposed MFMA aims to conserve marine biodiversity and support sustainable fishing and tourism, contributing to poverty alleviation (FiA, *in litt.*). It is expected to support and integrate with the existing CFIs and improve management effectiveness in order to counter ongoing resource declines. Three zones are to be identified: 1) Conservation Area (CA), in which any activity that has a negative effect on fishery resources are strictly prohibited, except for permitted scientific research; 2) Protected/Community Fishing Area (FA), where subsistence fishing is allowed; and 3) Multiple Use Areas (MA), where coastal development is allowed provided it does not destroy reefs (FiA, *in litt.*).

A zoning scheme that considers both the conservation goals and social-economic cost of fisheries is central to the success of the MFMA. Effective conservation prioritization also requires incorporation of information on threatening processes (Wilson *et al.*, 2009). Erosion and land runoff due to poor land management have been highlighted as a concern in Cambodia (UNEP, 2008) and riverine runoff has been observed at the site, with high levels of siltation of coral reefs, varying seasonally with the onset of heavy rains (van Bochove *et al.*, 2011). Commercially valuable fish species have also been reported to be decreasing in number (Van Bochove *et al.*, 2011; Leng, 2013). It is thus imperative that both sedimentation and fishing pressure are considered in the zoning scheme. This paper describes the preliminary spatial analysis that took place to feed into the consultation on the zoning scheme for Cambodia's first MFMA. A scoring analysis was first conducted using only ecological data to give an overview of potential areas of conservation interest for reef and reef-

associated species. A more comprehensive Marxan with Zones analysis using ecological (coral, mangroves and seagrass habitats) and threats data, was then conducted to identify the different zones.

METHODS

Data Collection

Ecological Data

Reef Check surveys (Van Bochove *et al.*, 2011) modified to include an extended species lists, was conducted at 156 locations around the islands by CCC between 2010 and 2012 (Van Bochove *et al.*, 2011). All potential reef areas were surveyed, with the exception of the south-east of Koh Rong Sanloem. Seven selected ecological criteria, namely target fish species abundance, fish species diversity, food fish abundance, target invertebrate species abundance, invertebrate species diversity, hard coral percentage cover and hard coral species diversity, were analysed and ranked for each site. Fisher's α index was used for all species diversities.

Coral reef habitat extent was derived by modifying remotely sensed shallow reef data from the International Coral Reef Research and Monitoring Center in Japan (ICRRMC; Kakuta *et al.* 2010) with CCC survey data and surveyors' input. Where this data set was incomplete, it was amended with UNEP-WCMC global coral reef data (UNEP-WCMC, 2010) and with reference to Marine Conservation Cambodia's 2011 reef survey report (Krell *et al.*, 2011).

Seagrass habitat extent was verified through rapid surveys using a transect method carried out between April to May 2013 (Leng P., *et al.*, in prep.) and mangrove extent determined using 5m resolution RapidEye satellite imagery from January 2013, groundtruthed in June 2013. Proposed fish

refuge areas were the result of zoning consultation through focus groups involving 281 participants across the 5 villages in the archipelago during April to May 2013, plus groundtruthing visits.

Fish and invertebrate distributions were estimated from CCC's survey data. These were assumed to be coral-associate species and their extents were extrapolated from the coral reef habitat extent. To target for areas of high fish and invertebrate species diversity and abundance, extents of less than the 50th percentile of diversity and abundance data were removed from the analysis, using a buffer of 150m around each survey site. CCC's surveys were conducted at two depths; a conservative approach was employed such that sites where only one of the depths had data above the 50th percentile threshold would be included in the extent. All calculations were made using R 3.0.1.

Threats Data

Sedimentation and fishing pressure were the two threats considered in the multi-objective zoning analysis in Marxan with Zones. Sediment plumes were hand digitized (following Evans *et al.*, 2012) by interpretation from 2013 Google Earth images. Relative values of sedimentation were derived by calculation of flow accumulation values from a digital elevation model (GEOSS, 2011) on ArcGIS and weighted by percentage of undisturbed habitat per watershed; forests, grasslands, marshlands and shrublands were considered undisturbed habitat. Land-use types were determined using 5m resolution RapidEye satellite imagery from January 2013, groundtruthed in June 2013. Artisanal fishing impact was derived from 55 individual fisher interviews and focus groups involving 60 households carried out between March to June 2013 (Leng, 2013) and classified as low, 1000; medium, 2000; high, 3000; and very high, 4000. No spatial explicit resource-use information equivalent to fishing was available for seagrass and mangrove habitats. It was assumed that intensities of use were similar to surrounding reefs and hence these habitats were allocated values of the nearest fishing cost.

Data Analysis

Scoring

Each site surveyed by CCC was allocated a 'conservation management value' (CMV) which was the sum of the number of biological indices that had above mean values for each index, producing a CMV score that ranged from 0 to 7. Areas of high CMVs and particularly high values of individual indices were then used to delineate areas of reef conservation interest. This followed an approach applied by CCC to identify potential sites for small-scale MPAs in the Philippines (Longhurst, *et al*, 2012).

Multi-objective zoning

Analysis was conducted using Marxan with Zones v2.01 and the graphical interface Zonae Cogito, in conjunction with ArcGIS 10.0. Marxan with Zones identifies multiple zones simultaneously based on zone-specific targets while aiming to minimize costs (Watts *et al.*, 2009). The software uses an algorithm called "simulated annealing", which uses iterative improvement while accepting some bad moves in initial iterations to provide near-optimal solutions for zoning configurations (Ball *et al.*, 2009). This algorithm has a randomisation component and therefore generates a different solution for each run. The study site was subdivided into a grid of 2324 planning units, which capture all areas that may possibly be selected as part of the zoning design. Each planning unit was 100m × 100m, set to be no smaller than the features mapped and no larger than is realistic for management decisions. The Marxan analyses involved running the software 100 times, each run consisting of a million iterations.

There are two major Marxan outputs: (1) the best solution and (2) the summed solution. The best solution had the lowest cost across multiple selections of planning units that collectively achieved conservation targets set, with cost in this study given by sedimentation and fishing pressure. The

summed solution gives the total number of times each planning unit was picked for a zone over all 100 Marxan runs for the scenario.

Conservation targets for the features (Table 1) were set to be much higher than the World Parks Congress 2012 global target of 20–30% of marine habitats to be effectively protected (IUCN, 2003). This is because the current spatial planning was not conducted on a national scale and a conservative approach was deemed necessary for this first Marine Fisheries Management Area to significantly contribute to Cambodia’s aforementioned national targets. The relative percent representation target set for each feature (e.g. coral diversity, fish refuge) was dependent on the extent, importance or rarity of the feature, based on the perceived significance of the authors. Threats were included in the analysis as a cost layer, which typically incorporates factors which may compromise the implementation of a zone to a specific area. In order to assign zone types to areas of different levels of threats, the two cost types were weighted differently in each zone. This was done by setting the zone cost function to reflect the relative influence of sedimentation and fishing pressure for each zone (Table 2).

Zones can be designated across many small or a few large areas and still meet the same conservation targets set. The level of clumping influences the effectiveness and ease of zone implementation. Too little clumping results in many small areas in each zone which may not meet minimum size requirements for species or habitat protection or to act as a productive fishing ground; too many boundaries may also be confusing and cause management challenges. Few large areas from too much clumping on the other hand, may cause overlaps and conflicts with resource users. In Marxan with Zones, a sensitivity analysis of the parameter, zone boundary cost, allows the user to explore different levels of compactness. Calibration was conducted and zone boundary cost was set to 1 across all zones.

RESULTS

The scoring method yielded conservation management values (CMVs) that were highest on the North-west and South of Koh Rong (Figure 1). Areas of high conservation interest that were estimated from these CMVs were in the North-west and South-west of Koh Rong, the latter being close to the village of Koh Touch, the South-west of Koh Rong Sanloem, and between Koh Koun and Koh Rong Sanloem, adjacent to the village of M’Pai Bai (Figure 1).

Artisanal fishing pressure was highest around Koh Ta Team to the north of Koh Rong , north-east and south-east of Koh Rong close to Prek Svay and Doem Thkov respectively, between Koh Koun and Koh Rong Sanloem around M’Pai Bai, and South-east of Koh Rong Sanloem (Figure 2). Sedimentation on the other hand, was in general higher on the predominantly shallower eastern side of both islands than on the west (Figure 2).

The Conservation Areas from the best solution from Marxan with Zones largely corroborated with the areas of high conservation interest on Koh Rong and in addition highlighted a few smaller potential Conservation Areas on the east coast of the island. However for Koh Rong Sanloem, there were areas on the east and the south of the island selected as Conservation Areas that were not highlighted by the scoring method. Within the area of high conservation interest between Koh Koun and Koh Rong Sanloem for example, only a small patch of habitats were selected as Conservation Areas by Marxan with Zones. Fishing Areas in the best solution were generally selected to be in the east side of Koh Rong and the north and south-east of Koh Rong Sanloem (Figure 3).

It should be noted that not all targets were met for this solution, though six of the eight features included in the analysis met above 70% of their target (Table 1; minimum proportion met > 0.7 for all features but seagrass and parrotfish abundance).

Discussion

The Conservation Areas identified from Marxan with Zones' best solution largely correspond to regions of high conservation interest identified from the scoring method, with a few notable exceptions. The lack of areas of high conservation interest highlighted on the east coast of Koh Rong is likely due to the island topography, as only few small areas are suitable habitat for reefs. The east coast, for example, is dominated by unconsolidated sediment which may have poor coral larvae survival rates by comparison to the boulders and rocky outcrops more common on the west coast and Koh Koun (Thorne *et al.*, in prep.), and there is significantly higher diversity of reef fish on the west than the east coast (Thuang, R., 2013). The best solution from Marxan with Zones on the other hand, highlighted a few Conservation Areas on the east side of the island, as despite high sedimentation levels in the east (Figure 2), the analysis was constrained by the high conservation targets set for mangroves and seagrass, which were not considered in the scoring method, and mostly located on this side of the island. The area between Koh Koun and north of Koh Rong Sanloem recorded high CMVs but the same area was selected as a Fishing Area in the best Marxan with Zones solution (Figure 3). This is due to the high to very high fishing pressure in that area, which excludes the Conservation Area zone from this site, dictated by the high zone cost weighting of fishing pressure for the zone (Table 2).

The scoring method is a quick and easy way of informing zoning plans but is not in itself sufficient to develop a zoning plan, particularly when socioeconomic costs are not considered. Systematic conservation planning methods using tools such as Marxan with Zones provide more comprehensive alternatives and allows for the user to explore different scenarios using different values of parameters. For example, the zone boundary cost can be adjusted to encourage further separation of conflicting uses; conservation areas can be placed far from multiple use areas. Zones which share

compatible management objectives can also be clustered; conservation areas can be located next to forested areas, so as to benefit from its buffering effects against terrestrial runoff.

Like the scoring method, spatial prioritisation software like Marxan with Zones is limited by data to adequately describe ecological, social and economic systems (Grantham & Possingham, 2012). Conservation planners often need to conduct prioritisations with less data than they would like and often without direct data on the variables of interest (Game *et al.*, 2013). The zoning of this MFMA is no exception. A number of assumptions had to be made to overcome the data limitations of this study. Groundtruthing of reef polygon data and species distribution modelling is necessary to provide more accurate information of the extents of various biological features. Participatory expert mapping or resource-use surveys can also improve the datasets and add on other important data that could be included as features in the analysis: spawning aggregation sites, recreational dive sites, and important species specific features such as turtle nesting beaches or seahorse breeding areas. We also acknowledge that the use of ordinal scales for fishing pressure is not ideal for prioritisation arithmetic (Game *et al.*, 2013). Fish catch data should be used when available, and data collection is currently underway to fine tune our understanding of spatial patterns of resource use amongst finfish fishers and gleaners harvesting in the intertidal zone. Sedimentation in the site is expected to originate from mainland sources (van Bochove *et al.*, 2011) and illegal inshore trawling around the Koh Rong Archipelago (Krell *et al.*, 2011). These estimates should be validated with total suspended sediment sampling or through expert mapping. Significant trade-offs between data capture and speed of MPA and MPA network establishment are required in Cambodia, and significant uncertainty exists when leveraging science for decision making in data deficient and resource poor contexts such as this (Mulligan *et al.*, 2013).

Marxan identifies optimal locations based on defined constraints and targets. Thus the development of these constraints and targets represents a key component in the zoning process. Target setting in

this instance, for example, was determined through the authors' interpretation of priorities using draft MPA goals. This was determined to be a valid approach given our individual levels of involvement with the zoning process and limitations of data. However, it does highlight a challenge in using multi-criteria support tools such as Marxan with Zones, namely how to develop targets or manipulate different scenarios in a participatory fashion where government capacity is relatively low. Like many other marine spatial planning tools, Marxan is technically complex (Stelzenmüller et al., 2013) and the in-depth understanding of the issues and processes needed for its use is unlikely to be present within local communities or even for government planners in most contexts. Basic approaches such as CMVs offer utility to marine planners who are not scientists or programmers and may be a good 'stepping stone' between broader community and government input and more complex spatial analysis.

Numerical optimisation tools, such as Marxan with Zones, allow the development of comprehensive zonation plans that consider an increasing number of variables and more complex interactions. Nonetheless, results from such a scientific initial assessment do not represent the final solution and should only be the building block for in-depth stakeholder consultation (Stelzenmüller et al., 2013). While it is important to reduce uncertainty of outputs by improving the quality of input data and reducing assumptions made for the assessment, careful consideration must be given to the balance between the amount of data captured and the speed at which an MPA is established. This study has highlighted some of the advantages of using tools such as Marxan with Zones, as well as some limitations, and has demonstrated that simpler, more rapid techniques, such as multi-criteria analysis, though not sufficient alone, may be used to support the initial development of a comprehensive zonation plan. In order for these tools to be employed successfully, the limitations of all approaches must be clear to all participants in the zoning process.

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FIGURE CAPTIONS

Table 1. Conservation targets developed for each zone

Table 2. Zone cost for each zone. The higher the zone cost weighting, the less likely the area is selected as that zone when that particular cost (sedimentation or fishing pressure) is high.

Figure 1. Conservation management values and areas of high reef conservation interest from the scoring method

Figure 2. Marine ecosystem threats: (a) fishing pressure; and (b) sedimentation levels at the study site

Figure 3. Initial zonation plan produced from Marxan with Zones in relation to areas of high reef conservation interest

FIGURES AND TABLES

Feature	Overall Target	Conservation Area (CA)		Community Fishing Areas (FA)		Minimum Proportion Met
		Target	Target Met	Target	Target Met	
1 Coral diversity	80%	60%	yes	40%	yes	1
2 Mangrove	70%	60%	no	40%	yes	0.726
3 Seagrass	100%	70%	no	30%	no	0.610
4 Fish Refuge (proposed)	100%	0%	NA	100%	no	0.784
5 Overall Fish diversity	90%	70%	yes	30%	yes	1
6 Invertebrate diversity	90%	70%	yes	30%	yes	1
7 Grouper abundance	100%	60%	no	40%	no	0.851
8 Parrotfish abundance	90%	40%	no	60%	yes	0.590

Table 1

Zone	Sedimentation	Fishing Pressure
Conservation Area	0.05	0.03
Fishing Area	0.03	0.0
Multiple Use Area	0	0.06

Table 2

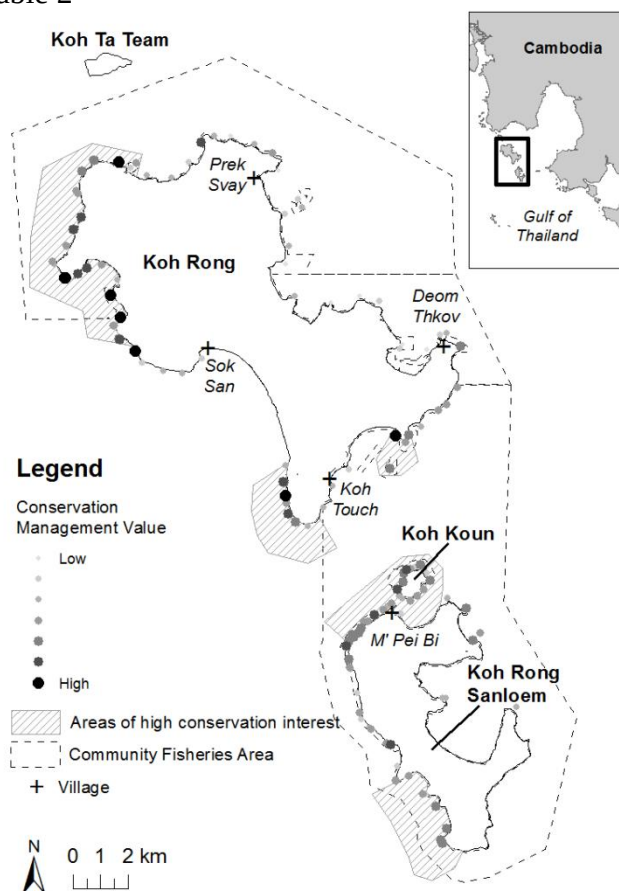


Figure 1

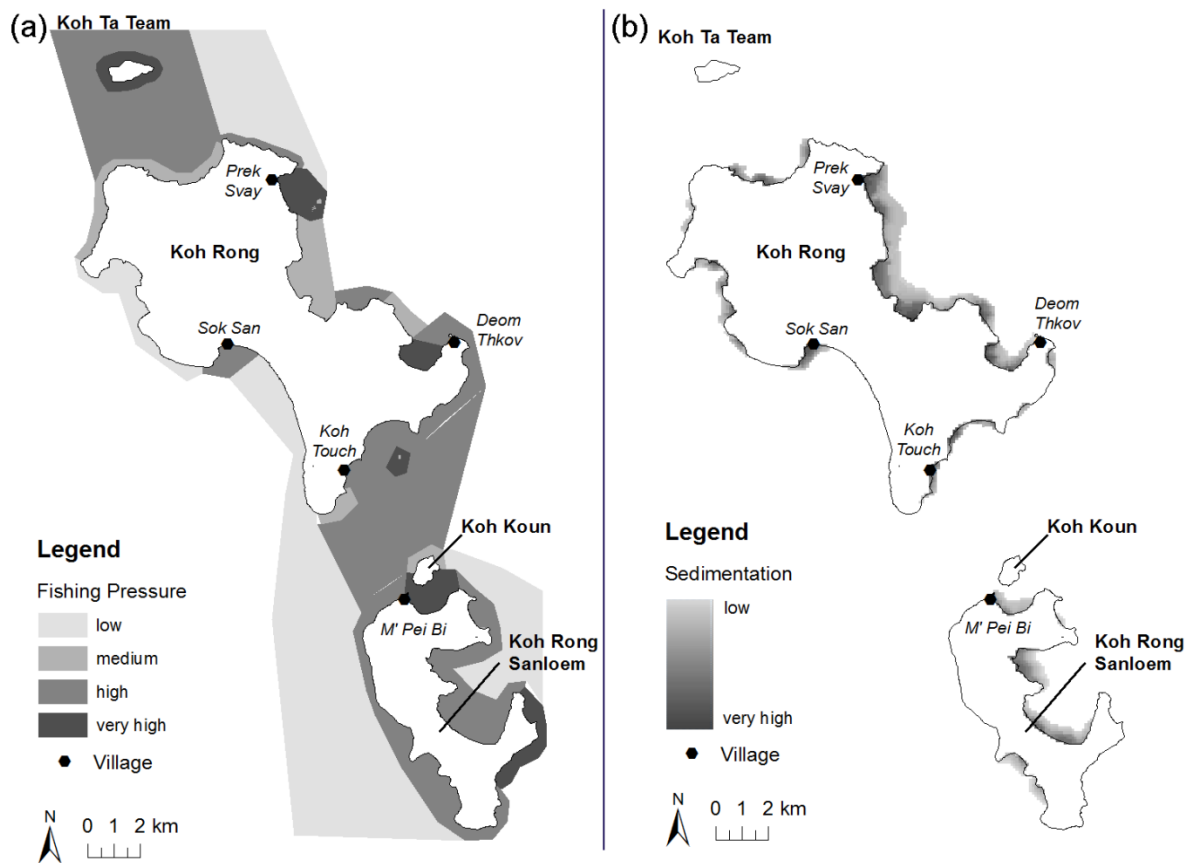


Figure 2

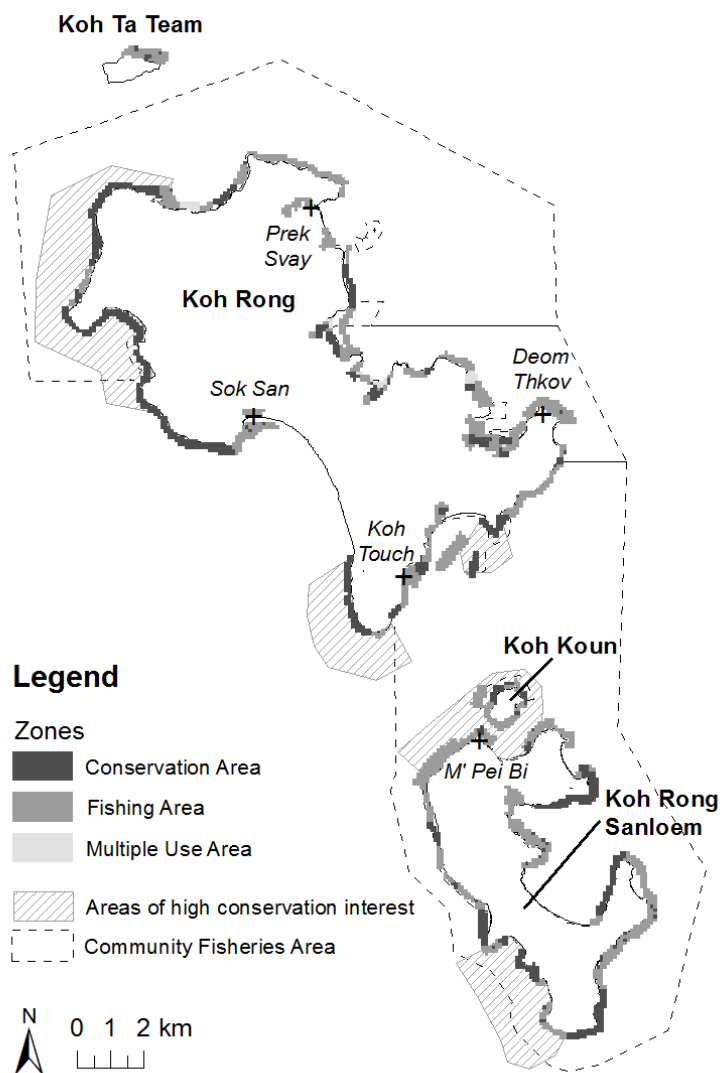


Figure 3