

Marine Protected Areas – Zoning for conservation and rehabilitation of coral reefs in data poor areas

A case study of north-eastern Tobago

Joshua d'Abadie

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Abstract – The coral cover of Tobago's reef systems has declined drastically in recent years falling from 22% in 2005 to 16% in 2008 and many sites across the island's fringing reef systems are showing less than 5% live hard coral cover (TCEMP Report, 2008). A report issued by the Coral Cay Conservation in 2009 outlined several recommendations for the development and capacity building of community efforts in regard to reef protection in the region such as incorporating a marine park and other 'replanting' schemes to encourage reef protection and rehabilitation in degraded areas. This paper seeks to build on these recommendations and in this regard, the overall aim of this project is to develop a method for establishing an effective and practical marine park network in north-eastern Tobago which incorporates a specific area designation for reef rehabilitation projects. Overall, the project seeks to apply the principles of Systematic Conservation Planning (Margules and Pressey 2000; Moilanen et al. 2009) through the use of Marxan with Zones to (i) develop a method for establishing a marine park zoning plan in a data poor area; and (ii) determine the most viable areas to implement marine rehabilitation projects which will contribute to the overall conservation targets which have been set. The primary scientific advance in this paper is the application of Marxan with Zones to determine an efficient suite of actions for both marine reserves and rehabilitation zones. While reef rehabilitation has been discussed in length by previous authors, it has never been prioritised relative to spatial marine reserve designation.

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1.0 Context – Literature review

Coral reefs sustain more than ninety percent of all marine life yet only comprise one percent of the earth's surface (World Resources Institute, 2010). Reefs provide invaluable protection and shelter to marine biota and serve as a habitat to many economically viable species. Additionally, many coastal dwelling populations rely heavily on the economic benefits generated through the harvesting of coral reefs' natural resources as well as the foreign income generated through the associated tourism industry.

1.1 Benefits of healthy coral reefs

Coral reefs provide several key functions to both natural ecosystems and the associated human populations including:

- ❖ Nurseries and refuges for significant (ecologically and economically) marine species;
- ❖ Natural filtering of seawater;
- ❖ Natural hardening of shorelines to prevent erosion;
- ❖ Economic stimulus through fisheries (artisanal and commercial);
- ❖ Economic stimulus through tourism; and
- ❖ Sustenance of biodiversity.

Costanza et al (1997) quantify the value of ecological biomes in regard to the contribution each biome makes to the functioning of ecosystems across the globe; the values are based on the overall ecological, economic and social contributions each biome makes to the functioning of global systems. Of the seventeen (17) biomes identified, coral reefs were listed as the seventh (7th) highest valued at an estimated USD\$6,075.00 per hectare annually (Costanza et al, 1997); the two (2) highest valued systems were estuaries (USD\$22,832.00 per ha annually) and swamps / floodplains (USD\$19,580.00 per ha annually).

The economic value of healthy reef systems is the derivative of the amenity as well as biodiversity and fishery values; well managed and healthy reef systems can contribute significantly to a country's economy through a variety of quantifiable benefits (Cesar et al, 2004). The tourism industry in Tobago comprises 46% of the island's annual gross domestic product (WTTC, 2005); 60% of the visitors to the island every year are a result of the allure of the island's pristine fringing reef systems (Burke et al, 2008). The primary source of income of 70% of the island's population stems from exploitation of the coral reef resources; of particular concern are the profits generated through artisanal fishing and eco-tourism (Burke, 2008).

1.2 Threats posed to coral reefs

Anthropogenic exploitation and disturbance is the primary cause of marine degradation at a global scale (Goreau, 2005). These disturbances generally fall under the following categories:

- ❖ Top-down impacts – key target species (generally of high commercial value) which occur at the top of the food chain become over-exploited – sometimes they are locally extinct. Subsequently, lower trophic levels are targeted and are depleted to levels below which they cease to deliver their ecosystem function;
- ❖ Bottom-up impacts – foreign components (generally exotic species) become introduced into a healthy ecosystem through the interference of humans – common occurrences are related to

the dumping of ballast water from international shipping vessels. These exotic species pose a potential threat to the ecological balance and may out-compete native biota for resources; additionally, foreign species may bring infectious diseases causing outbreaks or trophic interference of the lower levels (resulting in an un-suitable habitat for species at higher trophic levels);

- ❖ Chemical impacts – the primary cause of these disturbances is the result of poor land management practices – stimulatory disturbances result from high nutrient input generally associated with agricultural runoff leading to algal blooms and the ‘stifling’ of coral reefs through rapid algae growth. Inhibitory disturbances result in widespread death and degradation of reefs through the input of detrimental chemicals into the ecosystem;
- ❖ Physical impacts – relates to alterations in oceanic conditions particularly in regard to temperature, salinity, natural water circulation and movement, clarity and stratification – these impacts are associated with the onset of accelerated global warming;
- ❖ Structural impacts – comprises the physical destruction of hard coral and benthic structure through invasive practices of blast and poison fishing, dredging, trawling and improper anchoring of vessels.

Coral reefs throughout the Caribbean region have been substantially degraded in terms of their overall health and abundance since the early 1980's (Gardner et al., 2003; Mumby et al., 2006; 2007). This degradation has been in the order of magnitude of a 60% loss in hard coral cover over a 20 year period and can be attributed to a combination of physical damage from intense hurricane systems, the overfishing of primary grazers and the subsequent onset of coral diseases (Mumby et al., 2006; 2007).

The Tobago Coastal Ecosystem Mapping Project (TCEMP) Annual Report (2008) outlines the major threats to Tobago's coral reef systems as a combination of anthropogenic and natural factors including:

- ❖ Habitat degradation;
- ❖ Land-based pollution stresses;
- ❖ Climate change induced events; and
- ❖ Overfishing.

The coral cover of Tobago's fringing reef systems has declined drastically from 22% in 2005 to 16% in 2008 and many sites are showing less than 5% live hard coral cover (TCEMP Report, 2008). This reduction in coral cover can be attributed to a combination of climate change and anthropogenic factors as well as widespread coral disease that plagues the island's reef systems (SMACMP Report, 2009).

1.3 Marine Protected Areas – ecological and economical benefits

Boost in commercial biomass - Healthy reef systems and ecosystem rejuvenation

Marine protected areas serve as a refuge for an array of marine biota and more importantly, as a nursery for juvenile species of both ecologically and economically significant species of invertebrates and fish. Global research indicates that the implementation of MPAs promotes substantial growth in

the biomass of commercially targeted species across a variety of ecosystems (Gell and Roberts, 2003; Lester et al. 2009, McCook et al. 2010). The recovery of previously exploited fish populations was considerable within reserve systems on the Great Barrier Reef, Australia (McCook, 2010) and the subsequent increase in yield within the fishery industry clearly demonstrates the importance of implementing MPAs throughout regional ecosystems.

MPAs and no-take zones are most effective when used in conjunction with other traditional fishery management practices such as gear restrictions and seasonal closures of fishing grounds etc. (Garcia-Charton et al. 2000, Pauly et al. 2005, Roberts et al. 2005) and are becoming more widely implemented globally as an efficient, cost effective management tool to protect and bolster marine resources (Ward et al. 2001, Pauly et al. 2005, Roberts et al. 2005).

No-take zones often result in an increase in the biodiversity in marine areas which have been heavily over-exploited due to overfishing and other unsustainable extraction practices (Gell and Roberts, 2003) and as a result healthier, more resilient marine habitats are flourishing. Contrastingly, the ecological benefits of MPAs tend to be most pronounced in ecosystems which have been heavily overexploited and are on the brink of collapse (Gaines and Lester et al, 2010). Sedentary species are those most likely to experience an increase in abundance as a result of MPA implementation (Gaines and Lester et al, 2010); the effects on other, more mobile species are relatively unknown and often negligible.

Despite this, MPAs are designed to represent a wide range of marine ecosystems across a range of environmental gradients while being in close enough proximity to facilitate the successful dispersal of larvae and adults alike (PISCO, 2010). This design allows for spill-over effects from reserves into fishable areas (Jones et al, 2009; Planes and Jones et al, 2009) and subsequently, the promotion of sustainable fisheries. Studies conducted in the Channel Islands, California (Hamilton et al, 2010) and the Great Barrier Reef, Australia (McCook et al, 2010) has indicated significant increases in fish biomass and improvements to the overall health and reef systems demonstrating greater resilience to anthropogenic and environmental stressors. The health benefits are more pronounced among species with smaller home-ranges and those which are 'site-attached' (McCook et al 2010).

The spill-over effect

Implementing a marine reserve does more than affect the size and abundance of species inside the reserve, there are also "spill-over effects". Research conducted in Fiji and Florida demonstrated the effects of implementing MPAs on the rejuvenation of fishery ecosystems (Gell and Roberts, 2003). The closure of the clam fishery and 'black drum' fishery in Fiji and Cape Canaveral respectively, resulted in an exponential growth in biomass and catch numbers over the span of 5 to 10 years (Gell and Roberts, 2003). Notably, in both instances record size catches (individual) were reported on the outskirts of each of the respective reserves.

MPAs not only promote the health and sustenance of biodiversity within its bounds but serve to influence the eco-systems located throughout the wider region. In this regard, evidence suggests that due to the effects of larvae dispersal and species migration between reefs, areas outside of MPAs benefit significantly from the protection of biota within these reserves (McCook et al, 2009; 2010; Jones et al, 2009; Gell and Roberts, 2003; Planes and Jones et al, 2009). It was found that fish counts of both target and non-target species outside of marine reserve areas were substantially

higher following the implementation of the Great Barrier Reef re-zoning in 2004 (McCook et al, 2010). It stands to reason that in areas where the dependence on exploitation of reefs prevails, much benefit is to be gained from the implementation of conservation areas.

1.4 Coral reef rehabilitation

As previously mentioned, the SMACMP Report (2009) outlined several recommendations for further development and capacity building in regard to reef protection in Speyside (see Figure 1 below) such as incorporating 'replanting' schemes to encourage reef rehabilitation in degraded areas. The resilient nature of the reef systems in north-east Tobago makes the region an ideal candidate for rehabilitation and restoration projects as the coral systems will be able to successfully regenerate and grow under the pre-existing conditions. In this regard, a rehabilitation component should be incorporated into the proposed Marine Park Zoning for the region.

The global decline in healthy coral reef systems has stimulated the emergence of research into sustainable and practical methods of reef rehabilitation and restoration (Rinkevich, 2005; Seaman, 2007; Chuo, 2009). Restoration of marine habitats has been undertaken in a variety of ecosystems globally and while the preferred management method is the protection of reefs in their natural state, in several instances, the restoration of degraded marine habitats is necessary (Chuo, 2009; Seaman, 2007).

Coral reefs are generally resilient systems and given the right conditions are able to recover from adverse events to a state which can be considered stable and productive (Buddemeier, 2004; Goreau, 2005). Given the resilient nature of these systems, several methods have been developed which seek to restore degraded marine ecosystems to a stable state. Among the most common practices include:

❖ Transplanting of entire colonies

Entire sections of hard and soft coral reef are uprooted, and transported via tanks to another area (Chuo, 2009; Loh et al, 2006). This method tends to be very labour intensive and thus costly to implement however, studies in Malaysia and Thailand have determined that transplanted colonies experienced a 70% and 90% survival rate respectively and thus the method is being implemented throughout the marine parks in the relevant countries (Chuo, 2009; Loh et al, 2006; Rinkevich, 2005; Seaman, 2007).

Due to the intensive nature of the relocation method, it tends primarily to be utilised in repairing areas of reef which have been previously damaged – often associated with improper anchoring of vessels. As a result of the relocation, donor sites tend to be left depleted of coral and it is imperative that specific care be taken to ensure the sustenance of a minimum viable population at the donor site.

❖ Transplantation of coral fragments

Healthy coral fragments are transplanted either from a naturally occurring environment or from a coral colonisation farm and attached to an artificial or natural form of strata (Chuo, 2009). The apparatus is deployed in the desired location and allowed to colonise naturally under the existing environmental conditions (Chuo, 2009; Rinkevich, 2005; Seaman, 2007).

This is a more widely used form of coral restoration due to its unobtrusive nature and high coral fragment survival rates of 80-90% (Chuo, 2009; Loh et al, 2006). It is also a much more practical method as it can be deployed over a larger area more successfully however the survival rate is highly dependent on suitable environmental conditions for coral growth; the fragments are highly susceptible to environmental fluctuations.

❖ Substrate Modification

This process involves the deployment of artificial substrata into areas where restoration efforts are required – either to replace or supplement damaged benthic habitat (Chuo, 2009; Koenig, 2001). Coral growth results from either transplanting fragments onto the artificial strata or allowing growth to occur through natural recruitment (Chuo, 2009).

The method is low cost however, in some cases recruitment times tend to be slow and leads to ecosystem stagnation and possible failure. The recipient sites must maintain suitable conditions to sustain successful growth and reproduction of coral colonies (Chuo, 2009).

❖ Substrate Modification via Electrolysis

This process involves the use of simple oceanic electrolysis to create an enhanced environment for coral growth and in essence, produces an automated reef building apparatus (Goreau, 1996). A metallic structure (comprising a large negative cathode and smaller positive anode) is built to the shape and form necessary as required for the restoration purpose in question; low voltage direct current is then run through the apparatus electrolysing the adjacent water and depositing on the cathode, a substrate rich in calcium and magnesium (Goreau, 2005). Healthy coral fragments are attached to the cathode and allowed to grow naturally. The deposit of rich calcareous substrate provides coral fragments the necessary ideal chemical conditions under which they can flourish almost effortlessly (Goreau, 2005).

The structure requires constant power in order to produce consistent low voltage current to the apparatus. Over the years, several methods have been trialled using solar power, wind generators and tide-powered apparatus (Goreau, 1996; 2005). Several projects have been trialled throughout the Caribbean with alarming success rates – corals in Jamaica were found to grow at rates 3-5 times that of naturally occurring species (Goreau and Hilbertz, 1996); in Panama, areas which were once eradicated of sensitive staghorn corals experienced phenomenal growth rates (Goreau et al. 2005); structures in Turks and Caicos without hurricane events with over 80% of the transplanted coral fully intact.

Studies on coral bleaching in North Eastern Tobago have indicated that the reefs in the Speyside region tend to show signs of greater resilience to mass bleaching events and other disease outbreaks (O'Farrel et al 2006). This resilience to environmental stressors is probably due to the lack of coastal development in the area and also the presence of strong upwelling of currents which do not allow waters to stagnate and become warm (Armstrong et al, 2009).

2.0 Creating a Marine Park network in North-east Tobago – Marxan with Zones

In 2009, a report issued by the Coral Cay Conservation in collaboration with the Tobago House of Assembly described the potential for the implementation of a community-based marine management project focussing on promoting effective, community-led and capacity-building exercises for the Speyside Marine Area (SMACMP Report, 2009). The Speyside Marine Area Community-based Management Project (SMACMP) over the course of twelve months, successfully integrated a marine awareness education program into all school curriculums in the local area, facilitated the training of several marine park rangers and forged partnerships with various government departments (SMACMP Report, 2009).

The SMACMP Report (2009) outlined several recommendations for further development and capacity building of the project including the implementation of a marine park in the Speyside area – primarily around Little Tobago and Goat Island. Additional recommendations included the establishment of a marine park authority to undertake the respective management tasks associated with the marine protected areas as well as implementing coral rehabilitation schemes. At the time of publishing this paper, several initiatives into the protection of the reef have been implemented including the establishment of a community based organisation dedicated to the protection of the rainforest and reef systems in the north-eastern region; no Marine Park had yet been established in the area.

In this regard, the overall aim of this project is to develop a method for establishing an effective and practical marine park network in Tobago which incorporates a specific area designation for rehabilitation projects. This was done through a pilot study in the north eastern region of the island. The marine park system proposed will not seek to emulate that proposed by the Coral Cay Conservation but will determine an appropriate system based on detailed analysis of ecological data through specific systematic conservation planning software.

This project aims to employ methods of Systematic Conservation Planning (Margules and Pressey 2000; Moilanen et al. 2009) to develop a draft Marine Protected Area zoning plan for the northeastern region of the island (see Figure 1). Overall, the method comprises a combination of ecosystem mapping and basic species distribution data (as provided by the CCC) together with marine-area exploitation data to determine the most practical and effective configuration of conservation zones (see 'Methods' section below for detail). The parameters of the zones will be user-defined and optimised to achieve a balance between biodiversity conservation and economic benefits.

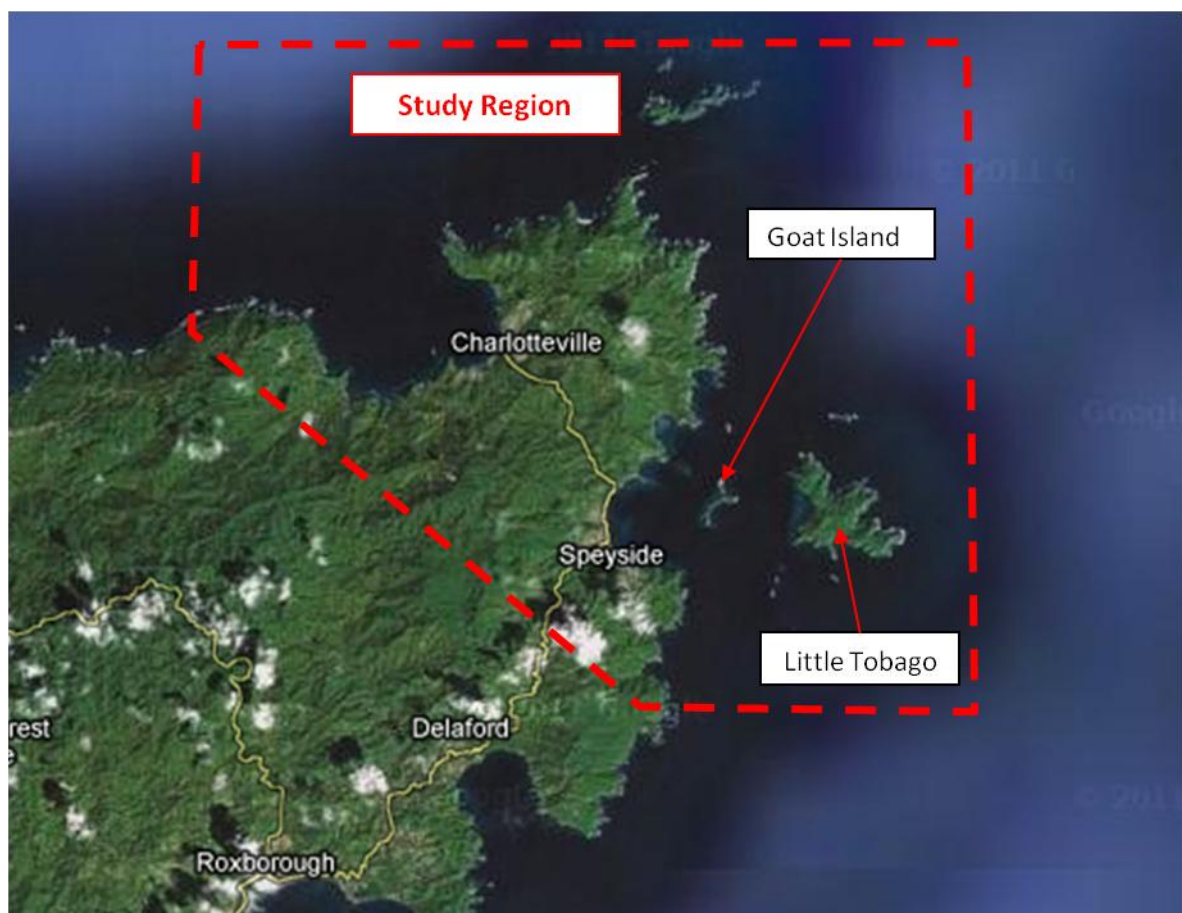
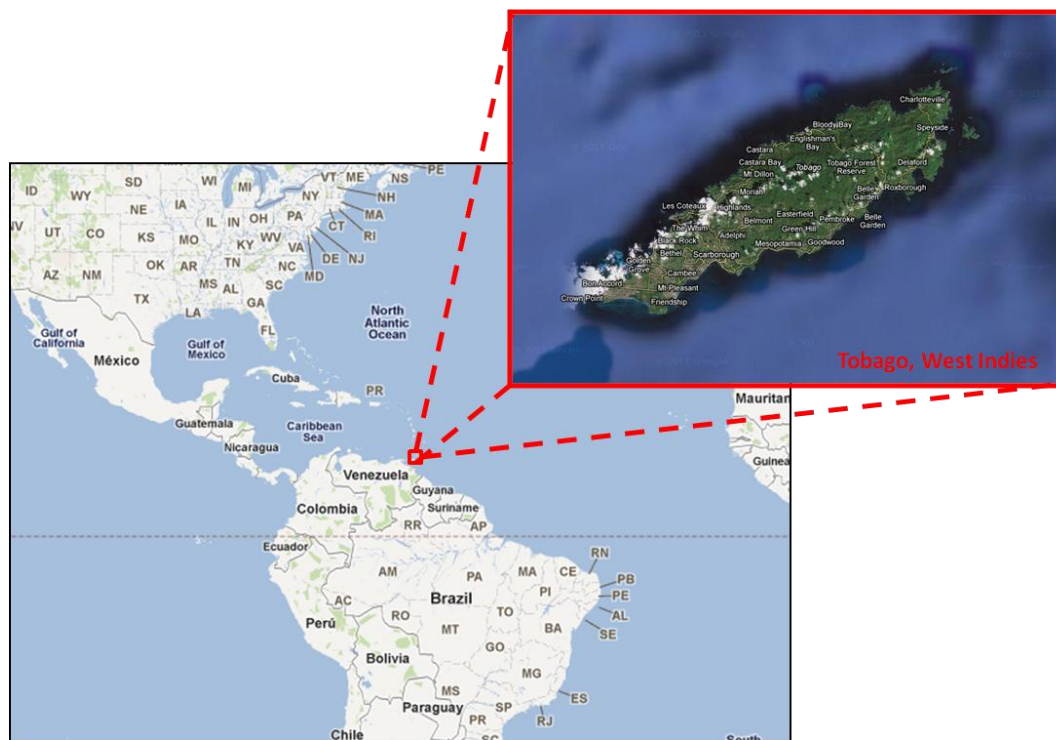


Figure 1 – Satellite image showing Study Region – Google Maps 2011

Marxan with Zones

The analysis is done exclusively using Marxan with Zones (Watts et al., 2009) which is freely available software from the Spatial Ecology Lab at the University of Queensland (www.ecology.uq.edu.au/marxan.htm). The software is designed to aid decision makers and other involved stakeholders in addressing a range of conservation planning problems; the algorithm is flexible and can be applied to a range of problems including but not limited to, reserve design and natural resources management for both terrestrial and marine systems (University of Queensland, 2011 - <http://www.uq.edu.au/marxan/index.html?p=1.1.1>).

The software uses a simulated annealing algorithm which enables it to determine near-optimal solutions to large problems quite quickly (Ball and Possingham, 2000; Possingham et al., 2000). For a set of conservation features – namely benthic habitats or commercially targeted fish species – a representation target is set for each within the reserve system. Subsequently, the parameters for each desired zone are set; each zone will seek to contain a certain portion of each conservation feature which will represent a contribution towards the overall target for that feature. For example, for a certain coral reef, the user requires that 80% of all healthy coral habitat be protected; further to this, 75% of this target must be located within the Conservation Zone.

Given a set of user-defined targets and parameters, the software will determine which areas of the reef (planning units) are best suited to be placed into a particular zone (Watts et al, 2009). Each planning unit is designated a 'cost' which relates to the intensity of stakeholder use in that given area; i.e. if a certain area of the reef is a favourite fishing spot as well as a popular dive site and those activities will be prohibited as a result of rezoning, that planning unit will be designated a higher 'cost' than an area where neither of the activities occur. Marxan will select a configuration of planning units which achieves all targets at the lowest cost (Watts et al, 2009); hence, areas of healthy reef which are not frequently used will be taken at highest priority. In short, the software seeks to determine the most cost effective configuration which meets all the conservation targets set by the user and adapts the output to be effectively integrated into geographical information systems (Watts et al, 2009).

The zoning approach we suggest contrasts with classical conservation planning that only considers two types of use – “no-take” marine sanctuaries and the opposite whereby no restrictions apply. The use of different zones in Marine Park planning enables decision makers to find a compromised balance between the relevant stakeholders and biodiversity conservation. Zones will allow potentially conflicting activities – fishing, recreational diving etc – to be effectively integrated within the same management system (Day, 2002).

Zones used

For the purpose of this report, we define the following zones:

1. Conservation Zone

This zone will prohibit any type of fishing or extraction activity. Areas of high coral cover (>30% cover) and high species richness (>30% of species – benthic and otherwise) will be targeted as high priority conservation areas in order to promote the protection of these healthy reefs and facilitate the benefits of the spill-over effects to the areas outside the zone.

Surface activity data (as collected by Coral Cay Conservation in detailed site surveys 2008 – 2009) has indicated that these areas tend to be hotspots for recreational activities (diving, tour operations, pleasure cruises etc) and therefore, these activities will continue to be allowed within the Conservation Zone at a controlled level. In this regard, anchoring within these zones will be prohibited and vessels will only be allowed to moor using fixed moorings; this method will also aid in limiting use of the area.

2. Rehabilitation Zone

The Rehabilitation Zone will prohibit any surface or sub-surface activity within the zone. Restoration and rehabilitation efforts will be concentrated within these areas in an attempt to re-establish healthy reef systems and boost species richness.

Areas which portray moderate to high levels of damaged coral (30-100%) and relatively low species diversity (<30%) will be targeted for rehabilitation projects. These zones – as best as possible – will be located adjacent to Conservation Zones to benefit from the spill-over effect and larvae dispersal from these areas.

Future planning may enable Rehabilitation Zones to be incorporated in stages into the Conservation Zones thereby increasing the area of healthy protected reefs in the region.

3. Open Zone

The open zone will not restrict any fishing or recreational activities. These areas will benefit from the spill-over effect of the nearby Conservation Zones and allow for sustainable management of commercial fisheries and the reef in general.

Overall, the project seeks to apply the principles of Systematic Conservation Planning (Margules and Pressey 2000; Moilanen et al. 2009) through the use of Marxan with Zones to (i) develop a method for establishing a marine park zoning plan in a data poor area; and (ii) determine the most viable areas to implement marine rehabilitation projects.

3.0 Methods

3.1 Background to project – Site context

The Coral Cay Conservation (CCC) group has been undertaking research throughout Tobago since early 2007. The organisation has been in collaboration with various local government entities and other non-governmental organisations (NGOs) in conjunction with the Tobago Coastal Ecosystems Mapping Project (TCEMP Annual Report, 2008). The primary aim of the project is to gather a baseline dataset on coral reef, mangrove and seagrass habitats throughout the island (TCEMP Annual Report, 2008). The findings of the preliminary research have indicated that several of the island's fringing reef systems are experiencing varying levels of environmental stress resulting in a loss of hard coral cover, a reduction in biodiversity richness and high levels of coral disease outbreaks (TCEMP Annual Report, 2008).

Reef systems throughout the Caribbean region as a whole have been experiencing a severe decline in health and abundance since the early 1980's (Gardner et al., 2003; Mumby et al., 2006; 2007). This degradation has been attributed to a combination of factors including damage from hurricanes, disease outbreaks, disease and overfishing of primary grazers and has resulted in a decline in coral cover from roughly 60% to less than 10% in some areas (Mumby et al., 2006; 2007). At a local scale, coral cover on the north-western reefs of Tobago have seen a substantial decline from 22% in 2005 to 16% in 2008 with several sites showing less than 5% live hard coral cover (TCEMP Annual Report, 2008); additionally a reduction in coral species diversity is apparent on shallow reefs which have experienced a phase shift from *Montastrea* dominated reefs to *Millepora* dominated ones (TCEMP Annual Report, 2008). Such a shift in coral species cover is representative of an ecosystem which is being placed under stress through multiple and frequent disturbances (Edmunds and Elahi, 2007; Witman, 1992). The changes to coral cover and diversity have been attributed to a combination of climate change and anthropogenic factors as well as widespread coral disease that plagues the island's reef systems (SMACMP Report, 2009).

Initiatives by local government organisations and NGOs operating on the island seek to limit the extent of these impacts and mitigate against any substantial future degradation. Such initiatives include education programs for local communities and the establishment of a marine park authority to oversee the progression and implementation of management initiatives in the area.

As previously mentioned, tourism comprises a significant portion of the economic sector in Tobago, accounting for approximately 46% of the island's GDP in 2005 (WTTC 2005). The north-east region of the island has remained largely under-developed when compared to the south-west where hotels and guesthouses have seen rapid growth in the last 15 years. Much of the reef system in the chosen study area (Speyside to Charlotteville) was deemed to have high conservation value by the CCC (SMACMP Report, 2009) and thus a perfect location for a pilot study of this nature.

3.2 Data Collection and Assimilation

All ecosystem data used in this analysis was obtained through the Coral Cay Conservation. The data was collected via several intensive underwater transect surveys along the reef crests which runs almost parallel coastline of the island (TCEMP Annual Report, 2008). Among the data collected were a variety of ecosystem variables and species distribution counts; for the purpose of this analysis, the following data was utilised:

- ❖ Commercial and pelagic fish species abundance – a list of species present and an estimation of size and biomass;
- ❖ Demersal species and other non-target reef fish – a list of species present and fish counts for each species;
- ❖ Benthic Cover – percentage of seafloor coverage comprising hard coral, algae, rock, sand or damaged coral;
- ❖ Surface Activity – any anthropogenic activity which was occurring within the vicinity of the survey site. This was categorised into: fishing, recreational and tours, and diving.

Data from each survey was recorded before being entered into the TCEMP database. Each survey site was appropriately logged into a GPS to facilitate use in spatial analysis exercises.

Other data was collected independent of the CCC including:

- ❖ Dive site frequency – several dive companies operating in the region were contacted and asked to identify which dive sites were most frequently visited on a monthly and yearly basis.

All data was sorted and stored as point data in a spreadsheet format to be input into ArcGis – see Figure 2 below.

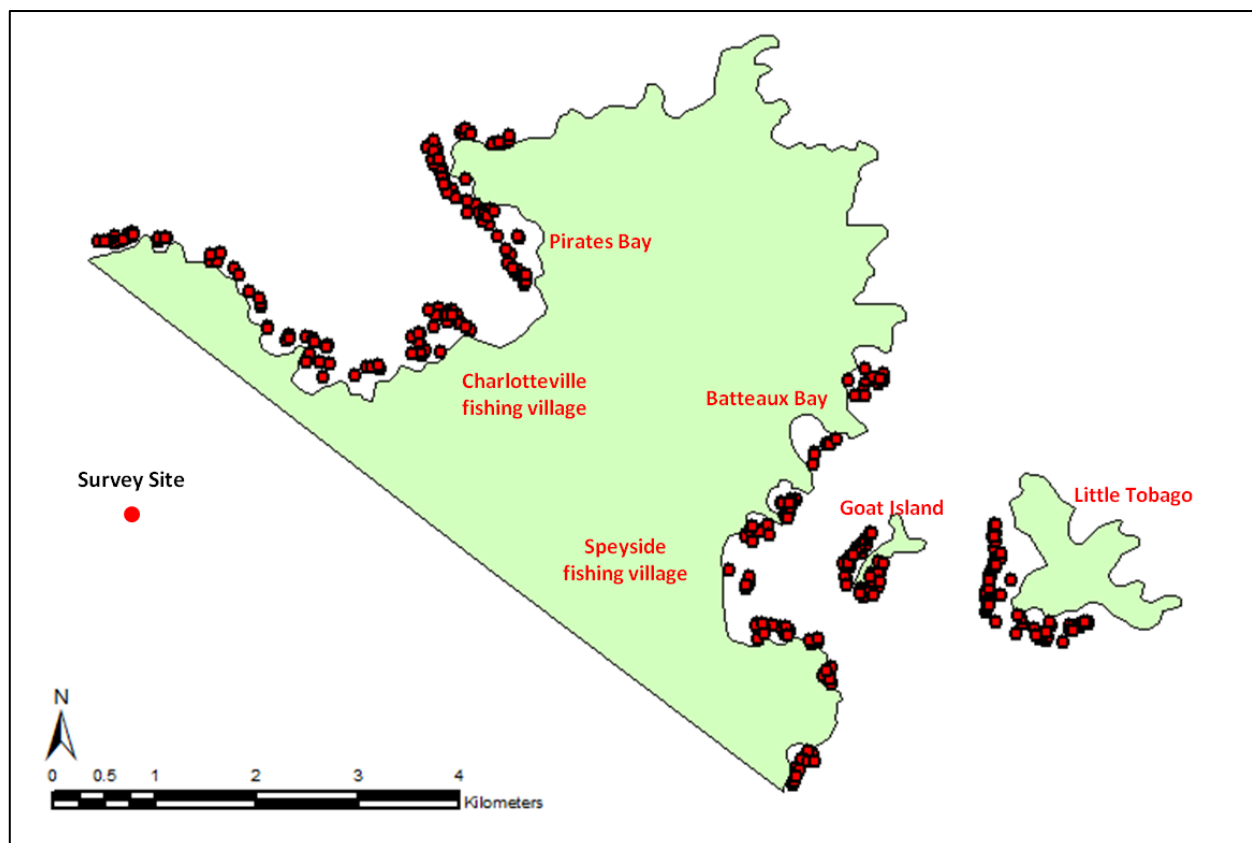


Figure 2 – Distribution of data sampling points throughout study area

Creating Distribution Layers

For the purpose of this analysis, species distribution layers were created using simple interpolation techniques available in ArcGis. In the absence of accurate species distribution maps and abiotic

information, interpolation techniques were seen as the best way of approximating species distributions.

3.3 Species Distribution – Kriging Method

The Kriging Method was the primary form of interpolation used to estimate species distribution using the data provided. Kriging is “*based on a model of stochastic spatial variation that fits well with reality*” (Oliver and Webster, 1990). Kriging utilises point data of a given distribution and will provide statistically sound estimates with minimum and known variance (Oliver and Webster, 1990). In this regard, surface interpolation through the Kriging method was deemed to be the most statistically accurate method available for the purpose of this analysis.

The method takes a distribution of individual data points and produces a smooth raster layer based on the assumption that the distance between sample points reflects a spatial correlation in data. The distribution is affected by the influence of the value of points nearest to each data point; i.e. for hard coral distribution, if a certain species of coral was found in high abundance at two points which are very close together, the surface between these points would represent a high density of that particular species. Conversely, if the density of a species was found to be high at one point and very low at a point close by, the distribution surface between the two points will show a sharp decline radiating outwards from each point.

Based on the sedentary and demersal nature of many of the species identified in the data, it was assumed that distribution was only influenced by the areas in the immediate vicinity of the point (see Results section for relevant output of this method).

An alternative approach would be to use standard species distribution modelling methods (Beger et al 2003) however the lack of environmental data made this impossible in this particular case.

Parameters

The parameters used for the purpose of interpolation were as follows:

Parameter	Property	Reason
Kriging Method Ordinary vs Universal Ordinary – assumes no overlying trend in data. Universal – assumes there is an overlying trend and attempts to fit a universal curve through the data.	Ordinary	It was assumed that species distribution throughout the region occurs randomly and with no particular trend.
Search Radius Option of Fixed or Variable – dependent on the number and distribution of data points.	Fixed	The data points are quite evenly distributed and in order to maintain consistency throughout the analysis, a fixed search radius was established.
Search Radius Distance The distance, in map units, specifying that all input sample points within the specified radius will be used to perform interpolation.	100 metres	It was decided that any biodiversity present at a distance greater than 100 metres away will have a minimal impact on the species distribution at the relevant data point.

Table 1 – Parameters use in Kriging Interpolation

Limitations

The distribution mapping methods used in this report are a very rough estimate of the actual species distributions. The dynamic nature of coral reef systems including species home ranges, dispersal ranges and migration patterns are unknown and beyond the scope of this exercise. A more in depth study would utilise specific species distribution modelling software and would incorporate a wider range of environmental factors and stochasticity. We used the Kriging method as it is straightforward and enabled us to pursue the primary issue, spatial zoning – more sophisticated spatial distribution modelling would be preferable.

3.4 Analysis – Marxan

Planning Units (PUs)

A planning unit size of 100x100 metres square was chosen. This was correlated to the Search Radius Distance utilised in the Kriging interpolation method for the species distribution layers developed previously.

The planning units were limited to within 500 metres of the coastline and within 100 metres of the data points to ensure that all PUs contained distribution data representative of the existing reef shelf.

Cost Layers

For each Planning Unit, a cost of making that PU a part of the marine reserve was determined. The surface activity data obtained through the Coral Cay Conservation was used in conjunction with the commercial fish biomass distribution throughout the study area. Each PU was given two separate costs for 'Fishing Activity' and 'Other Surface Activity' as follows:

Fishing Activity Cost – (Conservation Cost)

This cost was calculated for each PU as a weighted cost of all fishing activity (as recorded in spot counts of the number of fishermen in the area at a given time) and the biomass of commercially targeted species within the PU.

The cost of each planning unit is indicative of the fishing effort in the PU and the associated commercial gain which will be foregone if the PU becomes a marine protected area. The cost of a planning unit, C , takes into account the amount of commercial biomass within the PU and the associated effort of fishing occurring:

$$C = F + f.c.e$$

Where

C = Conservation cost of a planning unit

F = Fixed cost of planning unit that has no fishing

f = Number of fishermen in the planning unit (taken as a spot count at the time of survey)

c = Commercial fish biomass (kg per sqkm)

e = Catch efficiency of fishermen (taken as 40%)

Rehabilitation Cost

The cost of a relevant planning unit (PU) for Rehabilitation was taken to be the weighted sum of all surface activity occurring within the PU in addition to the Fishing Activity cost (i.e. Conservation Cost).

All other surface activity calculations were included in this cost value since the taking of a PU for rehabilitation would restrict all operations within that PU. For the purpose of determining the cost, the total head count of all activities was calculated and all given equal weighting towards the final value.

Calculation:

$$R = C + F + d + t + r$$

R = Rehabilitation Cost

C = Conservation Cost

F = Fixed Cost of Planning Unit

d = Weighted value of diving activity (recreational dives)

t = Weighted value of tourism activity (reef tours, sailing tours, etc)

r = Weighted value of other recreational activity (surfers, pleasure cruises, etc)

(head count of all persons involved in relevant activities taken as a spot count at the time of survey)

Limitations

The cost layers utilised as a part of this analysis have been developed based on single point observations. Additionally, the value of each activity has been weighted equally – this can be altered pending relevant negotiations with stakeholders. The surface activity data collected by the CCC was taken as a head count of people engaged in each relevant activity based on a single observation at a particular point in time. The activities occurring within each planning unit may vary seasonally and also be different from year to year. In this regard, a more accurate analysis of the activities occurring around the reef systems of NE Tobago would need to be conducted in order to fully analyse the costs of each planning unit. This may be possible through detailed surveys with the local tourism board and discussions among tour operators etc.

3.5 Analysis Parameters

This section of the report will identify all the parameters used in the Marxan Analysis. A brief explanation of the parameter itself will be provided along with the value used why this value was used.

Conservation Features

Table 2 below outlines the relevant Conservation Features which formed part of the overall marine park zoning analysis. A brief description in regard to the composition of each feature class is provided.

Feature Class	Description
Species Diversity (0-30%)	The total count of all species of coral and other biota found within each planning unit.
Species Diversity (30-100%)	
Benthic Cover – Algae (0-30%)	The percentage of each relevant Benthic Cover type found at each location.
Benthic Cover – Algae (30-100%)	
Benthic Cover – Sand (0-30%)	
Benthic Cover – Sand (30-100%)	
Benthic Cover – Rock (0-30%)	
Benthic Cover – Rock (30-100%)	
Benthic Cover – Hard Coral (0-30%)	
Benthic Cover – Hard Coral (30-100%)	
Benthic Cover – Damaged Coral (0-30%)	
Benthic Cover – Damaged Coral (30-100%)	
Commercial Biomass - Total	An estimate of the total Commercially targeted biomass found at each location.

Table 2 – Description of Conservation Features

Feature Targets for Conservation

This parameter defines the proportion of the existing distribution of each particular Feature which is required to be protected.

Feature Class	Proportion to protect
Species Diversity (0-30%)	40%
Species Diversity (30-100%)	80%
Benthic Cover – Algae (0-30%)	15%
Benthic Cover – Algae (30-100%)	15%
Benthic Cover – Sand (0-30%)	15%
Benthic Cover – Sand (30-100%)	15%
Benthic Cover – Rock (0-30%)	20%
Benthic Cover – Rock (30-100%)	20%
Benthic Cover – Hard Coral (0-30%)	40%
Benthic Cover – Hard Coral (30-100%)	80%
Benthic Cover – Damaged Coral (0-30%)	30%
Benthic Cover – Damaged Coral (30-100%)	30%
Commercial Biomass - Total	50%

Table 3 – Representation Targets for each Feature Class

Specific emphasis was placed on ensuring that healthy reefs were preserved as best as possible and as such, a target of 80% was set for preservation of areas which possessed greater than 30% of Hard Coral cover and greater than 30% of all species diversity.

A target of 50% protection of all Commercial Biomass was prescribed in order to ensure a sustainable population of commercially targeted species was protected. It was also sought to encourage protection of areas of damaged coral to facilitate the implementation of rehabilitation projects – a target of 30% was set for areas with high proportion of damaged coral and 40% for areas with a relatively lower portion of coral damage.

Zone Boundary Cost

This parameter can be adjusted to ensure that two zones are established adjacent to each other. For this analysis, the zone boundary cost between the rehabilitation and conservation zones was set to

be five times higher than that for the open zone. This was done to ensure that the rehabilitation zone would be located as best as possible adjacent to conservation zones in order to benefit from the spill-over effects and larvae dispersal associated with healthy reefs.

Zone Specific Conservation Targets

This parameter allows the user to dictate the proportion of each Feature Conservation Target to be allocated within each zone. For this analysis, this parameter was manipulated to ensure that the majority of healthy reefs protected were confined to the Conservation Zone and subsequently, the damaged and degraded reefs were placed in the Rehabilitation Zone. Additionally, in order to promote economic benefits through the effects of spill-over to adjacent zones, 30% of all commercial biomass to be protected was confined to the Conservation Zone. In this regard, the relevant Zone Specific Conservation Targets were identified as per below.

Feature	Conservation Zone	Rehabilitation Zone
Species Diversity (0-30%)	not specified	20%
Species Diversity (30-100%)	50%	not specified
Benthic Cover – Damaged Coral (0-30%)	20%	50%
Benthic Cover – Damaged Coral (30-100%)	not specified	50%
Benthic Cover – Hard Coral (30-100%)	50%	not specified
Commercial Biomass - Total	30%	not specified

Table 4 – Zone Contributions for each Feature Class

4.0 Results

4.1 Species Distribution Maps

The following figures illustrate the output results of the Kriging Interpolation for the spatial distribution of the Features relevant to the Marxan analysis.

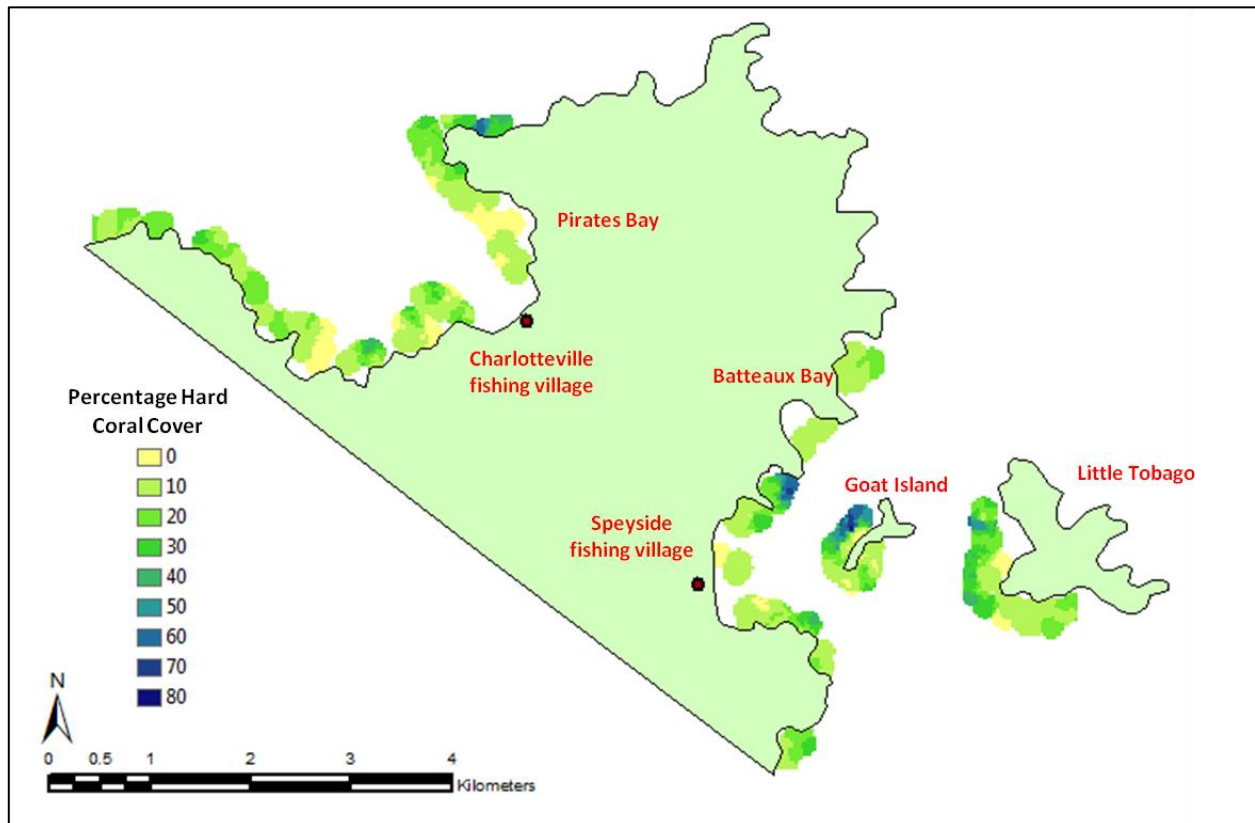


Figure 3 – Benthic Cover Distribution (Hard Coral Cover)

For the purpose of this analysis, Hard Coral cover was taken to be any rigid species of coral labelled as 'Hard Coral' in the dataset provided by Coral Cay Conservation. Areas of high hard coral cover represent parts of the reef which are considered relatively healthy and often show minimal signs of anthropogenic disturbance. These areas were given a high priority for conservation and in this regard, the analysis sought to protect 80% of the reef which demonstrated high values of coral cover i.e. between 30%-100% of live hard coral cover. Additionally, 50% of all areas of high hard coral cover to be protected were located within the Conservation Zone.

As indicated above, four (4) distinct locations in the study region comprise areas of hard coral cover of between 30-100%. These areas include the northern peninsula of Pirates Bay and Batteaux Bay on the mainland as well as the fringing reef areas located along the western side of Goat Island and Little Tobago. Areas with the highest percentage of coral cover were found in Batteaux Bay and off Goat Island.

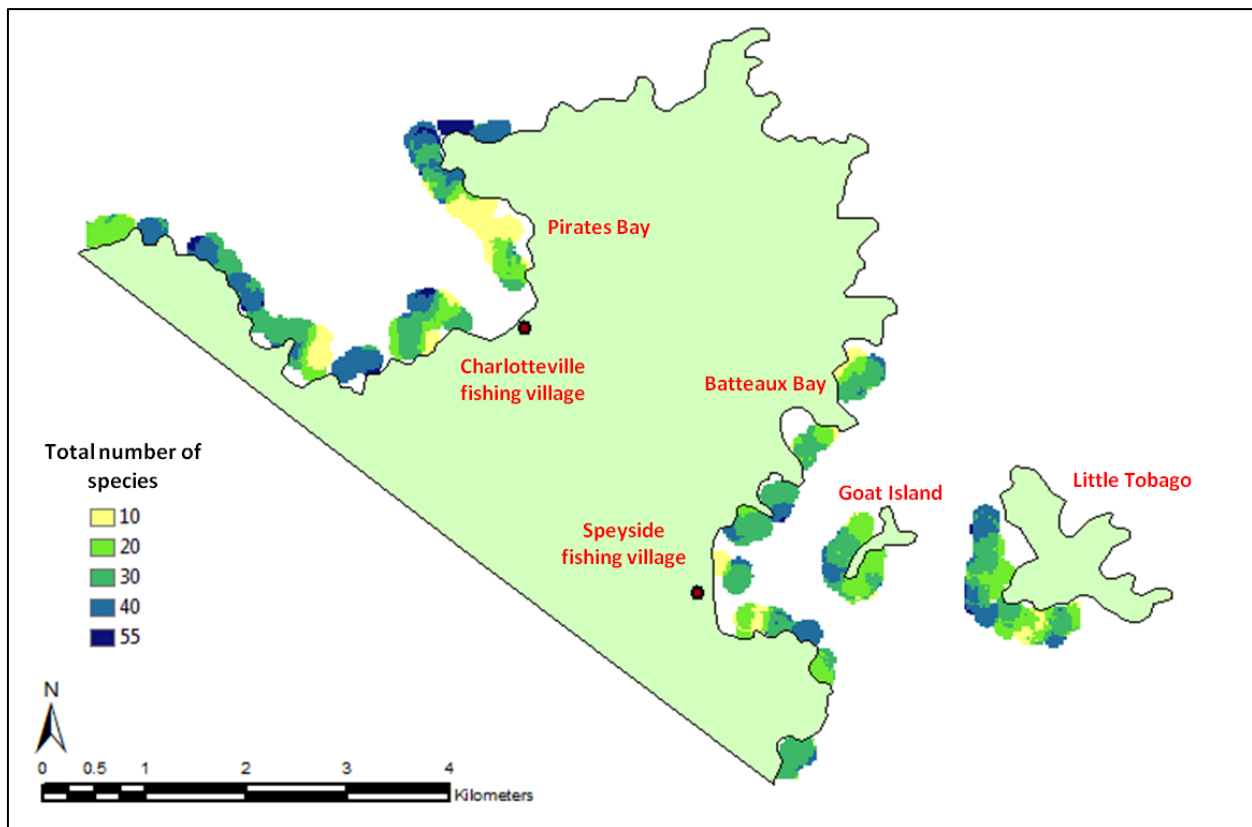


Figure 4 – Species Diversity – values in number of species (coral and other biota total)

The Species Diversity distribution represents the total number of species of biodiversity found in any location i.e. it includes total species counts for benthic cover, fish and invertebrates. A high species diversity value indicates areas of healthy and flourishing ecosystems which are not dominated by a few species; for the purpose of this analysis, areas containing greater than 30% of all species types were considered to be of a high conservation value – these areas are representative of relatively high species richness, below which reef systems were considered to be degraded.

The analysis sought to protect 80% of the areas which consisted of greater than 30% of all species diversity, with a minimum of 50% of the protected areas to be included within the Conservation Zone. A minimum of 20% of the parts of the reef which comprise less than 30% species diversity were included in the Rehabilitation Zone. The purpose of the Rehabilitation Zone is to encourage ecosystem regeneration and therefore, degraded areas showing low-moderate species richness were considered ideal sites for rehabilitation.

As shown in Figure 4 above, the most notable areas of high Species Diversity were found along the northern peninsula of Pirates Bay, and to the south of Charlotteville Beach as well along the western side of Little Tobago. Areas illustrating particularly low levels of Species Diversity were found primarily along the western coast of the study region in Pirates Bay and Charlotteville Beach; notably, a few areas of low species diversity were found along the southern end of Little Tobago.

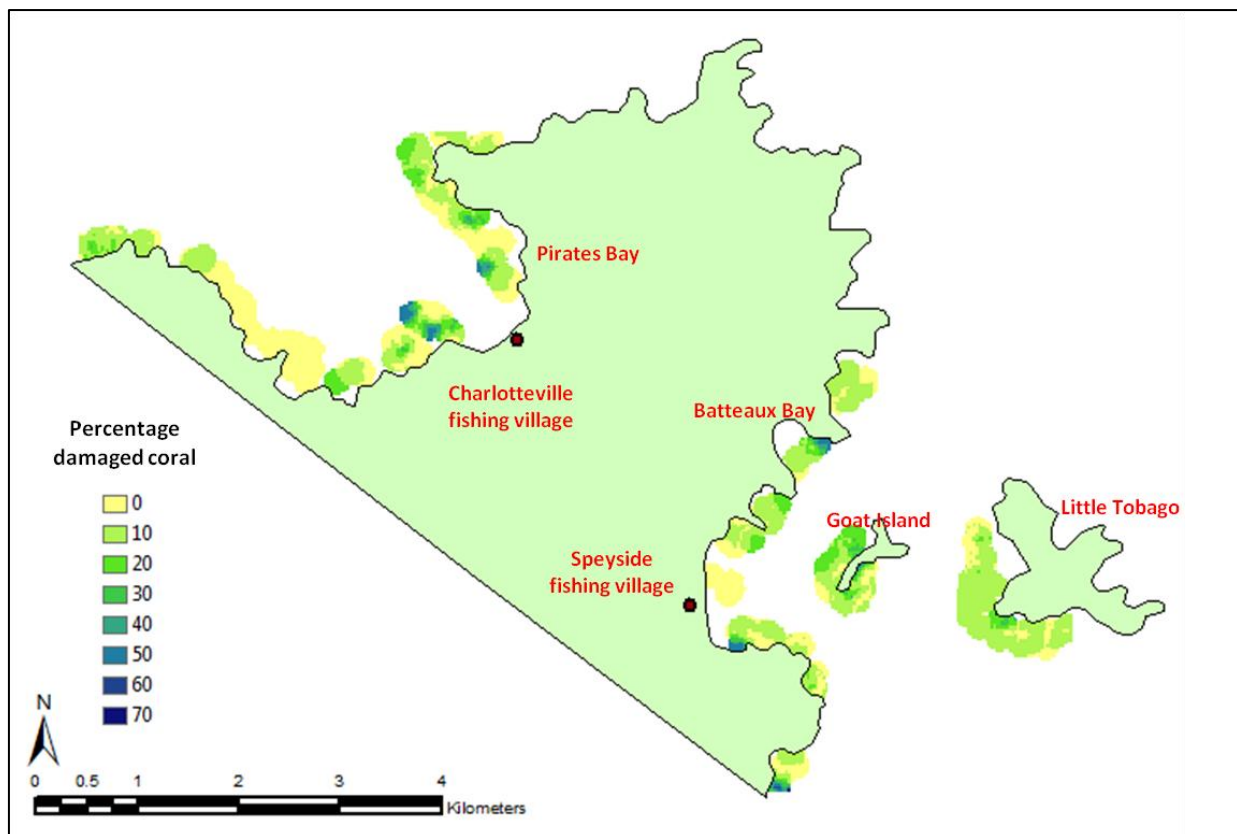


Figure 5 – Benthic Distribution (Damaged Coral Cover)

Areas of Damaged Coral Cover were those where the dominant benthic cover consists of damaged or dying coral. Damaged coral represents areas of high anthropogenic disturbance either due to physical damage or indirect factors induced from poor land management practices within the catchment area of the reef.

For the purpose of the Marxan analysis, an overall representation target of 30% of all areas of damaged coral was set; 50% of these areas are to be located within the Rehabilitation Zone. This facilitates the establishment of rehabilitation projects in areas where damaged coral is the dominant benthic cover type. Additionally, 20% of all areas which exhibited less than 30% damaged coral are to be included in the Conservation Zone; these areas are those which are partially damaged and therefore if located in the Conservation Zone, may regenerate under natural conditions.

Figure 5 above illustrates the location of areas which consist of high levels of damaged coral – unsurprisingly, these areas coincide with high-use areas and tend to be located closer to the developed villages. Notably, the southern end of Charlotteville Beach and Speyside fishing village both represent areas of high damaged coral cover.

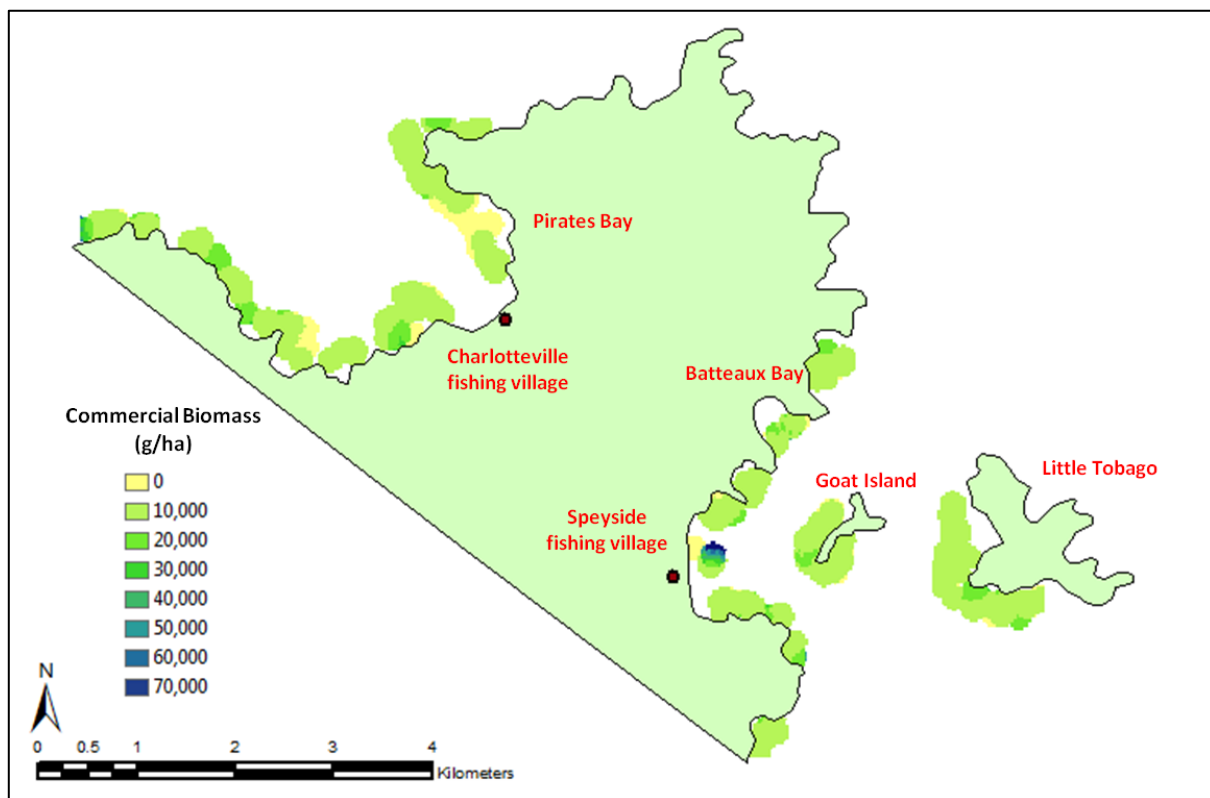


Figure 6 – Distribution of Commercial Biomass

Figure 6 above represents the indicative distribution of commercial biomass throughout the study region. Commercial biomass was calculated to be the total estimated biomass of all commercially targeted fish species identified at a particular location in the study region. These results were considered primarily in calculating the cost of a particular planning unit for the purpose of the Marxan analysis. Areas comprising high commercial biomass were considered to be those which were economically viable to the fishery industry (both artisanal and commercial) and therefore, placing these areas in a Conservation or Rehabilitation zone would be detrimental to the livelihood of many of the local inhabitants in the region.

Despite this, an overall target of 30% was set for all commercial biomass in the region – this was done to promote the spill-over effect as outlined previously in this report. By ensuring the protection of 30% of key areas of commercial biomass presence, the longevity of the fishery will be preserved at a sustainable level. Further, of this target, a minimum of 50% of all protected Commercial Biomass is to be located within the Conservation Zone.

The results shown in Figure 6 above demonstrate that throughout the study region, Commercial Biomass is quite evenly distributed at roughly 20,000 to 30,000 grams per square kilometre. Notably, there is a high concentration of Commercial Biomass in the area just off of the Speyside fishing village (70,000 – 100,000 grams per square kilometre) – shown in blue on Figure XXX; conversely, a substantial area to the northern end of Pirates Bay exhibits a substantially low abundance of Commercial Biomass with the majority of the area comprising 0 – 10,000 grams per square kilometre.

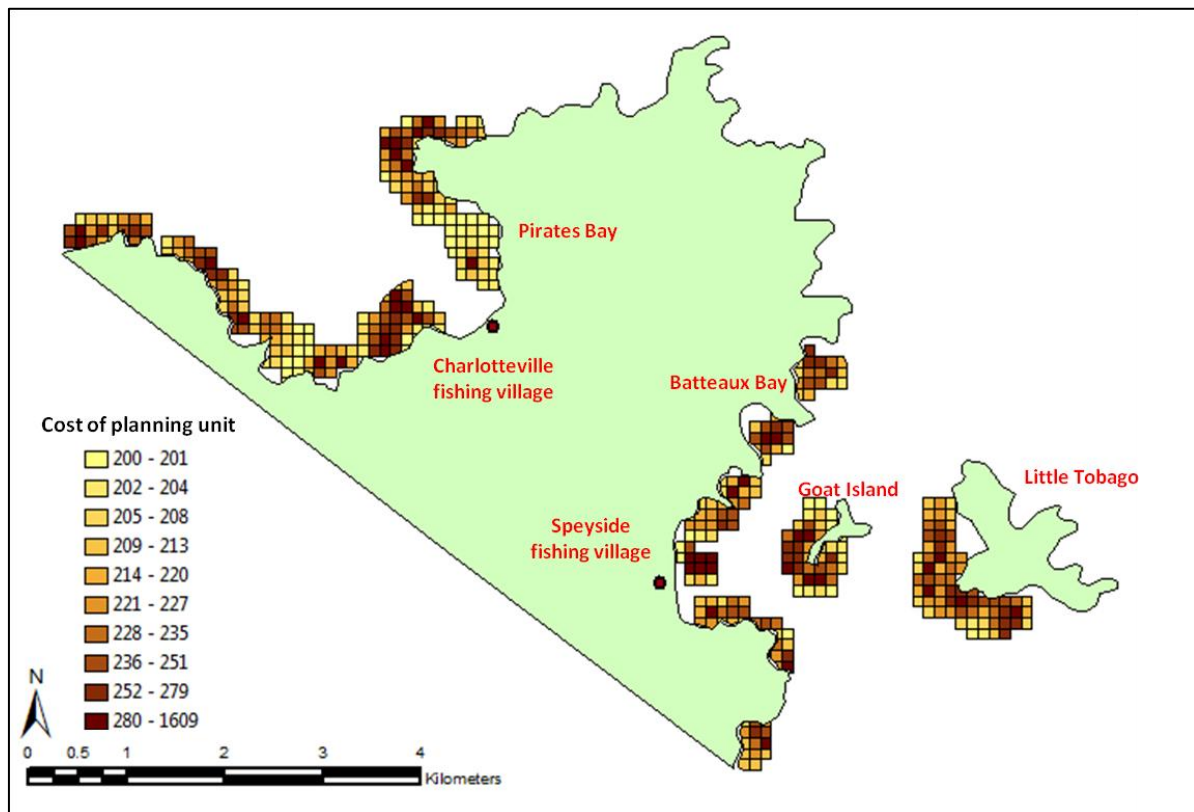
Cost Layer

Figure 7 – Total Cost of Planning Units

Figure 7 above represents the total costs of planning units throughout the study region. The costs demonstrated are the combined value of fishing effort and other surface activity (see equations in Methods section above). Darker areas on the map represent those with a high cost and are typically areas highly utilised for the purpose of tourism and fishing activities; Marxan seeks to avoid placing these areas into either of the prescribed restrictive zones in an attempt to minimise the overall cost of the solution and thereby minimising any adverse effects to these industries.

In many cases however, these areas may be highly regarded in terms of achieving a specific conservation target and will have to be 'taken' in order to fulfil the prescribed representation targets. For example, a certain planning unit may comprise a large area of high coral cover and high species diversity but also may be a particularly popular dive site and local fishing spot; it may be necessary to protect the planning unit in question in order to achieve the required 80% quota for Species Diversity conservation however in doing so, local fishermen will not be allowed to fish the area.

4.2 Marxan Output

The following Figures illustrate diagrammatic representations of the output files from the Marxan with Zones analysis.

Selection Frequency – Conservation Zone

The following Figure 8 demonstrates the frequency with which each planning unit was chosen by Marxan to be placed in the Conservation Zone. Darker colours indicate that the planning units were selected more often in Marxan's iterations and indicate a preference of these areas to be included in the Conservation Zone.

Based on the parameters used in the analysis, these areas represent those with a high percentage of Coral Cover and high Species Diversity. The extent of the Conservation Zone will be limited only by the intensity of fishing activity and the presence of commercial biomass occurring within the planning units. Figure 8 below is indicative of the preferred locations for Conservation Areas as determined through the Marxan analysis and can be a very helpful tool for decision makers. This concept will be explained in more detail in the Discussion section which follows.

It is noted that the selection frequency for the Conservation Zone shown in Figure XXX indicates that Conservation Zones may be implemented throughout the region. Key focus areas can be identified around Goat Island, Little Tobago and the northern peninsula of Pirates Bay. In addition to this, other highly selected area include the extent of reef stretching along the southern extremities of Charlotteville Bay and in pockets of Batteaux Bay and Speyside itself.

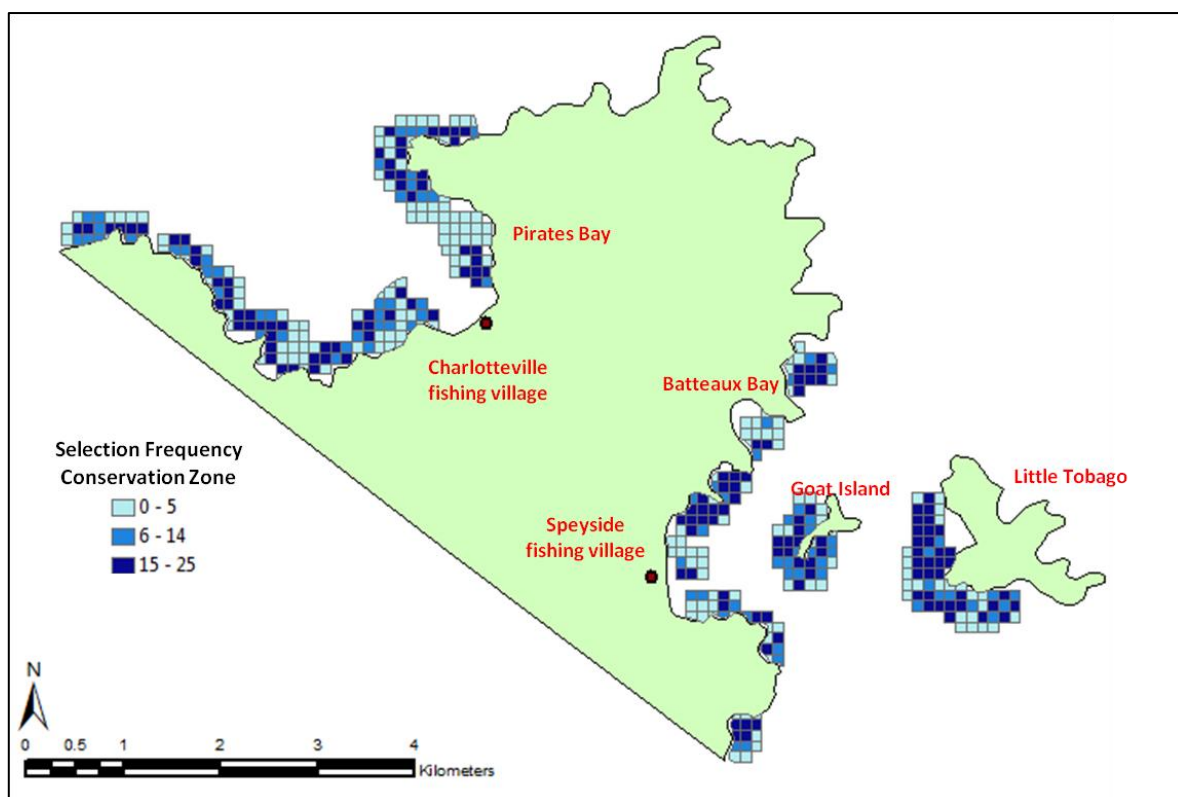


Figure 8 – Selection Frequency of Planning Units in the Conservation Zone

Selection Frequency – Rehabilitation Zone

Figure 9 below demonstrates the frequency with which each planning unit was chosen to be designated in the Rehabilitation Zone. Darker colours indicate that the planning units were selected more often in Marxan's iterations and indicate a preference of these areas to be included for rehabilitation purposes.

These areas are indicative of those where high levels of disturbance and environmental stochasticity have led to large portions of the benthic structure being severely damaged and subsequently a loss of biodiversity occurs. The parameters set in Marxan place a higher priority on including areas which have the potential for rehabilitation into the Rehabilitation Zone. These areas are those where damaged coral dominates the benthic cover type and species diversity has fallen to below 30% of the total diversity within the study region. Modification of the Zone Boundary Cost parameter in Marxan with Zones promotes rehabilitations areas to be located in close proximity to healthier reefs in Conservation Zones.

This map gives a good indication to decision makers into the potential and most viable locations for implementing rehabilitation projects. It is noted that unlike the data for selection frequency of the Conservation Zone (above), Figure 9 below demonstrates that potential rehabilitation sites are concentrated into a few key areas. This gives a clear idea of where projects should be implemented to both regenerate degraded reefs as well as to supplement the existing healthy ecosystems.

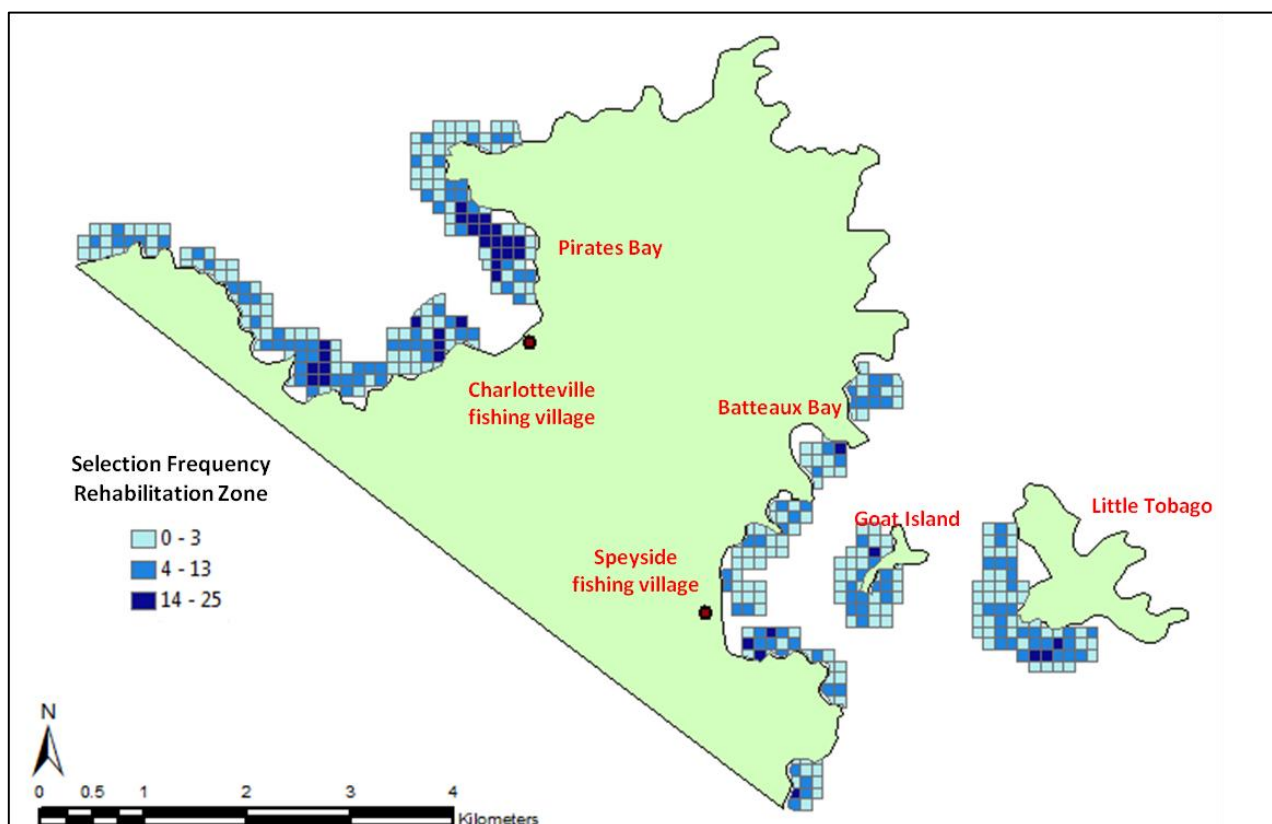


Figure 9 – Selection Frequency of Planning Units in the Rehabilitation Zone

Marxan – Best Solution

The following Figure 10 shows the probable Best Solution as determined by Marxan with Zones in regard to achieving maximum target representation for the minimum cost. Those Planning Units coloured green and purple are indicative of the preferred areas for conservation and rehabilitation respectively.

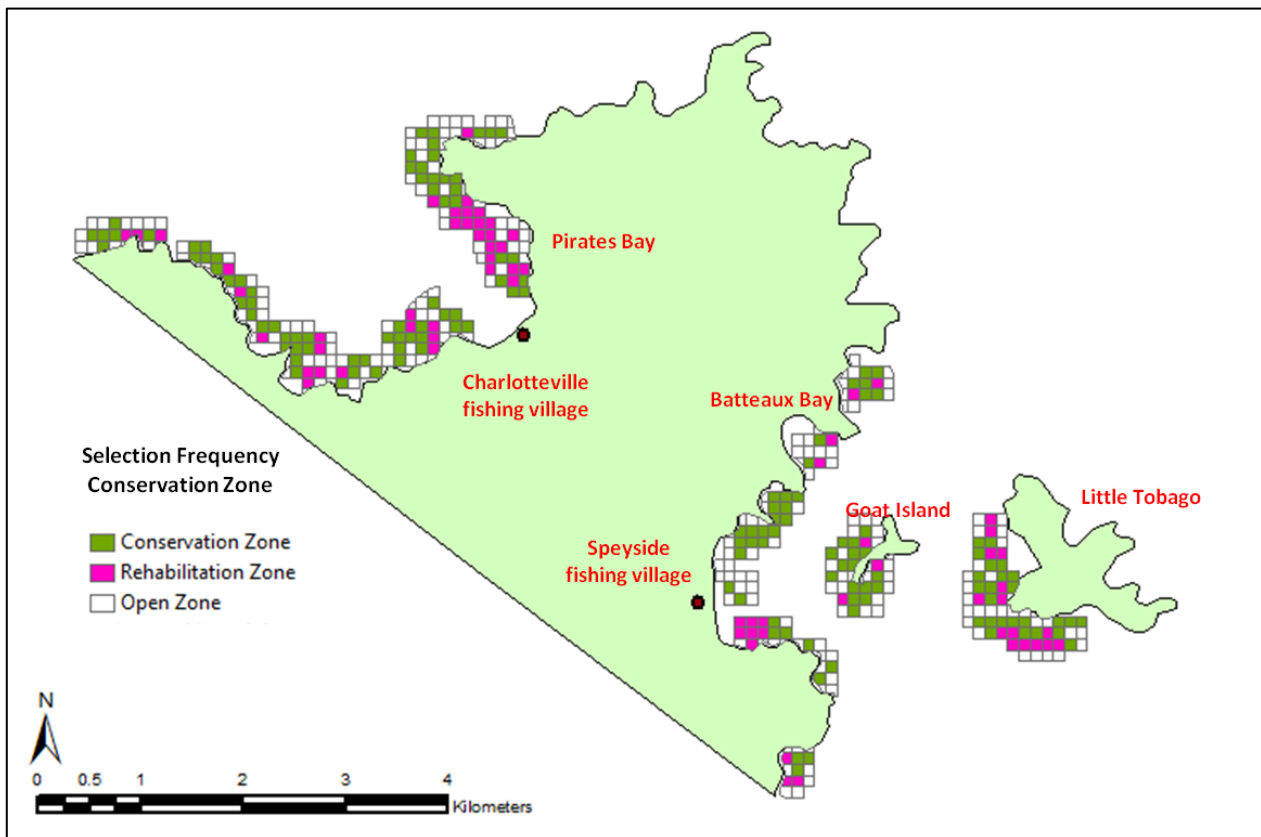


Figure 10 – Best Solution Output from Marxan with Zones

Notably, the Conservation Zone appears to be rather dispersed and encompasses much of the coastline on both the north and south coasts of the study region; there is the tendency to protect the reefs around Goat Island and Little Tobago as these areas possess the vast majority of healthy reef habitat within the study area.

The Rehabilitation Zone for the most part is confined to a few distinct pockets as shown on Figure 10 above. These pockets are indicative of areas where reefs have been degraded but still show potential for rehabilitation as there is still remnant hard coral cover and low species diversity in the area. The Best Solution zoning (Figure 10 above) indicates the preference for locating rehabilitation areas within the Conservation Zone particularly in the areas at the southern end of Little Tobago and Goat Island.

The above configuration represents the best solution for the parameters set in this analysis. It is not recommended that this exact layout be implemented as shown but rather used as a starting point for negotiations with the relevant stakeholders and interested parties.

5.0 Discussion

The primary scientific advance in this paper is the application of Marxan with Zones to determine an efficient suite of actions for both marine reserves and rehabilitation zones. While reef rehabilitation has been discussed in length by previous authors, it has never been prioritised relative to spatial marine reserve designation.

The overall aim of this project is to provide a straightforward and effective method for developing a marine park system which incorporates rehabilitation zones in Tobago and the Caribbean as a whole. Using the data provided by Coral Cay Conservation, a systematic analysis was performed using Marxan with Zones to develop a series of zoning solutions to achieve a set of representation targets at minimal cost. The theories and concepts driving the parameters used in the analysis were developed through comprehensive research in a detailed literature review outlined previously in this report.

5.1 Effectiveness of parameters

Conservation Zone

The parameters were geared towards promoting the theory of biodiversity 'spill-over' by encouraging the protection of areas which demonstrated high hard coral cover and high species diversity. These areas are representative of healthy reef systems and were the main focus of the representation targets set for conservation. The study region contains some of the most pristine reef systems on the island and the southern Caribbean as a whole (TCEMP Report, 2009). Thus, adequate protection of these areas was seen as a high priority and as a result, an overall protection target of 80% was set. As shown in the results above the preferred areas designated as Conservation Zone are dispersed throughout the study region and coincide with areas which demonstrate characteristics of healthy reef systems.

Protection of commercial biomass in the region was also a priority as the livelihood of many inhabitants of the study region, as well as the tourism industry on the island is heavily dependent on artisanal and commercial fishing as a means of income (TCEMP Report, 2009). Special consideration was given to promoting a sustainable fishing industry by attempting to strike a balance between economic gain and biodiversity conservation; in this regard, the commercially targeted species data was combined with fishing activity data to produce a cost layer which identified areas representative of high fishery potential. These areas were given a high cost in an attempt to restrict Marxan from placing the areas within a restricted activity zone thereby minimising any potential disagreements with local fishermen and hotel operators. Conversely, an overall representation target of 30% was designated for all commercial biomass within the study region. This sought to encourage a sustainable fishing industry by restricting fishing activity in those areas which were not heavily fished in order to protect a portion of the commercially targeted species.

The outcome is a Conservation Zone which achieves all set biodiversity targets and encourages sustainable fishing activities throughout the region with minimal objections from the various stakeholders.

Rehabilitation Zone

The purpose of the Rehabilitation Zone was primarily to identify suitable locations for implementing reef rehabilitation projects. The fringing reef systems across the island have been severely degraded in last decade (TCEMP Report, 2009; Mumby et al, 2006; 2007) and with such a significant portion of the island's economy based on tourism derived from the reefs themselves (TCEMP Report, 2009), regeneration of damaged reef systems can be considered a beneficial solution to this problem. In configuring the parameters for rehabilitation site selection, significant research was undertaken in regard to the viability of rehabilitation efforts as well as the success of similar projects in other areas (Rinkevich, 2005; Seamann, 2007; Chuo, 2009; Buddemeier, 2004; Goreau, 2005; Koenig, 2001; Goreau and Hilbertz, 1996). Positive results were found in many cases and the parameters for site selection were adjusted accordingly.

The rehabilitation sites selected will fall under one of two categories – 1) Heavily degraded sites in close proximity to healthy reefs; and 2) Moderately degraded sites which fall within areas of healthy reef systems. The method of rehabilitation undertaken at each site will vary depending on which of these categories the site falls under. For example, heavily degraded sites will require rehabilitation methods which are more intensive and thus require methods such as transplanting of coral fragments and / or the use of stimulating processes (electrolysis etc); while sites which demonstrate less severely damaged benthic cover and are located within healthy reef systems may respond well to less intensive methods such as substrate modification and other cost effective solutions. In both instances however, the rehabilitation sites will be heavily restricted in regard to activities occurring in the area. As previously mentioned, all surface activity will be prohibited in these areas to encourage the reef to regenerate without the threat of anthropogenic disturbance.

In this regard, the costs associated with declaring an area as part of the Rehabilitation Zone are much higher. By tuning the parameters for Zone Boundary Cost, Marxan's output encourages the location of Rehabilitation Zones to be in close proximity to Conservation Zones (i.e. healthy reefs). This facilitates the regeneration of degraded areas adjoining healthy systems; as the reefs regenerate and become self sufficient, the restrictions over that particular area may be lifted and the area can then be re-zoned for Conservation. This process will subsequently continue (restricted only by available resources) onto another part of the reef thereby increasing the extent of the healthy systems (Figure 11 below demonstrates this concept). The rehabilitated areas will now become available for recreational use however, fishing activity will still be restricted.

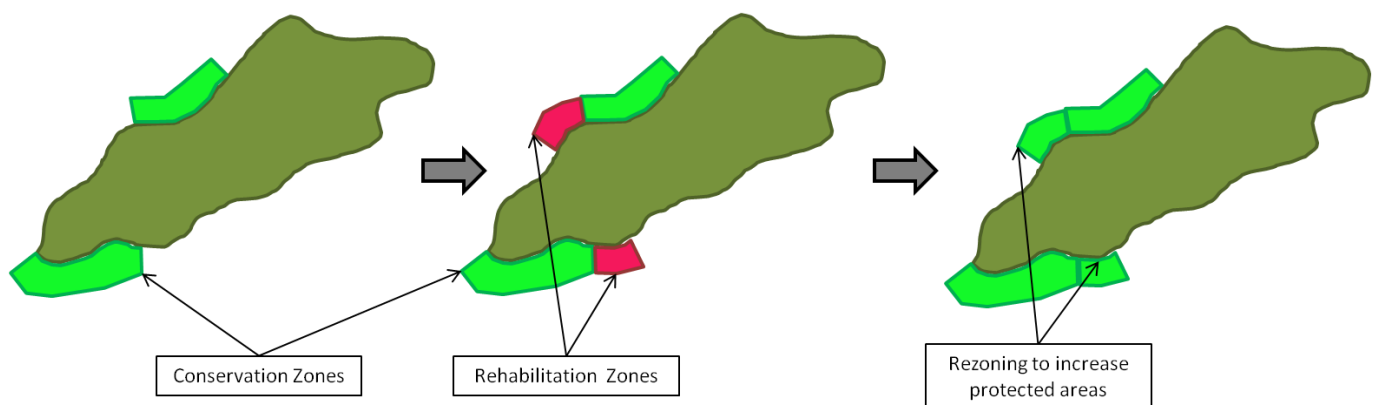


Figure 11– Rezoning of Rehabilitation areas to form part of a larger Conservation Zone

5.2 Limitations to the analysis – Potential improvements and steps forward for Tobago

Cost Analysis and Stakeholder Involvement

As previously mentioned, the calculation of the cost layer was done based on data derived from a single count of surface activity in a particular location. The Marxan algorithm is significantly influenced by the costs of the planning units and therefore, it is beneficial to ensure that the costs allocated are quite comprehensive and take into account all relevant stakeholders. For the purpose of this analysis, the data available to calculate costs was relatively limited and could not accurately depict the surface activity occurring throughout the study region.

Future studies should incorporate a more detailed analysis of the areas of the reef which are utilised for particular activities including tourist activities, dive operators, fishing (commercial and artisanal) and other recreational users. The analysis ideally will be done over the period of several years to gain an in-depth understanding of the areas of the reef which are more highly visited than others particularly on a seasonal basis. The analysis will need to incorporate a method of determining the economic value of a particular planning unit in terms of the revenue which stands to be lost if that planning unit is placed into a restrictive zone. The methods involved would include regular site surveys as well as consultations with tour operators, local fishermen and other interested stakeholders.

Species Distribution Mapping

The other significant factor which influences the output of the Marxan algorithm is the distribution layers for the relevant Features identified in the analysis. Accurate feature distributions enable the algorithm to determine the most cost effective configuration to achieve maximum representation of targets. For the purposes of this analysis, species distributions were derived using the Kriging Interpolation method (see Methods section above).

Species distribution modelling is a very well documented field of study and several authors have devoted years to developing detailed statistical models to determine near accurate distributions of several species globally (Valverde, 2008; Elith and Leathwick, 2009; Elith and Leathwick, 2009; Marmion, 2009). For the purpose of this analysis, the Kriging method was considered adequate in establishing a basic distribution model given the data provided however, the process outlined in this paper stands to benefit significantly from a more in depth distribution model.

Further improvements may include individual species distributions, subsequent seasonal variations, and identification of spawning grounds where practical. This information will be useful in determining the priority of conservation areas with regard to the significance of the species in question. More detailed analysis will facilitate the potential for incorporating seasonal closure of sensitive areas during spawning seasons to encourage more sustainable fisheries and resilient systems.

Setting Parameters

Once provided with in-depth cost and distribution layers, the most important step in any Marxan analysis is the fine-tuning of the parameters. The parameters drive the calculations made by Marxan

and ultimately determine the final configurations of the zoning plan. Alterations to all parameters can be made easily through the use of Marxan's user-friendly interface – Zonae Cogito (Watts et al, 2009). The interface allows users to interact with the various input parameters and to repeatedly run the Marxan algorithm and view outputs on screen (Watts et al, 2009).

The parameters set in this analysis i.e. representation targets, zone targets, zone contributions etc; are all based on a subjective analysis of the problem and facilitated by research into viable targets for representation. The parameters were initially set at the default values and adjusted until an appropriate solution to the relevant issues outlined was achieved. The results of the analysis are indicative only and may not represent the ideal outcomes required by key stakeholders and policy makers in Tobago; they are however considered by the author to be an appropriate solution given the data provided.

In order to achieve a solution appropriate to the context of the issues in Tobago, consultations with relevant stakeholders and policy makers will be required. Additionally, detailed ecology reports pertaining to the ecosystems present throughout the island will aid in determining adequate representation targets to facilitate sufficient population viability and regeneration where necessary.

5.3 Implementation of Results – Complications and alternatives

The results of this analysis should not be taken as the final and only solution but should be used by decision makers as an initial point from which to begin further negotiations. Implementation of the prescribed marine park system will not be ideal for all stakeholders involved and adequate consultation among the relevant parties will further augment the configuration of the zones. The plans will then be required to undergo public scrutiny and comment from which further changes will undoubtedly be made.

For the purposes of initial consultations and determining a basic layout for the marine park system, the selection frequency output maps (Figures 8 and 9) prove to be very useful. These maps illustrate which planning units were selected most often in all Marxan's iterations. This information is useful in identifying the most viable areas for locations of each of the zones. As shown in Figure 8, the selection frequency for the Conservation Zone was very dispersed throughout the study region indicating several potential areas for establishing marine parks. While not overly prescriptive, this map offers a range of options which can be taken to stakeholders for their opinions and input.

Similarly, as shown in Figure 9 above, the selection frequency for the Rehabilitation Zone demonstrates several key locations for implementing rehabilitation projects. As previously discussed, the parameters set for including sites in the Rehabilitation Zone were more prescriptive in regard to the characteristics of the areas to be included. Subsequently, the potential rehabilitation sites identified were far more concentrated in specific locations. Again, this gives decision makers a good indication of where the most viable locations for rehabilitation projects occur and through further discussions with relevant parties, may decide on one or several sites at which to undertake regeneration projects.

Additionally, an important aspect to consider in the implementation of the prescribed zoning plan, is the limitations in the ability to enforce the zoning regulations. Delegation of reef areas into a particular restrictive zone is rendered useless if users of the area do not abide by the regulations prescribed within that zone. In this regard, zone configuration must incorporate characteristics

which promote practical and effective implementation. Marine parks should be established at a size which is easily manageable given the resources available even if this means that some representation targets are not met. To achieve this, a Marine Park Staging Plan can be designed allowing certain areas to be initially designated as Conservation Zones and additional areas added over the course of a pre-determined timeline. Such an approach will mitigate against potential community outrage as the concept of the park restrictions will be slowly integrated into the functioning of the community.

Further to this, the marine parks should be established in areas which are easily accessible and can be serviced without excessive resource use. In this regard, parks should be located in areas which can be easily discernible from mainland vantage points to allow regulators to observe any activity occurring the parks. To supplement this, established marine parks should incorporate adequate visual demarcation to ensure that users are fully aware of the extent of the respective zones as well as any regulations governing the area.

To ensure that the prescribed zoning plan is achieving positive results in regard to the health of biodiversity on the reefs, a detailed and regular monitoring program must be implemented throughout the region in order to assess the ongoing success of the marine park. Monitoring should include, but not be limited to observations of commercial biomass found as well as changes to benthic cover particularly in rehabilitation areas. Regular assessments should be analysed by decision makers to determine the effectiveness of the parks and whether further restrictions need to be implemented or if additional parks should be incorporated. Results of all monitoring programs should be publicly announced to notify the local communities of the progress of the plans and to further promote the implementation of similar programs in the region.

5.4 Recommendations based on Results

Based on the results of this analysis, it is recommended that a Marine Park Zoning Plan be implemented throughout the study region following that outlined in the Marxan with Zones output for the Best Solution. In this regard, the following conceptual plan is proposed.

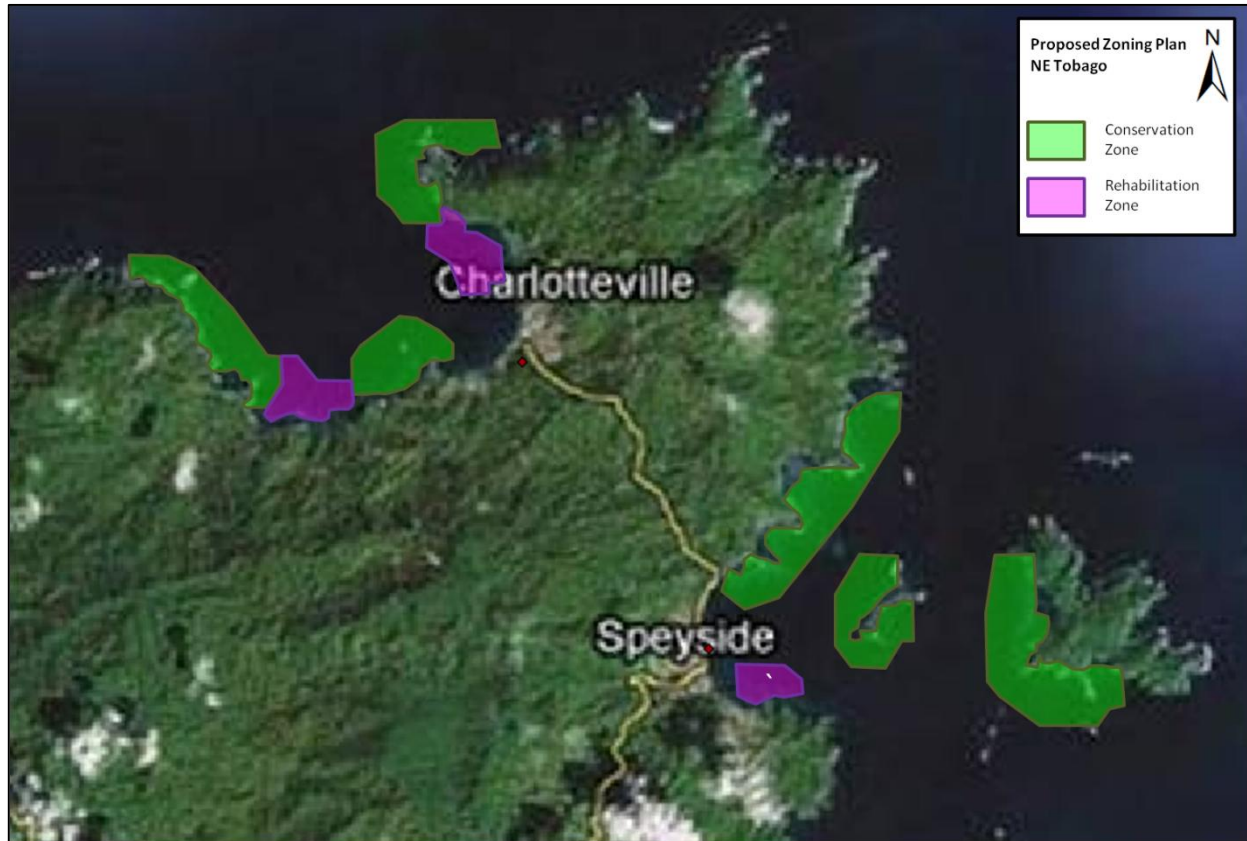


Figure 12 – Conceptual Marine Park configuration for Northeast Tobago

The proposed Marine Park Plan generally follows that prescribed in the Best Solution Output however varies to conform to the effective management criteria mentioned previously. The location of marine parks are to be in areas easily discernable from mainland vantage points as well as the relevant zones are established in easily manageable sizes.

To facilitate further ease of management, a general guideline should be established whereby all conservation areas are taken as a consistent distance from the shoreline – i.e. 300 – 400 metres. This will set a standard throughout the study region and ensure all users adhere to well known conservation guidelines.

In the case where resource availability limits the implementation of the marine park plan, a proposed staging plan will seek to establish the reserve areas on the eastern coastline and surrounding Goat Island and Little Tobago as a priority, given that these areas represent reefs in a relatively healthier condition and are more frequently visited by tour operators, dive charters and other recreational users. Subsequently, the conservation areas on the east coast may be established with rehabilitation projects being implemented in the final stage of the program.

6.0 Conclusion and Acknowledgements

This report has sought to develop a method for establishing a marine park system in Tobago, West Indies. The analysis was conducted using the concepts of Systematic Conservation Planning through the use of Marxan with Zones to determine the most effective marine park configuration which achieves a set of representation targets for minimal cost.

The data used was collected by the Coral Cay Conservation during their Ecosystem Mapping Project undertaken from March 2007 to April 2011.

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