

TOBAGO COASTAL ECOSYSTEMS MAPPING PROJECT

FINAL REPORT

Results of Community and Scientific Work

April 2007 – June 2011



Coral Cay Conservation

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Executive Summary

On the invitation of the Tobago House of Assembly and in partnership with several local Non-Governmental Organisations including the Buccoo Reef Trust and Environment Tobago, the Tobago Coastal Ecosystem Mapping Project (TCEMP) was initiated in March of 2007, by Coral Cay Conservation, a UK-based NGO. One of the key objectives was to collect extensive baseline and monitoring data on the health of the island's coral reef, mangrove and seagrass habitats. Between April 2007 and June 2011, Coral Cay conducted 927 baseline surveys of the coastal marine habitats around Tobago. This information has been summarised and used to develop spatial outputs in support of effective conservation management initiatives.

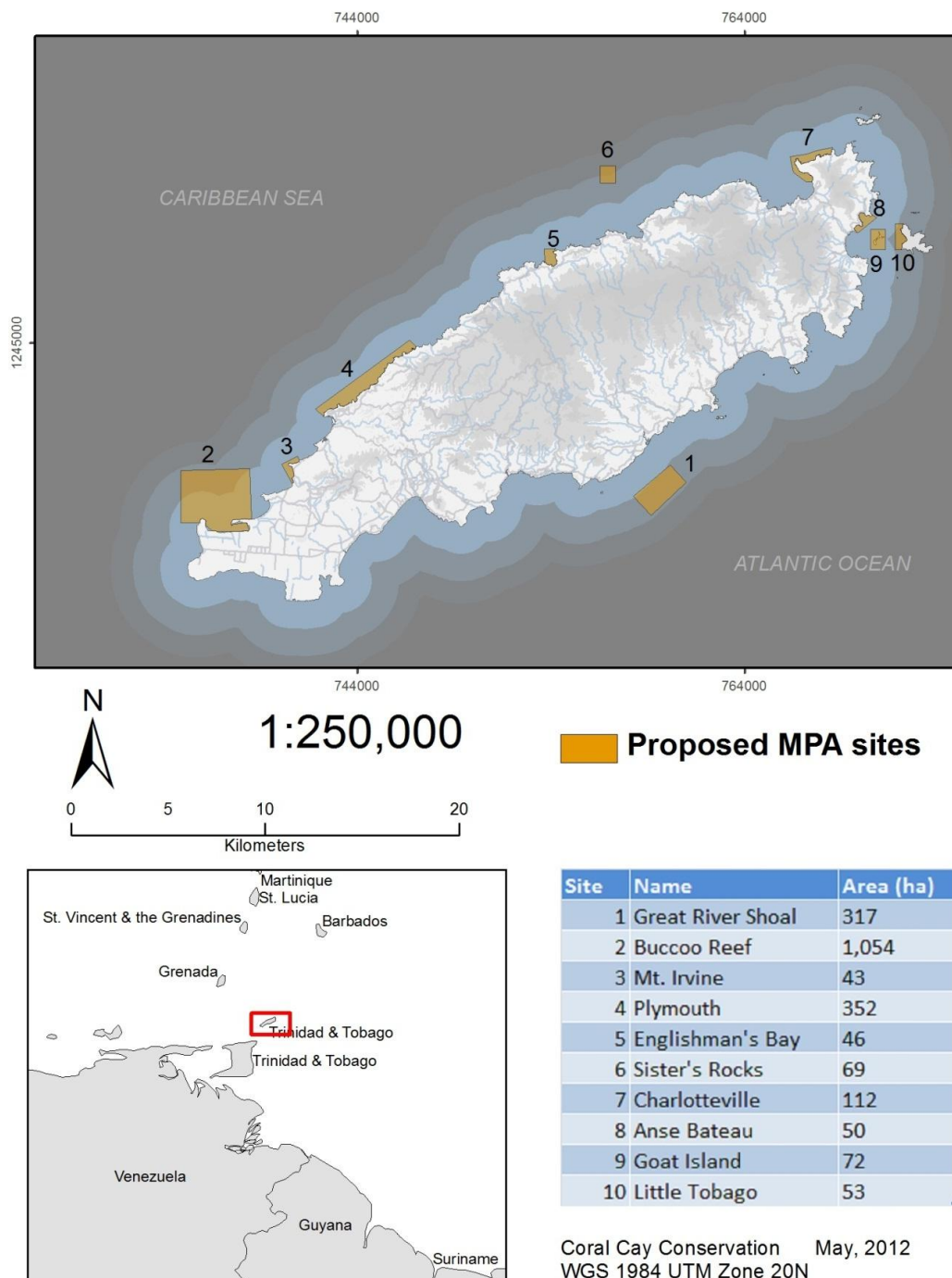
In addition to the scientific data collection, the TCEMP successfully ran a wide variety of environmental awareness raising campaigns in addition to an intensive, two or four week scholarship programme. The programme was successfully delivered to 64 scholars who received training in SCUBA diving and coral reef ecology, species identification and marine surveying.

The scientific results highlight the significant degradation that Tobago's coral reefs have suffered over the last seven years, following two subsequent coral bleaching events in the late summers of 2005 and 2010. The bleaching events have reduced coral cover and are thought to be linked to the coral disease outbreaks that followed. While some reef sites are severely stressed, other sites including Englishman's Bay, Mt. Irvine and Speyside, still maintain good biodiversity and have shown signs of resilience to regional impacts.

Based on scientific findings in this report and recommendations from other experts, the creation of several Marine Protected Areas should be made a management priority. In close consultation with local communities, an appropriate management plan should be developed and implemented to secure areas of high biodiversity and "bleaching-resilient" reefs. These sites will help to increase commercial fish stocks, improve local fisheries through a spillover of recruits and act as a source of coral recruits to downstream reefs around Tobago and potentially its neighbouring islands.

1. The creation of several no-take Marine Protected Areas as recommended in this report should be made a management priority. In close consultation with local communities, an appropriate management plan should be developed and implemented to secure areas of high biodiversity and "bleaching-resilient" reefs. These sites will help to increase commercial fish stocks, improve local fisheries through a spillover of recruits and act as a source of coral recruits to downstream reefs around Tobago and potentially its neighbouring islands.
2. Due to the likely increase in bleaching events in forthcoming years, there should be improved effort by the THA and developers to reduce coastal pollution from inadequately treated sewage effluent and sedimentation from land-based run-off of mud and silt. This will allow corals to recover from recent impacts and build the resilience of corals to future bleaching events. Particular efforts should be made to protect the upland forests and watersheds of Tobago to prevent siltation and pollution impacts on the surrounding reefs.

3. A long-term marine monitoring programme should be implemented that includes regular measurements of key parameters of environmental health (e.g. water quality, temperature, biodiversity, coral diseases, fish abundance) at fixed sites around Tobago's coastline. This data would be used to steer adaptive management practices and provide an important assessment of changes in the health of Tobago's coastal resources.
4. Continued community participation, education and capacity development will be important to improve awareness amongst Tobago's citizens about the benefits of well managed and protected coastal habitats to their livelihoods. Without this foundation of understanding and empowerment, it will be difficult to secure coral reefs for the future.

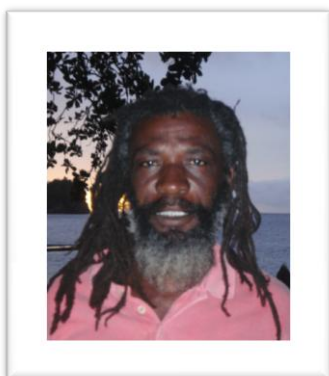


Acknowledgements

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- The Speyside Eco-Marine Park Rangers
- The United Nations Development Programme
- Global Environment Facility/Small Grants Programme
- Department of Natural Resources and the Environment, Tobago
- Department of Fisheries and Marine Affairs, Tobago
- The Integrated Watershed and Coastal Area Management in Small Island Developing States of the Caribbean (IWCAM)
- Giancarlo Lalshing and the rest of the staff at Save Our Sea Turtles, Tobago
- Jennie Mallela, Coral Reef Ecologist, University of the West Indies, Trinidad
- All the TCEMP staff and volunteers who contributed to the success of the project

This report is dedicated to Peter Trotman, who fought tirelessly to protect the natural resources of Charlotteville and Speyside but sadly passed away on the 19th of December 2011.



"All of us are contributors in one way or another; the damage has already been done. Reef resilience, if we want reef resilience we need to put proper waste management plans into place. Reason, without a healthy reef our livelihoods will be greatly affected."

Peter Trotman Former President of the Speyside Eco-Marine Park Rangers and Coral Cay Conservation Scholar.

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1. Introduction

Tobago's coral reefs are an integral part of the islands economy and cultural heritage. They provide its people with food and livelihoods through coastal fisheries and tourism, attracting thousands of visitors each year as well as providing protection against storms and coastal erosion. Coral reefs and their associated habitats furthermore provide various 'ecosystem services' such as food, shelter and a nursery grounds for many other species of commercially important fish as well as playing an important role in chemical cycles in our ocean.

An economic valuation conducted in Tobago by the World Resource Institute in 2006 estimated that the value of coastal resources derived from tourism, coastal protection and fisheries in 2006 was between \$100-130 million (Burke et al., 2008). This amounts to nearly half of the GDP for Tobago in that year and underlines the vital importance of the benefits derived from coral reef goods and services.

Disturbingly, the coral reefs of Tobago, like many of those throughout the wider Caribbean region, are in crisis (Wilkinson et al., 2010) and the overriding cause is thought to be human activity (see Mora, 2008). More than 75% of coral reefs in the Caribbean are considered threatened by human activities, with over 30% of reefs at 'high' and 'very high' threat levels (Burke et al., 2011). Tobago has been identified as a high-risk area. The coral reefs of Tobago have suffered from two mass-bleaching events in both 2005 and 2010, resulting in significant declines in coral cover and lowering their ability to cope with further stressors such as sedimentation and coral disease (van Bochove, 2010). The current rate of loss of coral reefs, mangrove habitats and seagrass beds could prove disastrous to the economy of Tobago and the livelihoods of its people. There is therefore an urgent need to mitigate local, human induced pressures in Tobago and responsibly manage the existing reefs for the benefit of future generations.

1.1 Project Background

After the 2005 Caribbean-wide bleaching event, Coral Cay Conservation (CCC) assisted the Tobago House of Assembly (THA) and the Buccoo Reef Trust (BRT) by providing technical resources and manpower to assess the extent of this event on the coral reefs of Tobago.

Following this successful collaboration, CCC and the BRT established a programme of systematic study with the THA and with support from the United Nations Development Programme (UNDP). This study, named the Tobago Coastal Ecosystem Mapping Project (TCEMP), was initiated in March 2007 with three aims, namely to:

1. Provide baseline data on the current status of coral reef, mangrove and seagrass ecosystems surrounding Tobago;
2. Increase awareness about Tobago's marine resources through environmental education programmes;
3. Build in-country capacity through CCC's scholarship programmes.

The coastal assessment programme was designed to provide relevant information for effective policy-making and management of coastal resources. Information collected was used by the Integrated Watershed and Coastal Area Management in Small Island Developing

States of the Caribbean (IWCAM) programme to provide the necessary knowledge to government bodies for effective decision making. The TCEMP also had strong community education and capacity-building components. These included training opportunities for local counterparts through the CCC scholarship programme, as well as environmental awareness programmes for school teachers and students. Such initiatives helped to increase public awareness and build lasting local capacity to assist in the effective management of Tobago's coral reefs.

The range of threats listed in the next section have resulted in widespread degradation of coral reefs in the Caribbean and an estimated decline in live coral cover from 50% to 10% over the last 30 years (Gardner et al., 2003), not including the damaging effects of the 2005 and 2010 mass bleaching events. In order to curb this trend and maximise the resilience of coral reefs to climate change events, it is crucial to minimise local man-made stressors resulting from coastal zone development, untreated wastewater discharge and overfishing. The mitigation and minimisation of these pressures can be achieved through an integrated sustainable management approach to the use of the coastal zone and its associated marine resources.

Action taken to reduce the pressures that Tobago's reefs face will give them a greater opportunity of withstanding and recovering from regional stressors such as coral bleaching. In order for management to be successful it is imperative that such initiatives strive to include all stakeholders including local and national government agencies, NGOs and resource users such as fishing communities and tourism operators. Management decisions and sustainable initiatives however, require accurate and current information on the status of the resources in question.

The ever-increasing demands placed on government agencies responsible for the management of the coastal zone requires: (1) a scientifically sound database of natural resources, (2) increased capacity to monitor local reefs and (3) improved public awareness. The TCEMP has successfully encompassed activities that address all three of these needs.

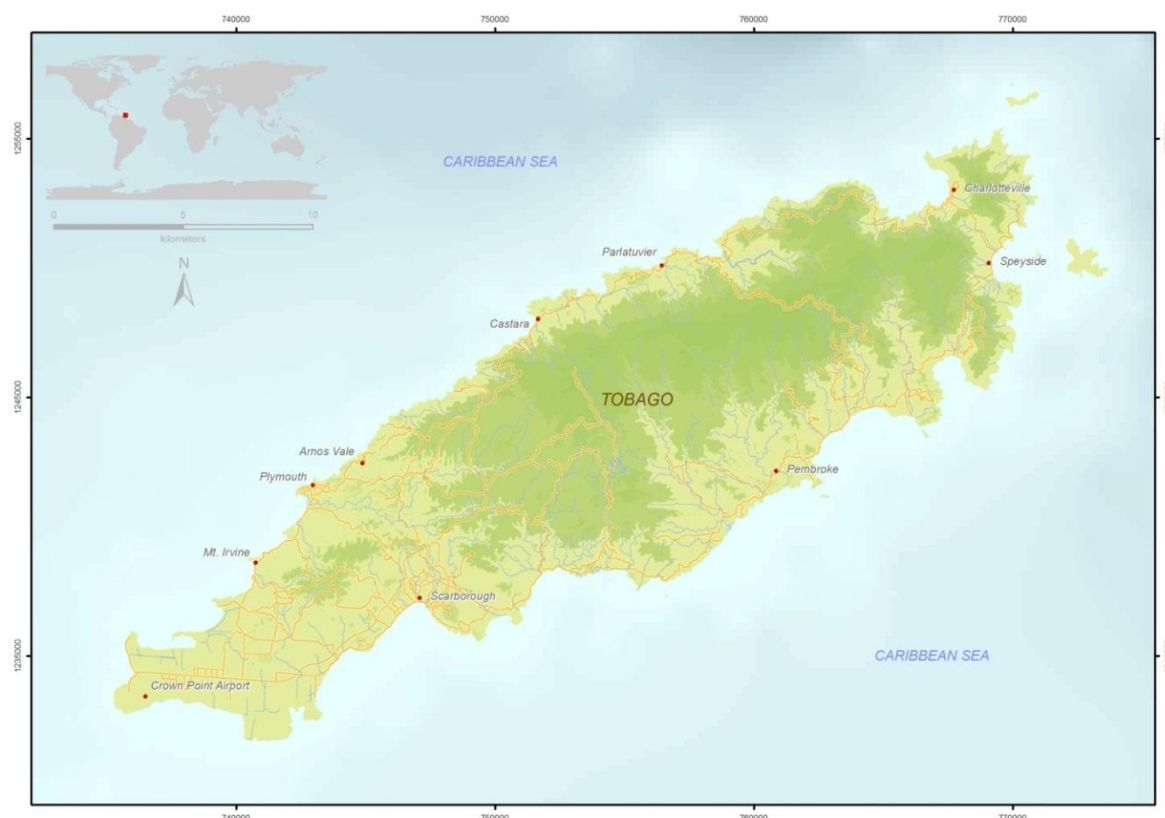


Figure 1 Map of Tobago Island, Trinidad and Tobago, West Indies. Inset: the position of Tobago in the world as red dot.

1.2 Coral Cay Conservation

Effective coastal zone management, including conservation of coral reefs, requires a holistic and multi-sectoral approach, which is often a highly technical and costly process that many developing countries cannot adequately afford. With appropriate training, non-specialist volunteer divers are able to provide useful data for coastal zone management at little or no cost to the host country (Hunter and Maragos, 1992; Mumby et al., 1995; Wells, 1995; Darwall and Dulvy, 1996; Erdmann et al., 1997). This technique has been pioneered and successfully applied by CCC, a British not-for-profit organisation.

Founded in 1985, CCC is dedicated to 'providing resources to protect livelihoods and alleviate poverty through the protection, restoration and sustainable use of coral reefs and tropical forests'. CCC works in collaboration with government and non-governmental organisations within a host country and does not charge that country for the services provided. CCC is primarily self-financed through a pioneering volunteer participatory scheme, whereby international volunteers are given the opportunity to join a phase of each project in return for a financial contribution towards the project costs. Upon arrival at a project site, volunteers undergo a training programme in marine life identification and underwater survey techniques, under the guidance of qualified marine scientists, prior to assisting in the acquisition of data. Finances generated from the volunteer programme allow CCC to provide a range of services, including data acquisition, assimilation and synthesis, conservation education, technical skills training and other capacity building programmes. CCC is associated with the Coral Cay Conservation Trust a charity dedicated to protecting coral reefs.

CCC has been successfully operating volunteer based conservation programmes in developing countries over the past 26 years with several internationally notable accomplishments, including the establishment of several Marine Protected Areas around the world. Examples of CCC successes include the creation of the UNESCO World Heritage Site in Belize, the Danjungan Marine Reserve and Wildlife Sanctuary for Negros in the Philippines, and the development of over a dozen no-take marine parks around Sogod Bay in the Philippines.

1.3 Aim of report

The primary aim of this report is to provide a basic analysis of the baseline surveys conducted throughout the four-year TCEMP. Geographical Information Systems (G.I.S.) has been used to illustrate key findings, trends and management recommendations. Baseline survey data has been displayed through spatial outputs in order to provide a summary of the main findings. Local community work and capacity building work has been summarised on a thematic basis including notable achievements.

In addition to the baseline survey effort, CCC has been monitoring the prevalence and severity of coral bleaching events and disease outbreaks that affected the island's reef systems throughout the survey period. Coral disease and bleaching data provide insight into the potential resilience of reefs sites to regional impacts, making it an important aspect of the survey programme.

The large extent of the data collected means that we have not aimed to provide an exhaustive (statistical) analysis of all the findings of the TCEMP project as doing so would dilute the report aim; to highlight key scientific finding and recommendations. Since the TCEMP project was established, numerous reports have been published. These should be seen as a supplement to the findings within this report. We also recommend consulting student thesis' reports, all of which can be found on the CCC website, www.coralcay.org. All the TCEMP data is made freely available to any third parties to use for non-commercial applications and we hope this dataset will serve as a useful baseline for future monitoring studies of the status of coral reefs around Tobago.

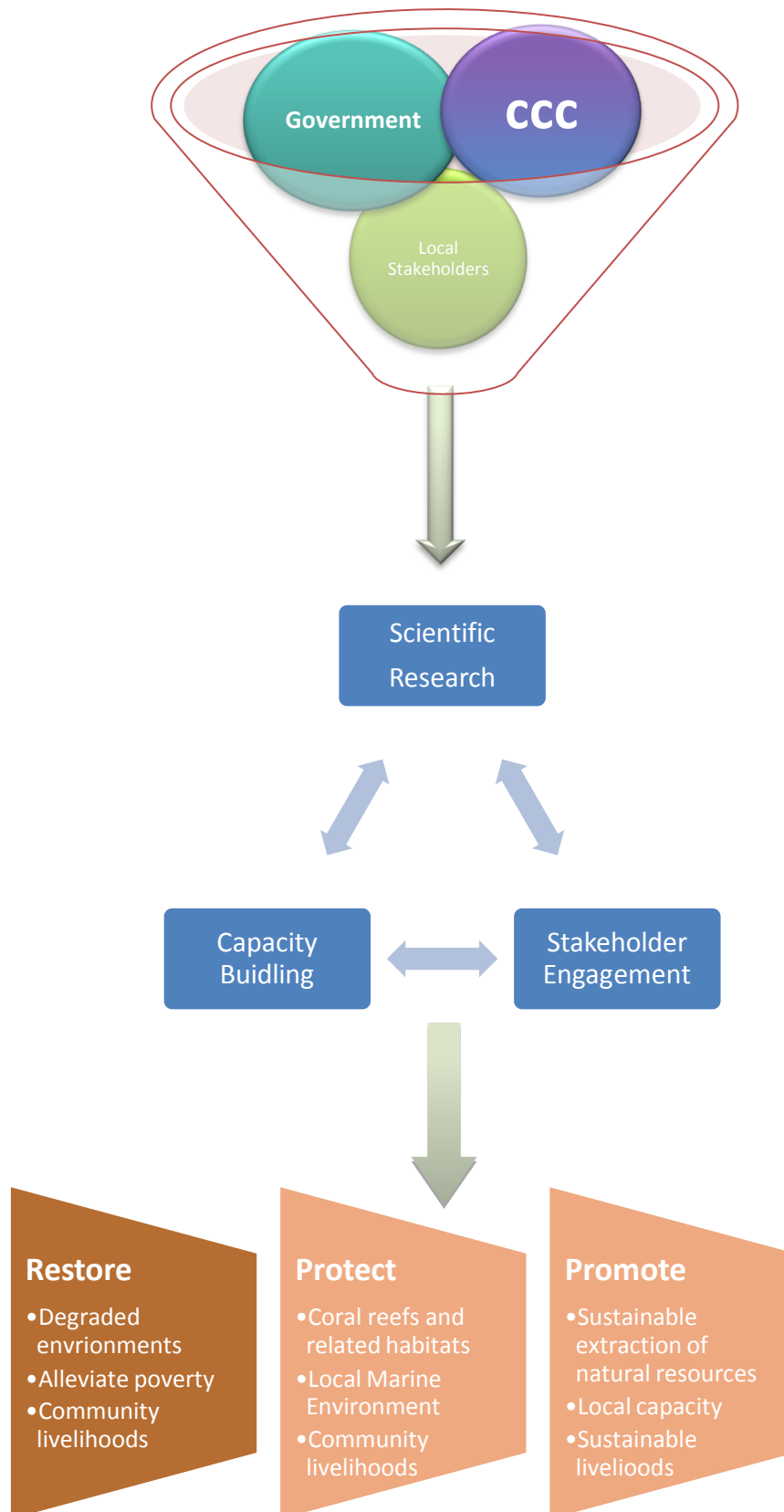


Figure 2 Flow process diagram of Coral Cay Conservation's implementation strategy.

1.4 Key TCEMP publications

In order of publication:

1. O'Farrell, S., Day, O., 2006. Report on the **2005** mass coral bleaching event in Tobago, Part 1: Results from Phase 1 Survey. Coral Cay Conservation and the Buccoo Reef Trust. 41 pp.
2. Harding S., van Bochove, J., Gibson, K.. and Raines, P. **2008**. Continued degradation of Tobago's coral reefs linked to the prevalence of coral disease following the 2005 mass coral bleaching event. Proc. 11th International Coral Reef Symposium.
3. van Bochove, J., Harding, S., Raines, P. **2008**. Tobago Coastal Ecosystems Mapping Project: Annual Report 2008. Results of Community and Scientific Work, March 2007 – July 2008. Coral Cay Conservation, London, UK 52 pp.
4. Wilkinson, C., Souter, D. **2008**. Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville, 152 p.
5. Wilkinson, C. 2008. Status of coral reefs of the world: **2008**. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, 296 p.
6. van Bochove, J., Harding, S., Head, K., Gibson, K and Raines, P. **2008**. Tobago Coastal Ecosystems Mapping Project. Results of Community and Scientific Work, March – December 2007. CCC report for IWCAM. Coral Cay Conservation, London, UK 52 pp.
7. Harding S., van Bochove, J., Gibson, K. and Raines, P. **2008**. Continued degradation of Tobago's coral reefs linked to the prevalence of coral disease following the 2005 mass coral bleaching event. Proc. 11th International Coral Reef Symposium.
8. Armstrong, H., van Bochove, J., Low-Décarie, E., Alemu, J., Raines, P. **2009**. Speyside Marine Area Community-based Management Project (SMACMP): Final Report 2009. October 2008 – September 2009. Coral Cay Conservation, London, UK 75 pp.

1.5 Threats to Tobago's coral reefs

Tobago's coral reefs are being threatened by a combination of both natural and anthropogenic factors. Threats from human activities include coastal development, sedimentation, sewage, overfishing, unsustainable tourism and land and marine based pollution stresses (Agard and Gobin 2000; Lapointe et al. 2001; Wilkinson 2008; Mallela and Harrod 2008).

Natural threats include climate change events, hurricanes and tropical storms, all of which can further impact the growth and development of the reefs. The large-scale bleaching events of 2005 and 2010 are examples of major climate change related events that have had significant, detrimental effects on the coral reefs surrounding Tobago. Some of the major issues threatening coral reefs in Tobago are described below.

Global and Regional-Scale Threats and Impacts

Carbon Dioxide (CO₂) levels in the earth's atmosphere have been rising steeply since the industrial revolution, mainly due to the burning of fossil fuels. Based on realistic scenarios of

future emissions this trend will continue and atmospheric CO₂ concentrations are expected to reach double pre-industrial levels by 2065 (Houghton et al., 2001). Coupled with this rise in CO₂ concentration, is an increase in global temperatures which are expected to rise anywhere between 1.8 – 4.0°C by the year 2100 (IPCC, 2007).

Climate change is regarded as one of the major threats to the future of coral reefs (Hughes et al., 2003). Coral reefs have evolved in relatively stable climatic conditions for the last tens of thousands of years. It is this relative climatic stability that has allowed them to develop into a complex ecosystem comprised of thousands of species and many intricate inter-specific relationships. Coral reefs can recover from acute stress (e.g. bleaching events) and also tolerate chronic (e.g. sedimentation) ones to a certain degree. However, chronically stressed reefs are far less likely to recover from an acute stress (Kinsey, 1988). A series of acute, against a backdrop of continued chronic stresses, can result in a phase shift and the replacement of the coral dominated community by one dominated by macro-algae or some other non-reef system. Such ecosystem shifts are well advanced in the Caribbean (Buddemeier et al., 2004) and in some cases; the combination of stresses has brought coral reefs to the point of local extinction. Coral reefs have accordingly been dubbed the “canaries in the coalmine of climate change”. What follows is a summary of some of the most concerning climate change induced phenomena that are predicted to have an impact on the coral reefs around Tobago.

Coral Bleaching

Coral species and their associated microscopic algae are highly sensitive creatures with a limited ‘tolerance zone’ within which they can thrive. Stressors such as increased UV light and thermal stress can threaten their survival. Coral bleaching refers to the loss of the symbiotic algae (zooxanthellae) from the coral tissue as a result of stress. Without these algae, the coral colony appears white. The zooxanthellae provide 90 % of the coral’s nutrition via photosynthesis. If a coral colony is not able to regain its population of symbiotic algae, it will starve within a matter of weeks.

Although there have been records of coral bleaching since 1870 (Glynn, 1993), extensive or regional bleaching appears to be a relatively new phenomenon, with a significant increase in the levels and extent of bleaching recorded in the past 20 years or so (Winter et al, 1998). Recent examples of corals reefs’ responses to elevated sea surface temperatures in the Caribbean were demonstrated by two large-scale regional bleaching episodes. In 1998 (*El Niño* Southern Oscillation, ENSO) bleaching effectively killed 16% of the world’s coral reefs and the mass bleaching event of 2005 resulted in an average 66% coral bleaching in the Caribbean (see Wilkinson and Souter, 2008). Such events are expected to become bi-annual within the next 20-50 years if drastic measures are not taken to reduce carbon emissions (IPCC, 2007).

Ocean Acidification

In addition to rising sea surface temperatures, another phenomenon is expected to affect the very structure and growth capabilities of hard corals through a process known as oceanic acidification. As more CO₂ is absorbed by the ocean the marine chemistry of the ocean

changes. Dissolved in water, CO₂ becomes carbonic acid, reducing the amount of carbonate available to calcifying organisms such as reef building (Scleractinian) corals that require carbonate to create a calcium carbonate (limestone) skeleton. In the last 200 years the surface ocean has absorbed about half of the CO₂ produced by industry, causing a fall in pH of 0.1, which equates to a 30% increase in H⁺ ion concentration (Royal Society, 2005). The predicted changes in seawater chemistry could have severe consequences for calcifying organisms, making it increasingly difficult for hard corals to maintain their limestone skeletons (Orr et al. 2005).

Coral Diseases

Disease outbreaks and subsequent mortality among corals and other reef organisms have been a major cause of the recent increase in coral reef degradation (Buddemeier et al., 2004) and in Tobago, coral diseases are a major contributor to coral reef degradation and decline following the 2005 bleaching event (Harding et al., 2009). The incidence of coral diseases has been linked to thermal stress (Bruno et al., 2007) which coincide with local reports of disease outbreaks following bleaching events, as is the case in Tobago (see van Bochove et al., 2008). There is a lack of knowledge about the causative agents of many diseases affecting corals. However some studies that have investigated coral diseases have shown that microbial pathogens are a source of diseases such as yellow band disease, Black band disease, aspergillosis and White-band disease (Cervino et al., 2004). The latter disease is responsible for more than a 90% reduction in populations of Elkhorn (*Acropora palmata*) corals, which was once the dominant shallow-reef building coral in Tobago but is now listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as an endangered species (Laydoo, 1984). Some of these pathogens have been linked to sewage and agricultural outputs (Voss et al., 2006, Smith et al., 1996) providing strong evidence for the effectiveness of proper waste management schemes in order to minimise disease impacts on coral reefs.

Precipitation and Storm Damage

Another concerning effect of global climate change is the expected dramatic changes in weather systems. Tropical precipitation has increased over the past century by 0.2–0.3 % per decade in the 10°S–10°N region (Houghton et al., 2001). The frequency of heavy precipitation events is expected to increase (IPCC, 2007). Increases in precipitation can lower salinity and increase sediment discharge and deposition near river mouths, at times leading to mass mortalities on nearby coral reefs (Wolanski et al., 2003). Proper management and restoration of natural watersheds can greatly minimise direct runoff from rainwater.

Hurricanes are also becoming both stronger and more unpredictable (Webster 2005). Healthy reefs can recover from infrequent damage caused by tropical storms but those already weakened or under stress may degrade further and have little opportunity for recovery. The impact of natural threats has been illustrated by the destructive force of Hurricane Ivan, which caused considerable damage to coastal areas and the shallow marine environment in 2004.

Intermediate and Local-Scale Threats and Impacts

Although climate change is now considered to be the major underlying threat to tropical marine ecosystems, impacts to coral reefs are exacerbated by local, anthropogenic events. To maintain hard coral populations on reef systems around the world it will be necessary to carefully manage direct stressors such as pollution, sedimentation, overfishing and coastal development, and hope that some coral species are able to adapt to the warmer environment (Wilkinson and Souter, 2008). Studies conducted on relatively undisturbed coral reefs in the absence of direct human pressures have indicated that these reefs have a greater ability to recover from bleaching events. This was demonstrated in the remote archipelago of Chagos following the 1998 ENSO event (Sheppard et al., 2008).

Threats to reef health, caused by local anthropogenic factors include:

- Changes in water quality due to input of nutrients
- Siltation from construction, dredging and runoff from upland deforestation and agriculture
- Overfishing to the extent where key groups of species are removed and it is no longer sustainable.

These are briefly discussed below.

Nutrification

Coral reefs thrive in regions often referred to as the '*marine deserts of the tropical oceans*'; in which the waters are clear and devoid of nutrients. The addition of nutrients from land-based agricultural runoff and/or untreated sewage discharge can modify the dynamics of the ecosystem which can promote the growth of phytoplankton and seaweeds (macro-algae), the latter of which can out-compete corals for space and light. This effect is further exacerbated if overfishing removes key herbivores that normally help to keep algal populations in check. Consequently the physiological resistance of corals is adversely effected which makes them more susceptible to disease. Recent studies have identified a link between increased nutrient levels and the rate at which coral diseases spread (Voss et al., 2006).

Sedimentation

High levels of sediment from land-based sources such as vegetation removal, mining and coastal development in addition to the re-suspension of marine sediment created by dredging or trawling, can interfere with the coral polyps' ability to filter feed. Corals under stress from sedimentation have to divert much of their energy accordingly to actively removing sediment particles causing stressed corals to be more susceptible to disease (Riegl and Branch, 1995). When sediment is suspended in water, the amount of light available to the coral is limited and thus critically restricts coral growth and ultimately the coral's survival.

Due to its proximity to South America, Tobago's reefs experience major sedimentation on an annual basis from the Orinoco and Amazon Rivers (Muller-Karger et al., 1988). Consequently,

reefs are characterised by sediment tolerant coral species (Laydoo, 1991). Coral reefs in naturally turbid waters, such as many of those in Tobago, are generally more resilient to sediment loading (Larcombe and Woolfe, 1999). However, increased sediment run-off from various small-scale construction projects, upland deforestation and increased sediment loading from the Orinoco and Amazon River system are driving Tobago's corals beyond their normal threshold levels. Furthermore, Tobago is characterised by steeply sloping hills, much of which have been cleared for agriculture or infrastructure development. As a result, much of the rainwater washes off the island and onto the reefs, carrying with it mud which can smother and kill the corals (Figure 3).



Figure 3 Tobago's location relative to the Orinoco and Amazon River systems (left), topographical map of Tobago (top right), and the impact of upland development on the reefs of Charlotteville.

Overfishing

Overfishing, the unsustainable fishing or collection of marine resources, such as conch shells and lobsters, and with them, the ecosystem functions they perform, is a global problem with an extensive history of impacts across the entire marine ecosystem (Jackson et al., 2001). In parts of the Caribbean, widespread overfishing of reefs has removed many of the herbivorous fish that help maintain algal populations, which has consequently upset the competitive balance between corals and seaweeds, often leading to a fundamental change in the community. Consequently, management of fish stocks is a key component in preventing phase shifts and managing reef resilience (Hughes et al., 2007). There is now evidence that chronic overfishing of top predators such as sharks can have top-down effects on reef productivity (Myers et al., 2007).

Local stewardship of fisheries, under guidance of management experts, can be an effective means for conservation of reefs and improved local fish stocks. Recommendations, including implementing and enforcing permanent closures, seasonal protection of spawning sites, fishing equipment restrictions and catch limits can all guide effective conservation and management of near-shore fisheries.

2. Summary of Community Work and Capacity Building Programmes

This section provides a summary of the community educational work and capacity building programmes that CCC conducted between October 2009 and June 2011. Community work conducted before this period has been highlighted in previous reports.

The community educational and capacity building projects are designed to raise the environmental awareness of the local community, provide marine science training to local scholars, and strengthen ties with local counterparts and government bodies. CCC's community and capacity building programmes compliment the scientific survey effort and were a key aspect of the TCEMP project.

2.1 CCC Scholarship Programme

CCC has run three variations of the scholarship programmes in Tobago. The scholarships were open to residents of Trinidad and Tobago wishing to make an active contribution towards the protection and sustainable use of Tobago's coral reefs. This includes tourism professionals, fishermen and women, government employees, university students, graduates and educators.

The three main types of scholarships offered to community members, Tobago residents and nationals of Trinidad and Tobago were:

- **Coastal Zone Management Workshop (CZM):** A one-day course in which participants were trained in snorkeling, identification of reef invertebrates, major fish and coral groups; as well as learning about coral reef ecology, threats to the marine environment and potential management options through a series of lectures and case studies.
- **Reef Check Scuba Award:** A two-week award in which participants were certified to PADI Advanced Open Water level, trained in the identification of target marine life forms and trained in Reef Check survey techniques.
- **Reef Conservation Scuba Award:** An intensive four-week course in which participants were certified to PADI Advanced Open Water level, trained in the identification of over 300 marine life forms and in scientific survey techniques of coral reef ecosystems.

Flexible scholarship awards were also offered to local residents of Tobago, enabling scholars to continue with their work schedules and train with CCC on a part time basis.

Since the start of the project in April, 2007, 79 Reef Conservation Scholars, 20 Reef Check Scholars and 44 Coastal Zone Management Scholars were trained (Table 1).

Table 1 Summary of CCC Scholarship Programmes as part of the TCEMP.

Scholarship	Duration	PADI SCUBA Training	Science and Surveying	Participants
Coastal Zone Management Workshop (CZM)	1 Day	Introduction to Snorkeling	Identification: reef invertebrates, major fish and coral groups Discussion: reef ecology, threats and potential management of options	79
Reef Check Scuba Award	2 Weeks	PADI Advanced Open Water	Reef Check certification Identification of marine life and surveying techniques	20
Reef Conservation Scuba Award	4 Weeks	PADI Advanced Open Water	Reef Check certification Identification: over 300 marine life forms Scientific surveying of coral reef	44

2.2 Summary of Meetings and Community Activities

A key aspect of the TCEMP project was to increase community awareness and knowledge of the marine environment. A variety of educational programmes were conducted through school and community events at the CCC project site, and within the public buildings and festivals in order to impart information to all levels within the communities. This section provides some examples of the main meetings and events that CCC field staff and volunteers attended in Tobago between October 2009 and June 2011. See the past project reports, listed in the previous section, for a summary of activities conducted previously.

School Visits

CCC staff and volunteers made monthly visits to primary schools where they introduced students to coral reef ecology and conservation through fun interactive lectures which involved craft making, snorkeling and educational activities. The school visits also emphasised lessons learnt through a puppet show which proved extremely popular with the children. Other school education activities included:

- An afterschool Environmental Club, run by CCC was open to students of the Seventh Day Adventist School (SDA) and Charlotteville Methodist School. The environmental club focused on educating 6 to 16 year olds about the importance of coral reefs around Tobago and the threats they face. Attendees also had the opportunity to go snorkeling and see coral reefs first hand
- Marine lectures about turtle ecology and the threats to Tobago's sea turtles in partnership with the NGO, 'Save our Sea Turtles, Tobago'
- Coral reef exhibits at the Speyside High School Science Fair
- Competition for the best images to adorn reusable bags with presentations held at Pembroke, Ebenezer and Rosborough Primary schools, reaching over 250 students and teachers
- Waste management lectures and decorating bins distributed around Charlotteville, in partnership with students from the SDA.

- Rainforest hikes to expose children to the natural beauty of Tobago, led by one of CCC's scholars, Jace Bishop guided as part of the Environmental Club lessons
- Coral Reef Ecology Courses held at the Methodist Primary School over four days

Outreach Activities

CCC helped to provide a variety of community outreach programmes including conservation presentations, careers events and waste management projects. Many of these projects were run with the THA, Speyside Eco-Marine Park Rangers, and The Community of Speyside Marine Environment Improvement Collaboration. Further highlights included:

- A workshop run in collaboration with the Caribbean Natural Resources Institute to inspire Tobagonians to sustainably develop businesses through natural resources.
- Promoting coral reef awareness at the Tobago International Game Fishing Tournament 2010
- A Coastal Zone Management Workshop at Man O'War bay cottages including an introduction to Reef Check
- November 2009: His Royal Highness Prince Phillip Duke of Edinburgh attended a presentation by CCC summarising the work conducted by the CCC in Tobago
- A partnership between CCC and the Trinidad and Tobago Solid Waste Management Company Limited (SWMCOL) saw the donation of five metal bins to Charlottesvile, to reduce the amount of rubbish being distributed to the reefs via rivers and a competition was held at the Environmental Club at SDA to design and decorate these bins
- A clean-up of the Belle Garden Wetlands area in partnership with Environment Tobago, resulting in 150 bags of rubbish being removed
- An underwater clean-up of Pirates Bay, Charlotteville as part of the Earth Day activities



Figure 4 Selected images highlighting the community work conducted by CCC staff and volunteers, including carnivals (top), beach clean-ups (middle) and school group snorkels (bottom).

3. Scientific Methods

3.1 TCEMP Baseline Survey Programme

CCC's quantitative baseline survey technique was designed to provide a comprehensive, quantitative assessment of shallow coastal ecosystems. Surveys are performed mainly on the fore reef between 2 and 16 metres (m). Regardless of the location on the reef, the technique used does not vary. Aerial or satellite imagery is used extensively to guide the survey work in the field as this allows ground surveys to be positioned at key reef sites visible on the image.

Survey sites are located at set 'stations', every 250m along the coastline. Surveys are conducted parallel to the reef crest, which usually runs parallel to the coast. Surveys are run contiguously and in the direction of the next survey location. For example, a survey starting at site AV01 would be conducted towards AV02 (usually in a north-easterly direction for the north coast of Tobago).

The survey technique has been developed in order to make it compatible with existing, regional survey methods conducted in the wider Caribbean such as AGRRA (Steneck *et al.*, 2003) and Reef Check (www.reefcheck.org) monitoring protocols. This will allow for the comparisons of results from Tobago with other islands in the region. It also ensures that the data collected in Tobago contributes to reef status reports for the Caribbean. Survey depths have been chosen at intervals where coral cover and diversity is generally highest. In addition to this, the 7 and 12m depth bands follow the same method conducted in the bleaching surveys carried out by CCC in 2005 (see O'Farrell *et al.*, 2005). This survey technique is therefore ideal for the long-term monitoring studies of reefs around Tobago.

3.2 Survey Technique

Surveys were conducted along two 50m transects which were laid along each depth contour parallel to the reef crest for each station surveyed. Each transect was surveyed at four pre-determined depth bands: 2, 7, 12 and 16m (Figure 5). The 2m depth band was surveyed using a team of snorkelers and the other three were surveyed using teams of divers. At some locations, not all of the four depth bands were surveyed. This was due to the lack of suitable reefs present or limitations in depth.

For a summary of survey diver roles, see Figure 6. For every survey, data was collected on the abundance and diversity of fish species and families, coral cover, coral disease and benthic species and composition. Commercial and pelagic fish were further estimated into four size classes (5-10, 11-20, 21-40 and >40cm). The target species and families were selected to represent a range of organisms characterising the main functional groups present on Caribbean reefs, including sessile benthic organisms, motile invertebrates, and reef fish. See Appendix A for a full species list.

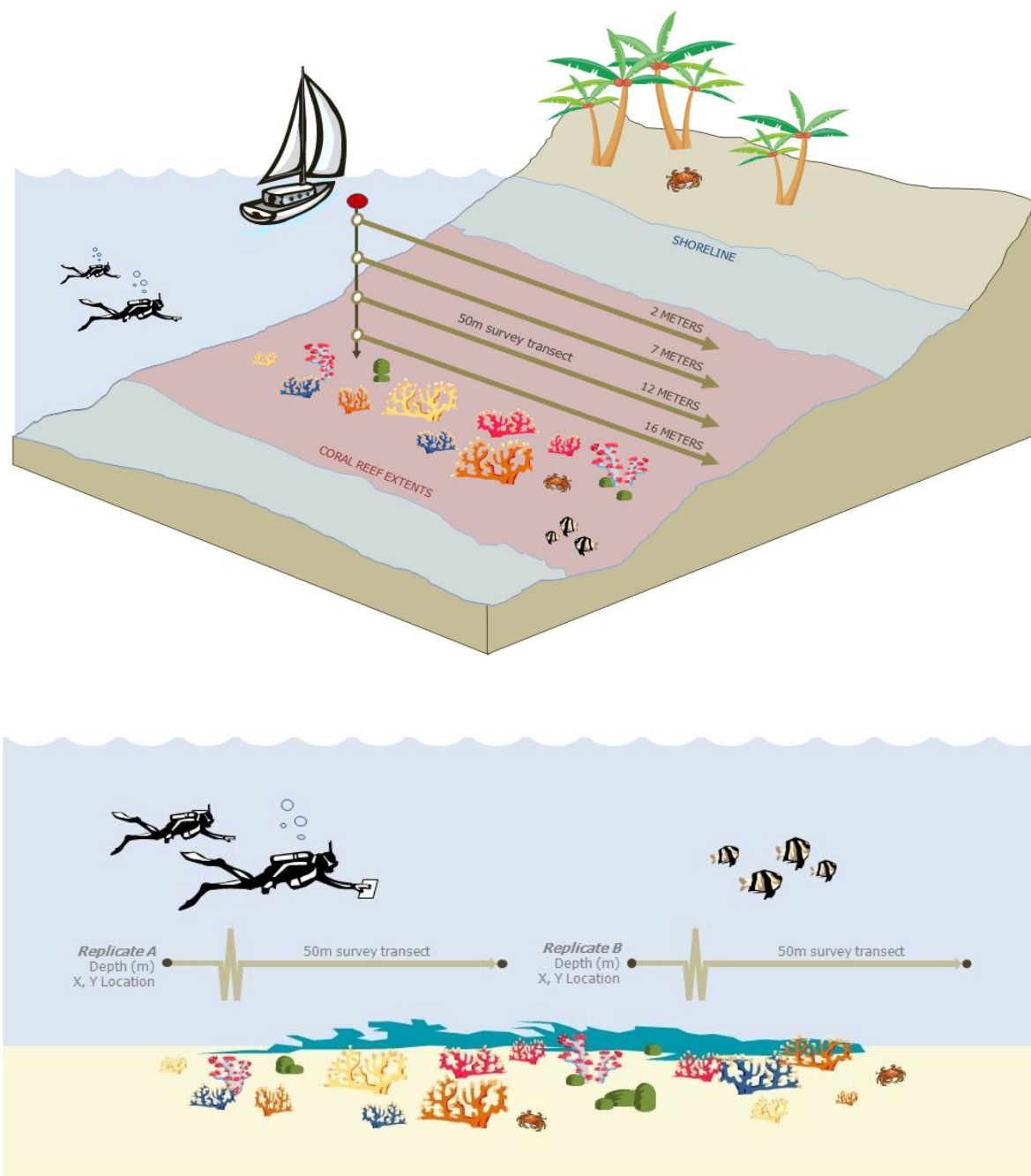


Figure 5 An overview of the baseline survey methodology. Schematic diagram of two 50m replicates (below) and transects at four depths (2, 7, 12 and 16m), parallel to reef crest (above).

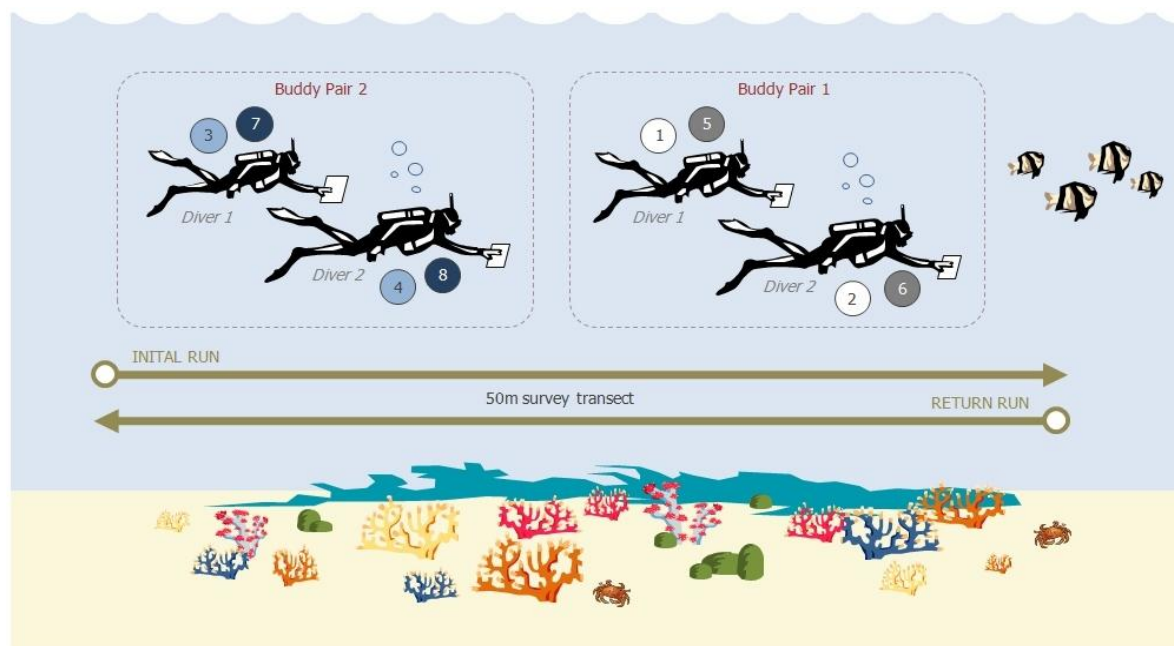
Underwater fish counts were conducted along two 50m transects at each of the survey depths. Fish were counted within 2.5m on either side of the transect (English and Wilkinson 1997). For each survey, fish abundance and size estimates were collected for all targeted commercial and pelagic fish species recorded. The abundance of demersal and more cryptic reef fish families and targeted species were recorded along the same belt transect. Fish of less than 5cm in length were generally not included unless the adult phase was less than this length.

At 50cm intervals along the 50m transect, the type of substratum or benthic organism (sessile) under each point were recorded. This was done over two 20m sections of the 50m transect with a 5m gap between sections (0-20m and 25-45m), of which each section contained 40 points. Each depth contained four 20m replicates forming a total of 160 benthic survey points.

Coral recruits and bleached corals were also recorded if they were found directly underneath a point. Coral disease and bleaching prevalence was estimated along four 10m by 2m sections along the 50m transect. Within each section, the total numbers of healthy and diseased and/or bleached colonies were estimated.

Other data collected included oceanographic data and observations of anthropogenic impacts and activities. Sea surface temperature, tide level and salinity were recorded from the survey vessel. Survey divers recorded the temperature at survey depth, reef rugosity and the reef zone. Visibility, a surrogate for turbidity (sediment load) was recorded both vertically and horizontally. A Secchi disc was used to measure the vertical visibility, while horizontal visibility through the water column was measured by divers' estimates while underwater. A water sample was taken at the survey depth to measure salinity.

Survey divers qualitatively assessed the strength and direction of water currents at each survey site. Similarly, the surface team qualitatively estimated the strength and direction of the wind at each survey site. Cloud cover was measured on a scale of 1 to 8 Octas. Natural and anthropogenic impacts were assessed both from the surface and at depth for each



INITIAL RUN

- 1 **Diver 1:** Records the abundance and size of all the targeted commercial and pelagic fish species.
- 2 **Diver 2:** Records the abundance of demersal and more cryptic reef fish families and targeted species.
- 3 **Diver 1:** Indicates to the rest of the survey team where the transect is to be undertaken, notes the abiotic factors and underwater impacts.
- 4 **Diver 2:** Responsible for correctly laying down the survey line along the pre-determined depth band.

RETURN RUN

- 5 **Diver 1:** Reels in the survey line and detaches the marker buoy at the end of the survey.
- 6 **Diver 2:** Records the prevalence of coral disease and coral bleaching.
- 7 **Diver 1:** Records the type of substratum or benthic cover.
- 8 **Diver 2:** Records the abundance of all invertebrates, sea fans, sea rods, black corals, sea plumes and anemones.

Figure 6 A summary of the baseline survey roles.

survey. Surface impacts were categorised into 'driftwood', 'algae', 'litter', 'sewage', 'nets' and 'other'. Sub-surface impacts were categorised into 'coral fragmentation', 'major overgrowth', 'fish bite damage', 'litter', 'human' and 'other'. All data was collected as 'present/absent'. Any boats seen during a survey were recorded along with information on the number of occupants and its activity.

3.3 Data Analysis

Data from each survey was recorded onto data forms and checked prior to being entered into a MS Access database, compatible with a range of Geographical Information Systems (GIS) software utilised for further data analysis (ESRI ArcGIS 10). Shannon-wiener diversity indices were generated in PRIMER-5 (Plymouth Routines in Multivariate Ecological Research). A regression analysis was used to test for relationships between depth and coral bleaching prevalence. A t-test was used to look at changes in coral cover between 2005 and 2010. These tests were performed in SPSS17.0.

Benthic data were converted into percentage cover and belt transect data (fish and invertebrate abundances) were converted into the number of individuals observed per hectare. Commercial fish abundances were converted to biomass (kg/ha) using published length weight relationships (Froese, R. and D. Pauly, 2009). A list of all target species can be found in Appendix III. Coral disease and bleaching prevalence were calculated by dividing the percentage of diseased and or bleached colonies by the total number of colonies of that coral genus/species.

3.4 Geographical Information System (GIS)

Because the location of each survey has been recorded with a GPS unit, ecological values can be imported into a Geographic Information System (GIS) to enable spatial analysis. Relationships between the data from various survey sites were investigated in order to highlight areas of interest for conservation management. The visual nature of GIS outputs facilitates the interpretation of such data by non-technical persons who may nonetheless be key decision-makers.

Surveys with less than 5% live hard coral cover were removed from further analysis. Survey results from a total of 917 baseline surveys from four depths were divided into 38 survey sectors, based on their geographic location and general proximity to each other and within a particular reef site (Figure 7, Table 2).

The GIS outputs aim to provide a general picture of the status of coral reefs around Tobago with a particular focus on the Caribbean side and Speyside areas where the majority of surveys were conducted.

To calculate the Conservation Management Value (CMV) of each survey site, an inter-survey analysis is made to determine the ecological 'value' of each survey site relative to the others (see Harding et al., 2006). To do this, the average value for each of the nine indices is calculated for each site, and these values are then used to determine the overall averages for each index across all sites. The indices used are the site record values for 1) live hard coral cover, 2) biotic (live) cover 3) reef rugosity 4) the total number of benthic targets (not including nutrient indicator algae), total number of 5) demersal and 6) commercial fish

targets, and the Shannon-wiener Biodiversity Indices for 7) benthic 8) invert and 9) reef fish targets.

The sites are then compared against these overall averages to determine the number of indices in which each site is above or below the overall average. If, for example, a site is below average in all nine indices, it would score a CMV value of zero; if it was above average in only one index, it would score a CMV value of one, and so on up to a maximum CMV value of nine (above average in all nine indices).

Note that this technique compares each site against the other sites within a region, and thus it is a *relative value* for that region only. The fact that a site is displayed as a low CMV does not necessarily mean it is biologically 'poor', but simply that there are biologically 'richer' areas in the same region.

4. Results

4.1 Baseline survey summary

Between April 2007 and June 2011, CCC survey teams conducted 927, 50m transects around the coastline of Tobago (Figure 8). This amounted to a total of 78,158 individual benthic survey records, 77,950 invertebrate records and 104,179 fish records. In addition to this, 31 coral disease surveys were completed between March and July 2008.

It is important to note that, due to the project scope and logistical and weather constraints, sectors were surveyed at different time periods throughout the three year project (Table 3). This means that results obtained from surveys conducted at the beginning of the project may no longer give an accurate representation of the status of those particular sites. Nonetheless, general parameters can be obtained to give a good representation of coral reef and fish health for each sector.

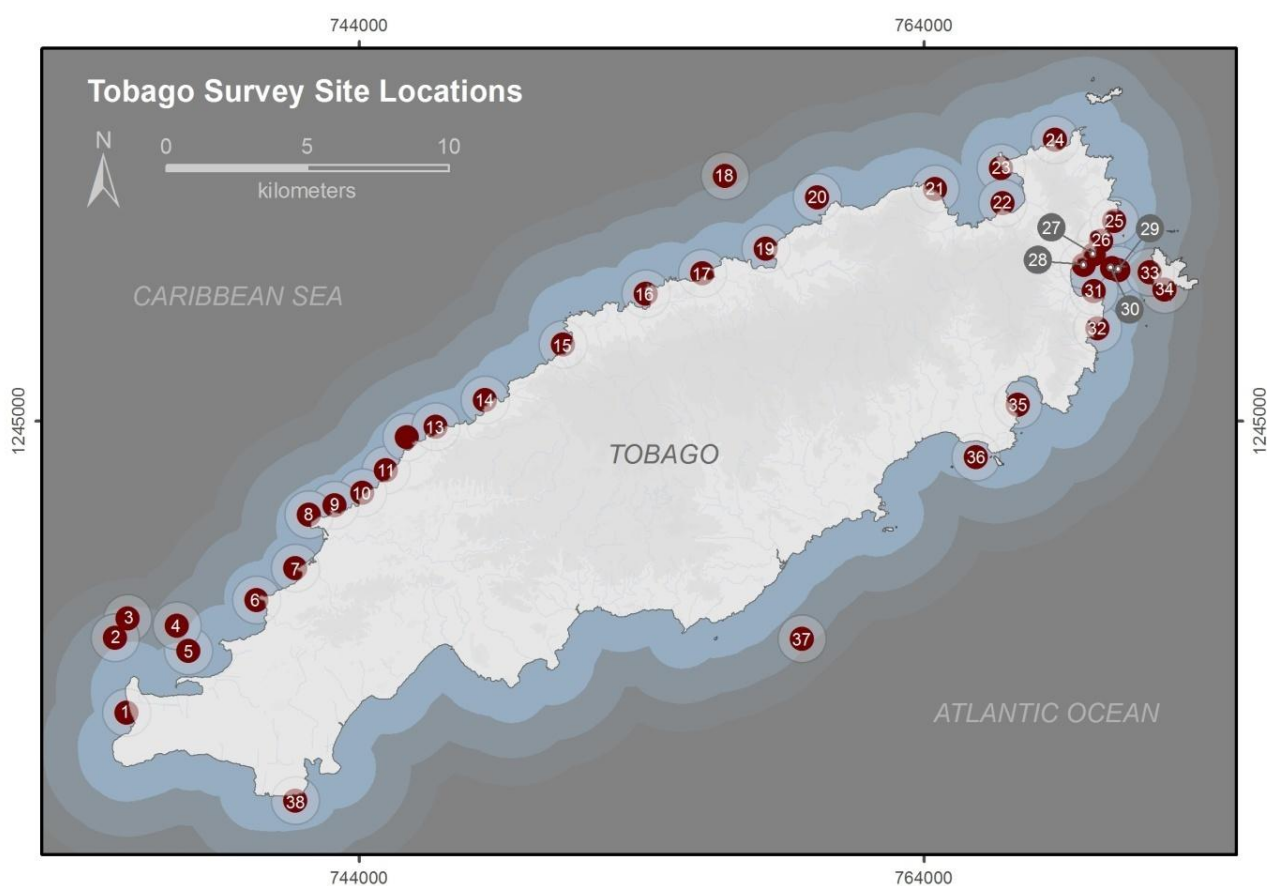


Figure 7 Locations of 38 survey sectors around Tobago, used for analysis and GIS mapping.

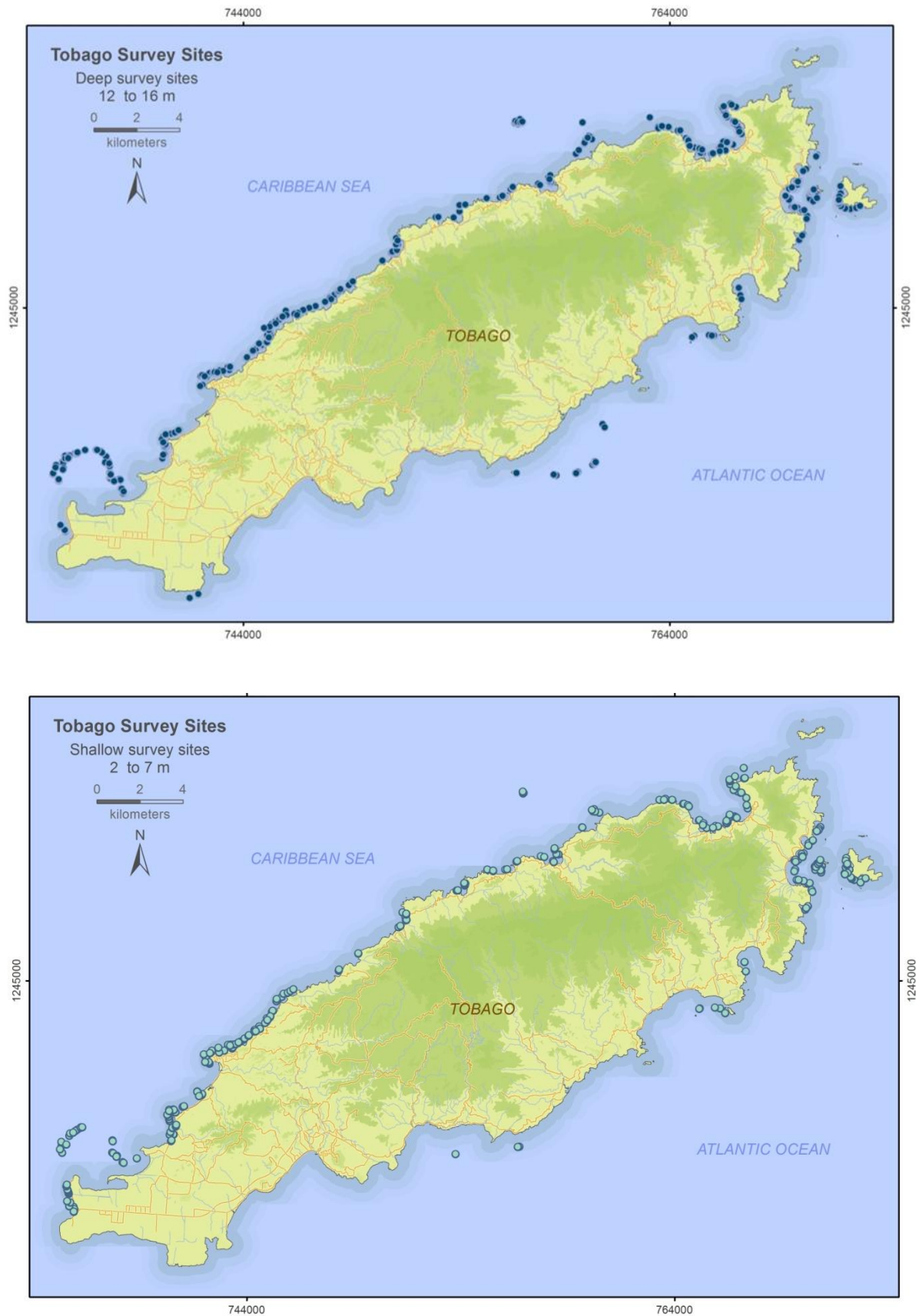
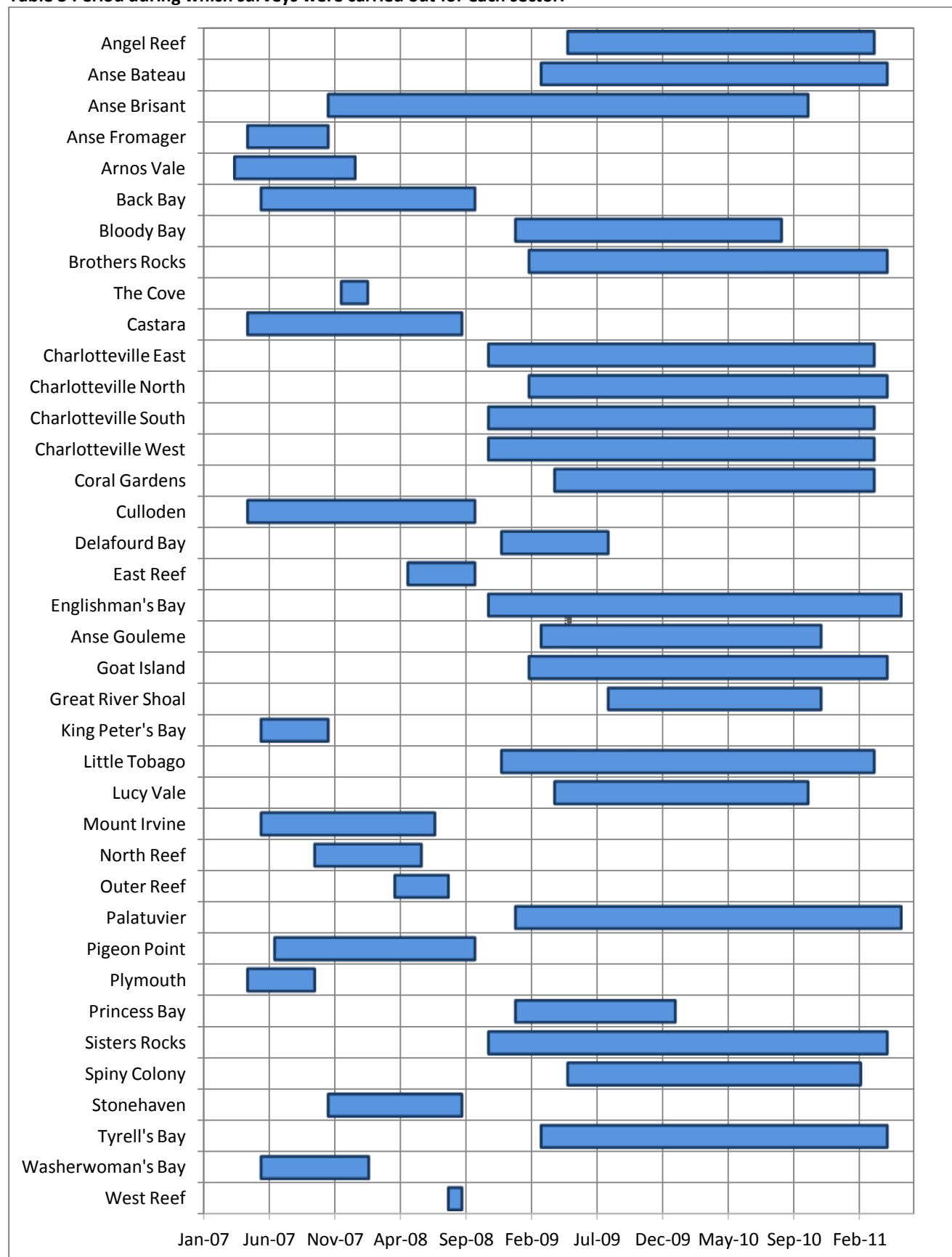


Figure 8 Baseline surveys conducted around Tobago between 2007 and 2011 sites for deep (12 and 16m) and shallow (2 and 7m) surveys.

Table 2 Survey Sector characteristics.

Sector #	Name	From	To	2m	7m	12m	16m	Total
1	Pigeon Point	Jul-07	Oct-08	14	0	4	0	18
2	Buccoo West Reef	Aug-08	Sep-08	0	6	6	2	14
3	Buccoo North Reef	Oct-07	Jun-08	0	8	9	4	21
4	Buccoo Outer Reef	Apr-08	Aug-08	0	2	13	0	15
5	Buccoo East Reef	May-08	Oct-08	0	6	10	2	18
6	Mount Irvine	Jun-07	Jul-08	6	17	18	6	47
7	Stonehaven*	Nov-07	Sep-08	2	4	0	0	6
8	Plymouth	May-07	Oct-07	2	6	8	2	18
9	Back Bay	Jun-07	Oct-08	2	8	6	7	23
10	Arnos Vale	Apr-07	Jan-08	2	8	0	2	12
11	Anse Fromager	May-07	Nov-07	2	10	12	6	30
12	Culloden	May-07	Oct-08	0	8	10	10	28
13	Washerwoman's Bay	Jun-07	Feb-08	0	0	4	9	13
14	King Peter's Bay	Jun-07	Nov-07	0	4	8	9	21
15	Castara	May-07	Sep-08	4	4	7	4	19
16	Englishman's Bay	Nov-08	Jun-11	1	12	14	4	31
17	Palatuvier	Jan-09	Jun-11	0	8	10	4	22
18	Sisters Rocks	Nov-08	May-11	0	8	11	4	23
19	Bloody Bay	Jan-09	Sep-10	0	12	12	9	33
20	Brothers Rocks	Feb-09	May-11	0	10	10	6	26
21	Charlotteville West	Nov-08	Apr-11	0	22	27	16	65
22	Charlotteville South	Nov-08	Apr-11	8	13	14	8	43
23	Charlotteville East	Nov-08	Apr-11	0	20	22	12	54
24	Charlotteville North	Feb-09	May-11	0	4	5	6	15
25	Anse Gouleme	Mar-09	Dec-10	2	4	5	3	14
26	Anse Brisant	Nov-07	Nov-10	0	6	5	0	11
27	Anse Bateau	Mar-09	May-11	0	4	4	4	12
28	Tyrell's Bay	Mar-09	May-11	3	6	6	4	19
29	Goat Island	Feb-09	May-11	1	4	7	3	15
30	Angel Reef	May-09	Apr-11	7	20	21	6	54
31	Spiny Colony	May-09	Mar-11	4	13	12	8	37
32	Lucy Vale	Apr-09	Nov-10	0	3	4	5	12
33	Little Tobago	Dec-08	Apr-11	5	16	12	8	41
34	Coral Gardens	Apr-09	Apr-11	2	14	14	8	38
35	Delafourd Bay	Dec-08	Aug-09	0	4	4	0	8
36	Princess Bay	Jan-09	Jan-10	0	8	8	0	16
37	Great River Shoal	Aug-09	Dec-10	0	2	16	5	23
38	The Cove*	Dec-07	Jan-08	0	0	2	0	2
*Limited data available		Total		67	304	360	186	917

Table 3 Period during which surveys were carried out for each sector.

Certain target taxa or abiotic categories have been shown to be effective indicators of overall reef health (Hodgson, 1999) and a number of these have been selected here to highlight findings from the surveys. Depending on the particular target category, variables can indicate impacts of coral bleaching, disease, overfishing, nutrient pollution, sedimentation, direct coral damage and the removal of organisms for the curio or aquarium trade.

4.2 Biotic cover

Biotic (living), benthic cover was used as an indicator of the overall biotic diversity of the reef site by including corals, soft corals and other cnidarian in addition to sponges, anemones and zoanthids. Macro-algae were left out of the analysis since they are more often associated as a negative impact to reef health. Highest biotic cover (>50%) was found around the north-eastern end of the island, including Speyside reefs (Figure 9). The Cove reef site also displayed high cover of living substrate.

4.3 Bare substrate

In contrast to biotic cover, bare substrate, free of macro-algae, was used as a proxy for potentially suitable substrates for coral larvae resettlement. It has been shown that in spite of recent disturbances to Tobago's reefs, corals were still successfully recruiting, albeit in low numbers (Mallela and Crabbe, 2009). Bare substrate therefore provides a useful indicator of the amount of substrate available for corals to recolonise. Bare substrate included rock, rubble, recently killed coral and encrusting coralline algae. Particularly high bare substrate cover (>40%) was found around the Buccoo reef area, indicating a die-off of corals here in the recent past (Figure 10). This is supported by anecdotal reports that much of the substrate cover around Buccoo was previously Elkhorn coral. Particularly low bare substrate was found around the Speyside area. This area also had high biotic cover.

4.4 Reef Complexity

Reef complexity was measured on a scale from 1 to 3 at every survey depth, where 3 was the highest value (highest rugosity). As complex reef architecture supports important niches and refuges for many reef fishes (see Alvarez-Filip et al.), the reef complexity of sites serves as an indication for its ability to sustain higher fish numbers and diversity. The Cove, Charlotteville North and Englishman's Bay all displayed relatively high reef complexity of over 2.5 (Figure 11). Mount Irvine and Sister's Rocks also had high reef rugosity.

4.5 Octocorals

Octocorals such as seafans, sea plumes and other branching soft corals can be locally dominant groups of benthic organisms, particularly in areas of strong current where they filter out plankton. They are also susceptible to a number of diseases, mainly *Aspergilliosis*. High abundances of octocorals were found around King Peter's Bay as well as other sites along the central Caribbean coastline of Tobago (Figure 12).

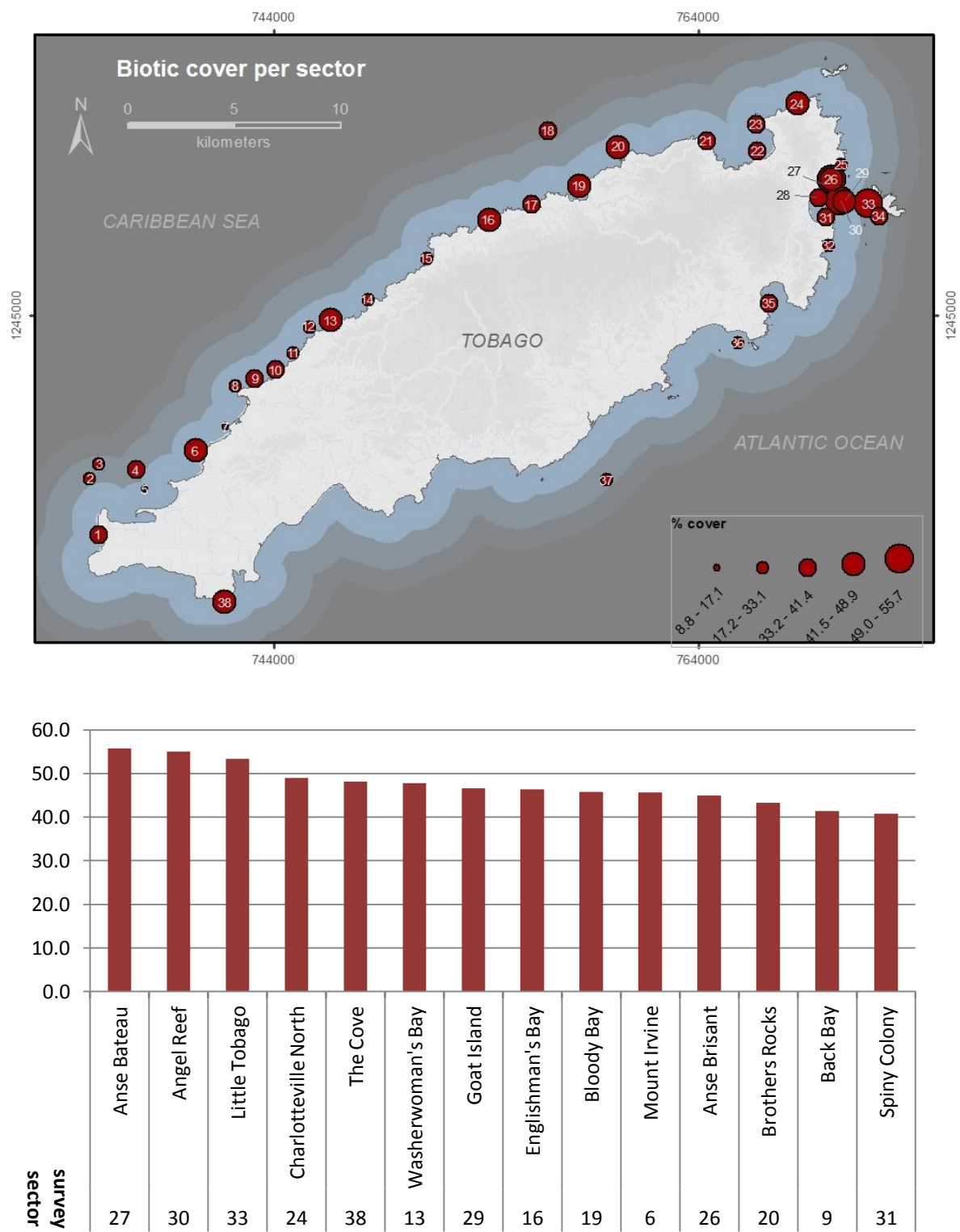


Figure 9 Map of biotic cover (%) for survey sectors around Tobago (above) and table of 14 survey sectors with highest biotic cover (below).

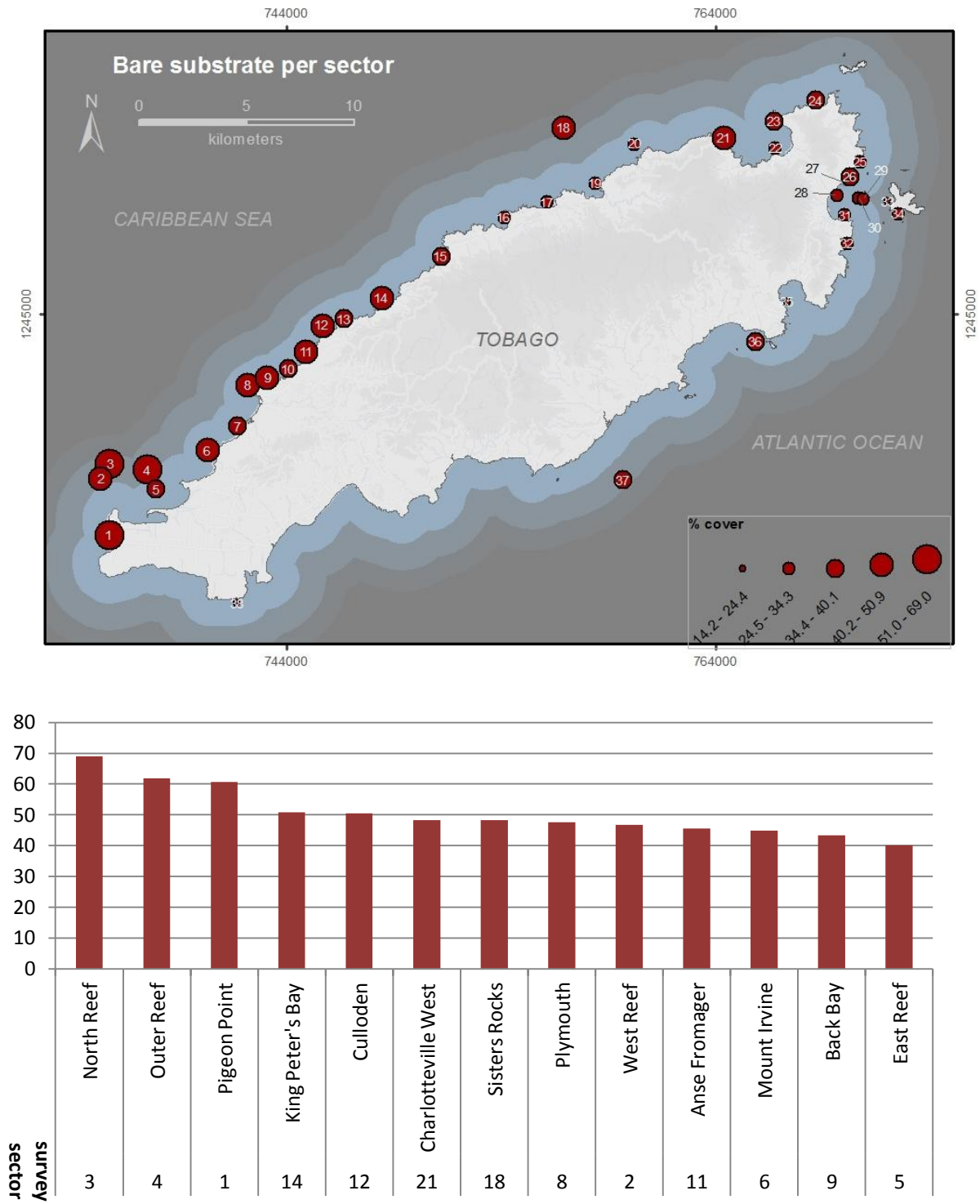


Figure 10 Bare substrate (%) for survey sectors around Tobago.

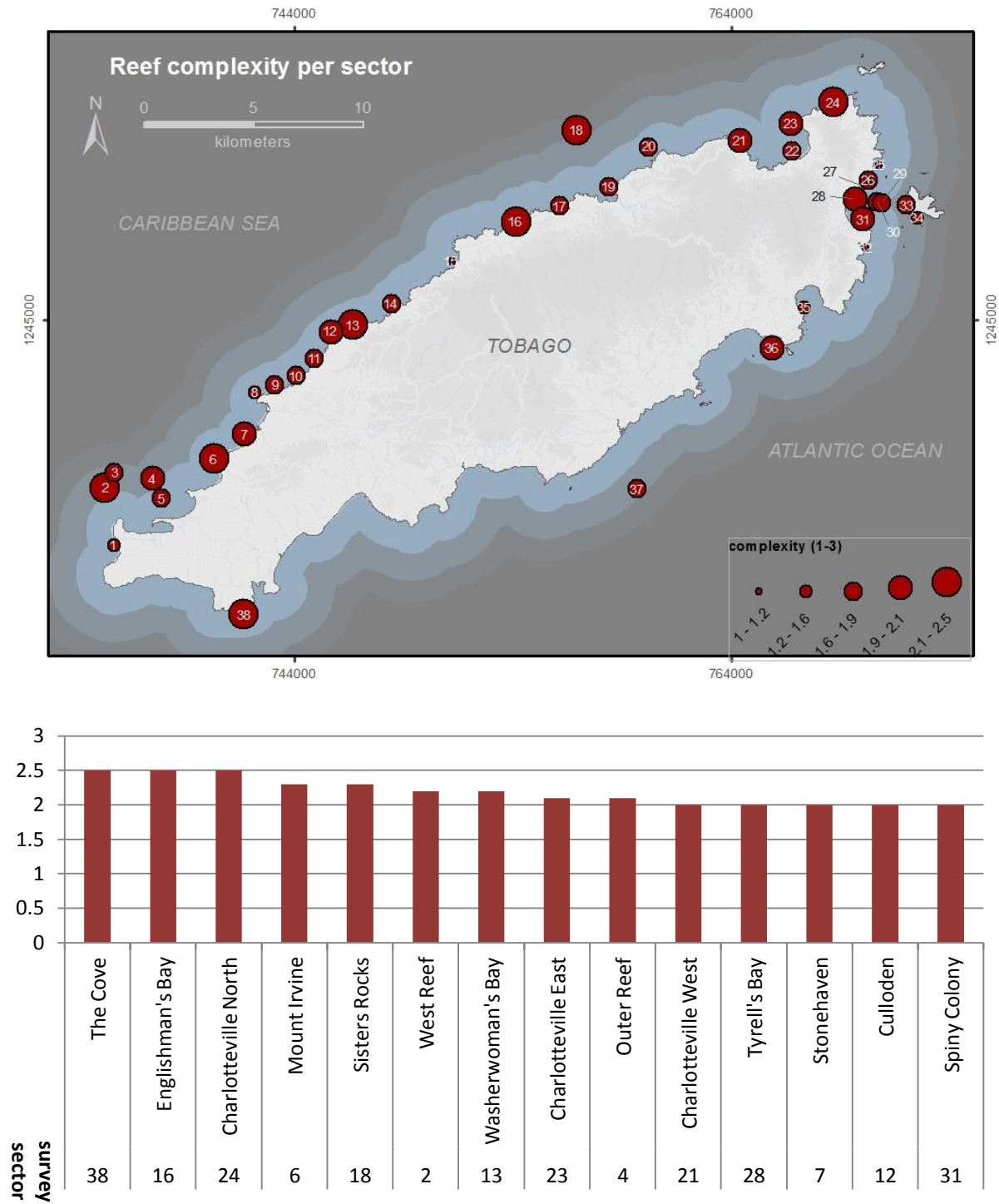


Figure 11 Reef complexity (Shannon-wiener scale) for survey sectors around Tobago.

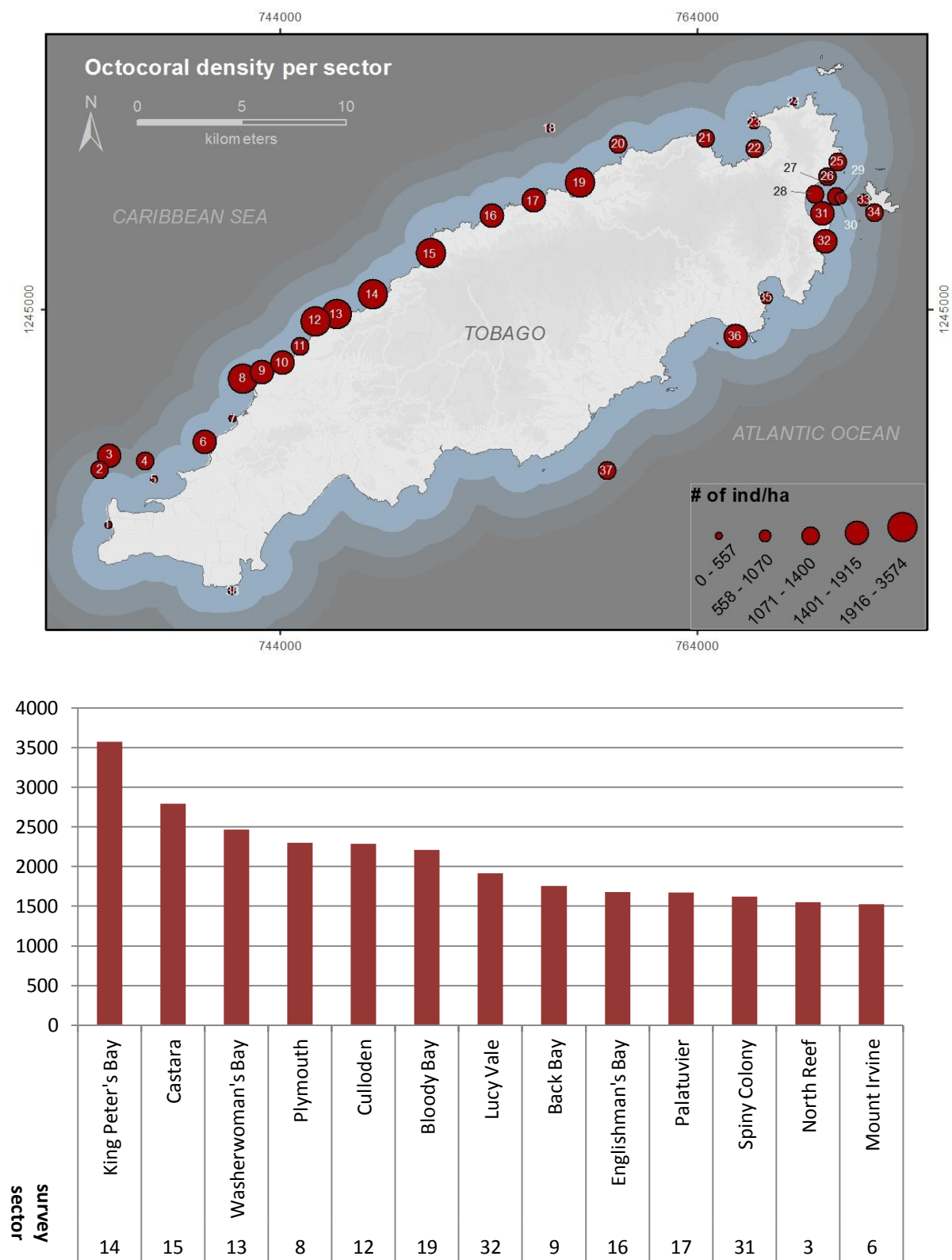


Figure 12 Octocoral density (# per hectare) for survey sectors around Tobago.

4.6 Macro-algae cover

High densities of fleshy algae can be an indicator of local eutrofication of the water. Algae often bloom adjacent to areas of high sewage outputs or land runoff. Additionally, large, fleshy algae often compete with corals and other benthic organisms for light and space. Once a degraded or polluted reef habitat is colonised by algae, it becomes difficult for coral larvae to settle back onto the reef. Reef sites with high macro-algal cover may indicate that it would struggle to shift back from an algal to coral dominated habitat. The Great River Shoal on the Atlantic side of Tobago, had notably higher (~50%) macro-algal cover than other sectors (Figure 13). These findings are in line with Mallela et al (2010) who also found high macro-algae cover on the Atlantic side (~40%). This may be due to high sedimentation from the Orinoco and Amazon Rivers rather than land-based runoff from Tobago. Most sectors displayed algae cover of less than 20%.

4.7 Coral Cover and Diversity

Live hard (scleractinian) coral cover is considered to be a good indicator of reef health, and therefore used to provide an overall impression of the current status of a particular reef site. The mean live hard coral cover ($\pm$ SD) across all surveys was 16.7% ($\pm$ SD 11.4%). The highest live hard coral cover for one survey was at 12m at Angel Reef in Speyside where corals covered up to 62% of the substrate ($\pm$ SD 11.3%, Figure 14). The indicator does not however, provide any information as to whether coral cover for a particular reef is increasing or decreasing. Monitoring information on coral cover changes on key reef sites has been presented in section 4.9 as well as previous reports. Highest live hard coral cover (>25%) was found around sites in Speyside, Mount Irvine and Washerwomen's Bay. In contrast to three other sites surveyed on the Atlantic side, Delafour Bay had relatively good coral cover (19%). The Shannon-wiener Diversity Index (H' (loge)), used for diversity analysis, and takes into account both the number of species and the area each one covered for each survey. Coral diversity was highest around Spiny Colony in Speyside (H' = 2.85, Figure 15). Washerwomen's Bay and Mt. Irvine also displayed relatively high coral diversity ($H' > 2.7$).

Table 4 displays the different taxa of hard coral recorded for all surveys. A total of 43 hard coral targets were observed with *Millepora* spp. the most abundant, comprising 14% of corals observed. *Montastrea* was the most common coral genus comprising 21% of corals seen. *Montastrea* corals (apart from *Montastrea cavernosa*, 7%) were not always identified to species level. Of the species identified, *M. faveolata* and *M. franksi* were the most abundant (6% and 3%). *Siderastrea sideria*, *Diploria strigosa* and *M. mirabilis* were also relatively abundant corals (9%, 12% and 8%). These seven species of coral dominate Tobago's north-western reefs, comprising over 60% of reef-building hard corals. Elkhorn coral, *Acropora palmata*, once a dominant coral in shallow water, was rarely observed, comprising less than 1% of shallow-water corals. For a list of all target species, see Appendix A.

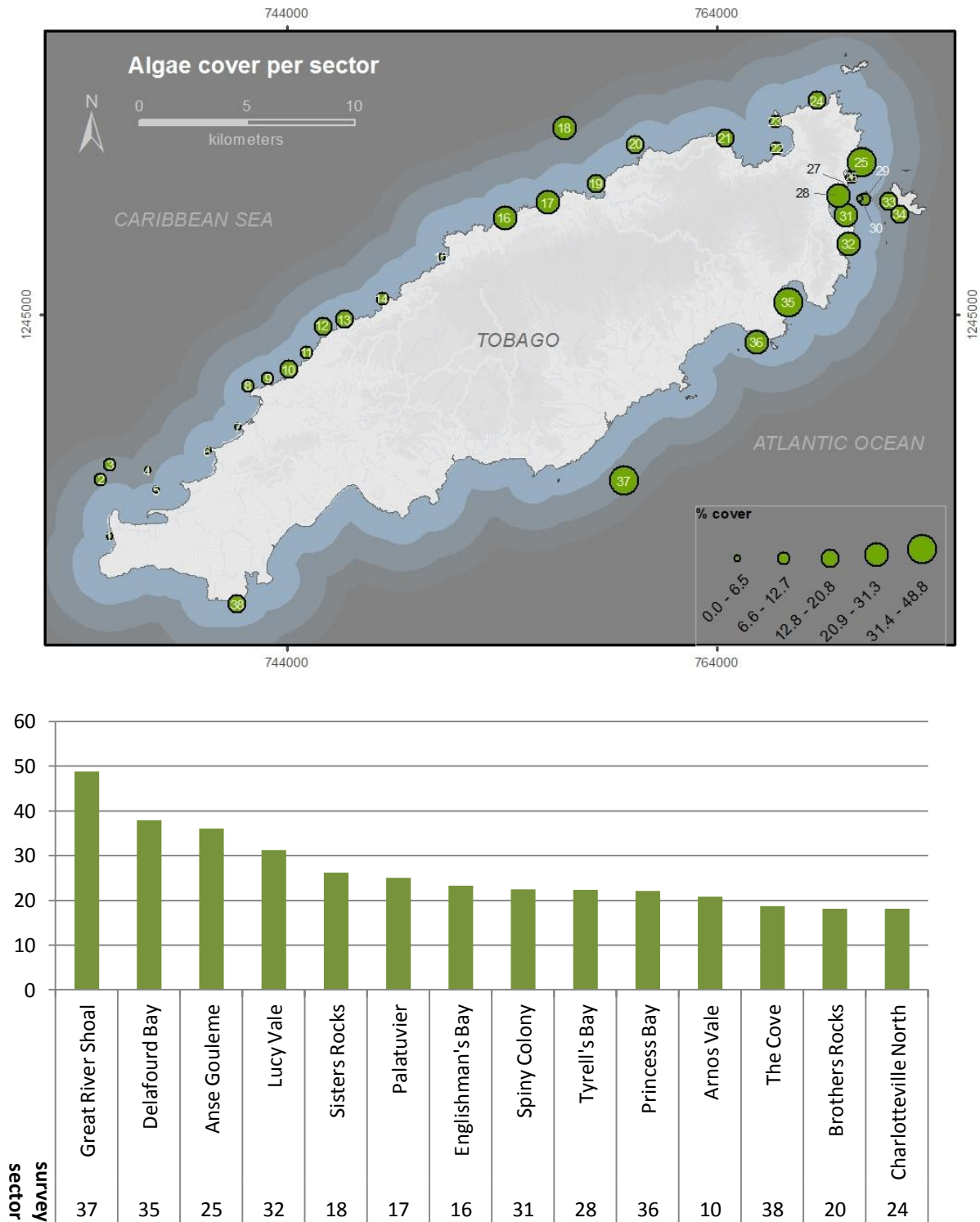


Figure 13 Macroalgal cover (%) for survey sectors around Tobago.

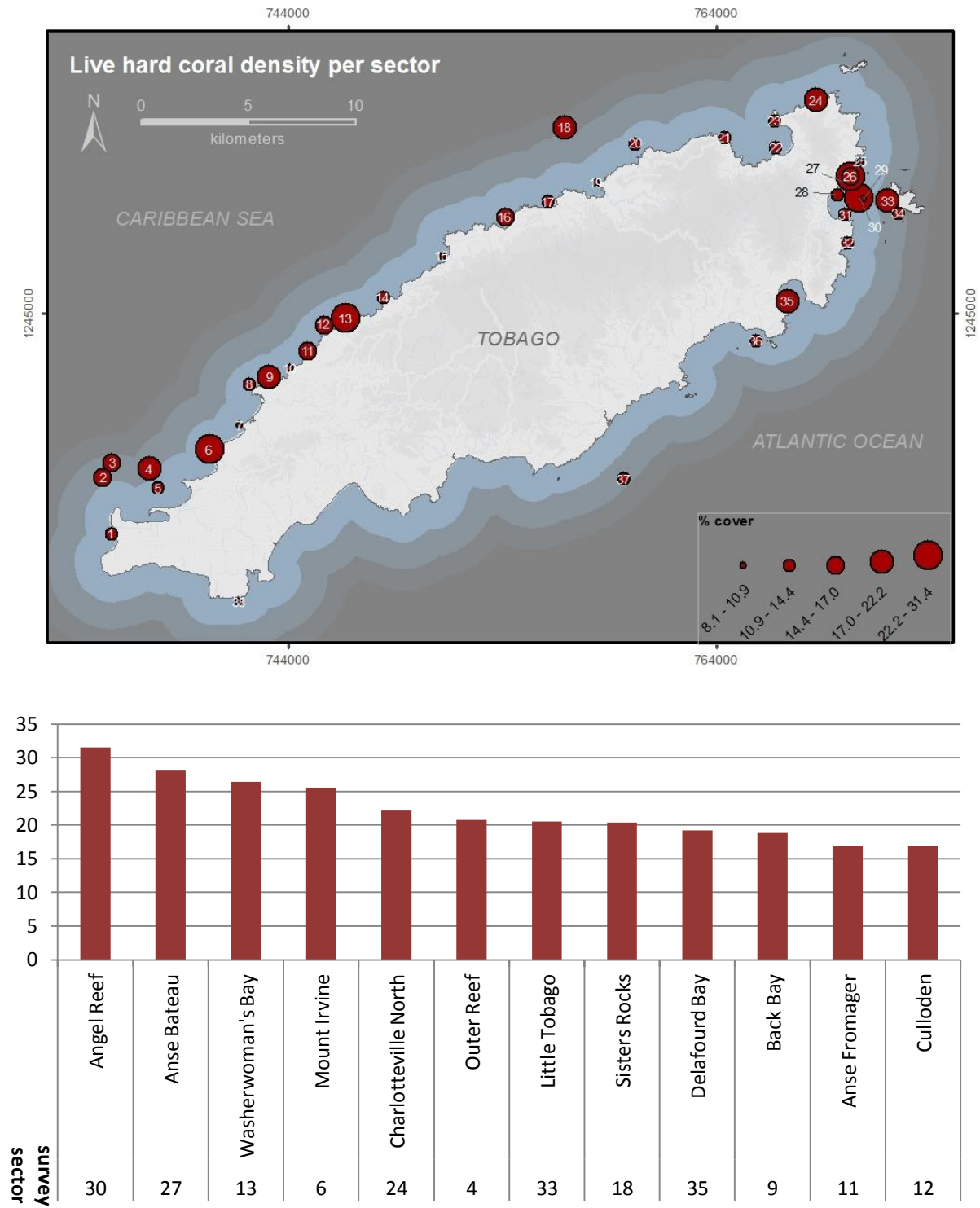


Figure 14 Live hard coral cover (%) for survey sectors around Tobago.

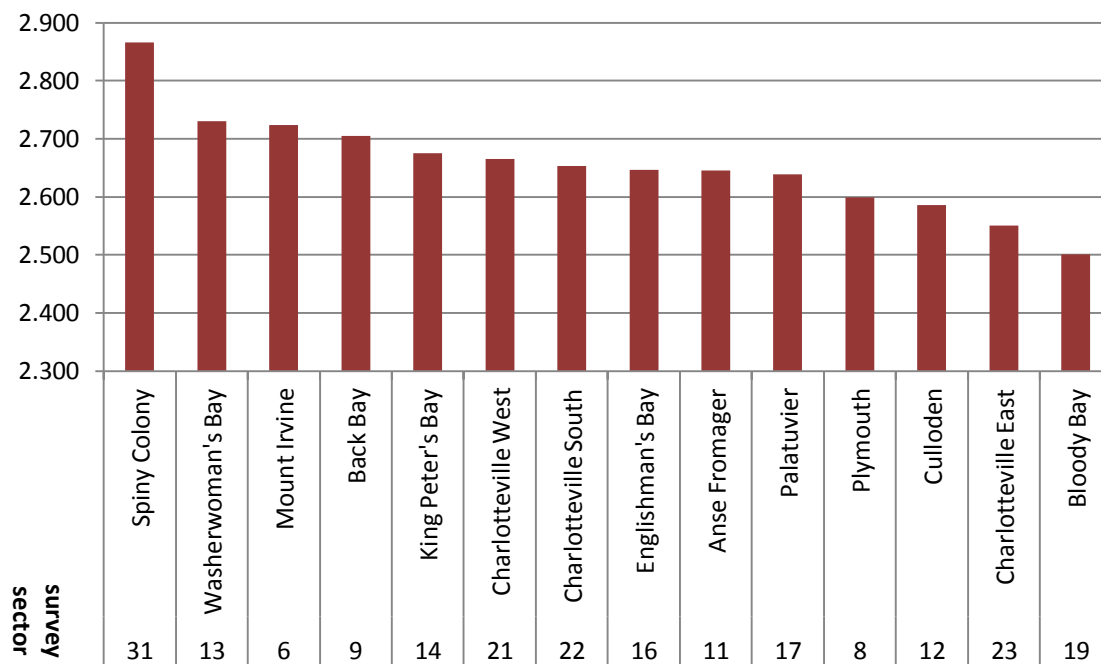
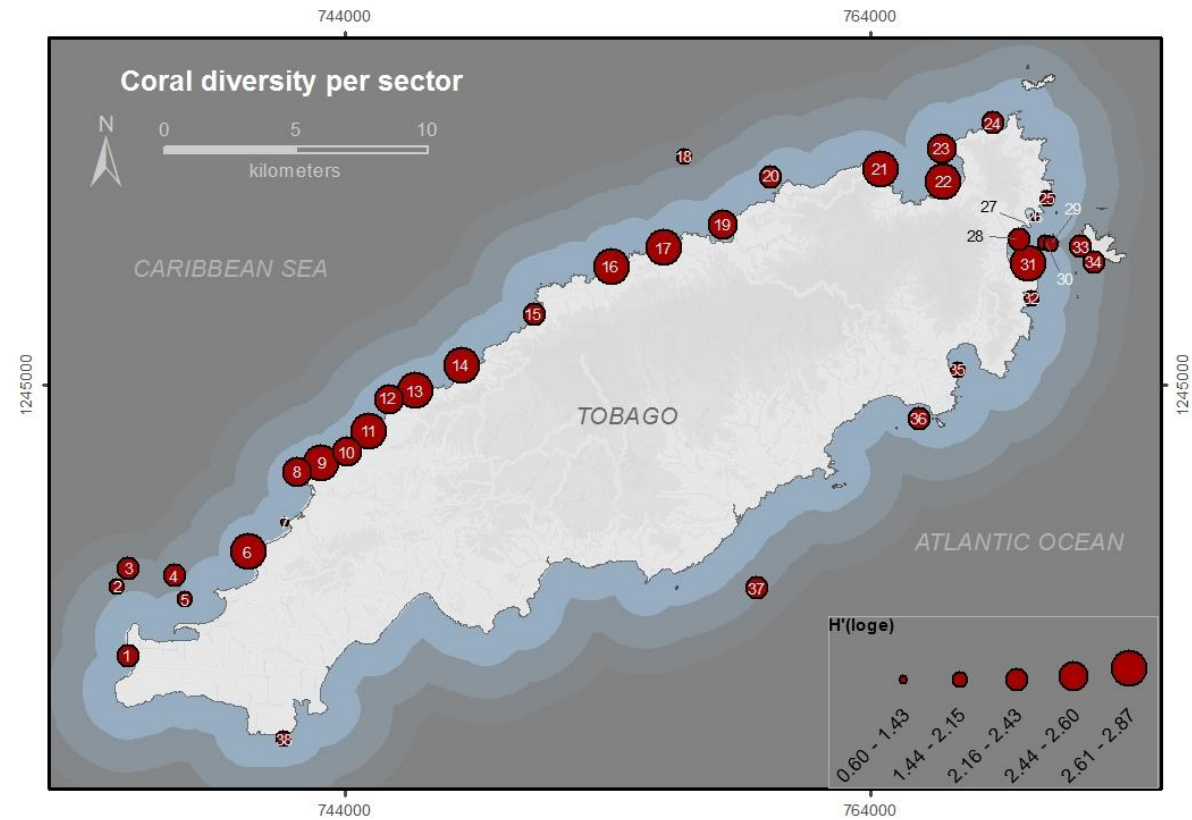


Figure 15 Coral diversity (Shannon Wiener diversity index) for survey sectors around Tobago.

Table 4 Hard coral species recorded during surveys around the coast of Tobago.

Hard coral species	Common name	% of all coral species
Montastraea spp.	Boulder Star Complex	21.1
<i>Montastraea faveolata</i>	Mountainous Star	5.7
<i>Montastraea franksi</i>	Boulder Star	3.3
<i>Montastraea annularis</i>	Lobed Star	0.4
Millepora spp.	Fire coral spp.	14.2
<i>Diploria strigosa</i>	Symmetrical Brain	12.2
<i>Siderastrea siderea</i>	Massive Starlet	8.5
<i>Madracis mirabilis</i>	Yellow Pencil	8.0
<i>Montastraea cavernosa</i>	Great Star	7.0
<i>Colpophyllia natans</i>	Boulder Brain	4.3
<i>Porites astreoides</i>	Mustard Hill	3.7
<i>Meandrina meandrites</i>	Maze	3.5
<i>Agaricia agaricites</i>	Low Relief Lettuce	2.8
<i>Madracis decactis</i>	Ten-Ray Star	2.0
<i>Diploria clivosa</i>	Knobby Brain	1.9
<i>Diploria labyrinthiformis</i>	Grooved Brain	1.7
<i>Siderastrea radians</i>	Lesser Starlet	1.6
<i>Agaricia</i> spp.	Lettuce spp.	1.6
Unidentified coral	Unidentified coral	0.2
Other coral species		5.7
<i>Dichocoenia stokesi</i>	Elliptical Star	0.88
<i>Acropora palmata</i>	Elkhorn	0.68
<i>Scolymia</i> spp	<i>Scolymia</i> spp.	0.63
<i>Helioseris cucullata</i>	Sunray Lettuce	0.56
<i>Stephanocoenia intersepta</i>	Blushing Star	0.49
<i>Porites furcata</i>	Branched Finger	0.36
<i>Porites porites</i>	Clubtip Finger	0.24
<i>Eusmilia fastigiata</i>	Smooth Flower	0.24
<i>Solenastrea bournoni</i>	Smooth Star	0.22
<i>Madracis formosa</i>	Eight-Ray Finger	0.17
<i>Agaricia tenuifolia</i>	Thin Leaf Lettuce	0.17
<i>Favia fragum</i>	Golfball	0.15
<i>Mussa angulosa</i>	Spiny Flower	0.15
<i>Dendrogyra cylindrus</i>	Pillar	0.12
<i>Stylaster roseus</i>	Lace	0.10
<i>Manicina areolata</i>	Rose	0.10
<i>Porites divaricata</i>	Thin Finger	0.09
<i>Solenastrea hyades</i>	Knobby Star	0.09
<i>Mycetophyllia lamarckiana</i>	Ridged Cactus	0.07
<i>Isophyllastrea rigida</i>	Rough Star	0.07
<i>Acropora cervicornis</i>	Staghorn	0.03
<i>Tubastrea coccinea</i>	Orange Cup	0.03
<i>Oculina diffusa</i>	Diffuse Ivory Bush	0.02
<i>Mycetophyllia aliciae</i>	Knobby Cactus	0.02
<i>Mycetophyllia ferox</i>	Rough Cactus	0.02

4.8 Reef Fish

Reef fish play an important role in balancing the overall health and diversity of coral reef ecosystems. Herbivorous reef fish such as Parrotfish (*Scaridae*) help to reduce macro-algal cover, thereby increasing the amount of substrate available for coral recruitment (Lirman 2001). Commercial species such as Groupers (*Serranidae*) and Snappers (*Lutjanidae*) are at the top of the food chain and help maintain a balance between other fish species. They are prized by fishermen and tend to spawn once a year in aggregations, making them vulnerable to overfishing.

High commercially important fish densities (>3,500 fish/ha) were found around the Great River Shoals, a large reef system on the Atlantic side of Tobago (Figure 16). On the Caribbean side, Bloody Bay had relatively high commercial fish densities, in addition to Coral Gardens in Speyside. Commercial fish biomass (Figure 17) was by far the highest in the Great River Shoal area (3,000kg/ha). Demersal (reef associated) fish densities were highest for Sister's Rocks and Castara (Figure 18).

Parrotfish (*Scaridae*) are an important reef grazer, particularly so after the *Diadema* die-off of the 1980's (Mumby *et al.* 2006). Parrotfish densities were relatively high around Buccoo Reef and reef sites on the western end of Tobago (Figure 20). Lower densities were found towards the eastern end, including the Speyside reefs.

The diversity and abundance of fish species are important indicators of reef health and the ability of reefs to cope with and absorb external stressors. The overall diversity of fish varied greatly between sectors and was highest along reef within the Charlotteville Bay area, mainly around Pirates Bay (Figure 19). The Buccoo Reef area also had good fish diversity.

4.9 Invertebrates

A number of important invertebrate indicator species have been selected which are either commercially harvested or ecologically important (see Appendix A). These were combined to give an indication of the diversity of motile invertebrates for each survey site. Relatively high invertebrate diversity was found all along the island, particularly around Arnos Vale and Englishman's Bay (Figure 21).

4.10 Conservation management values

The Conservation Management Values (CMVs) give an impression of the overall status of a particular sector in comparison to the others. Several sites along the Caribbean coastline had relatively high CMV values with Englishman's Bay having above average values for all of the nine criteria (Figure 22). Outer Reef, Mount Irvine, Back Bay and Washerwomen's Bay also had relatively high CMV values, scoring high on 8 of the 9 criteria.

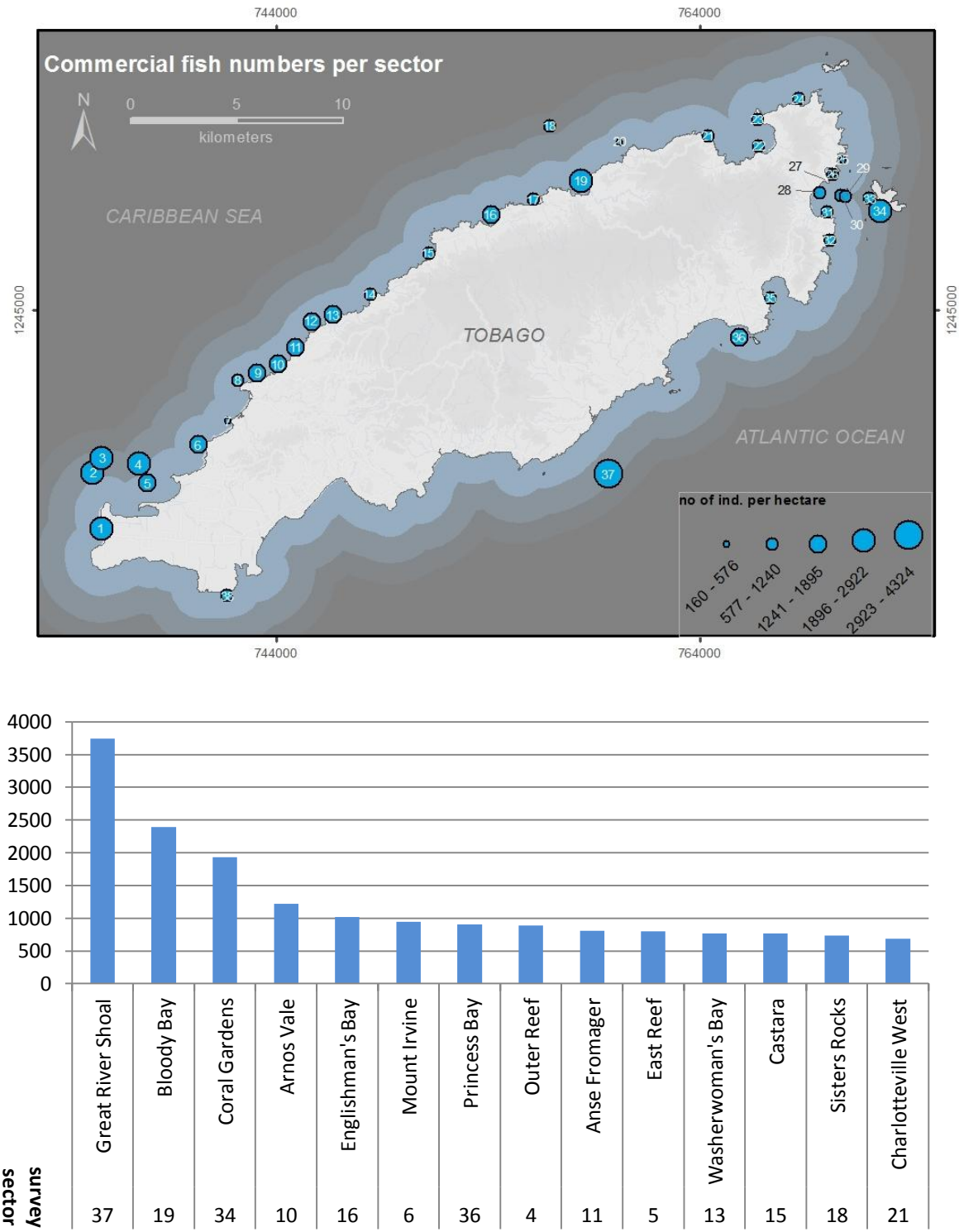


Figure 16 Commercial fish densities (# per hectare) for survey sectors around Tobago.

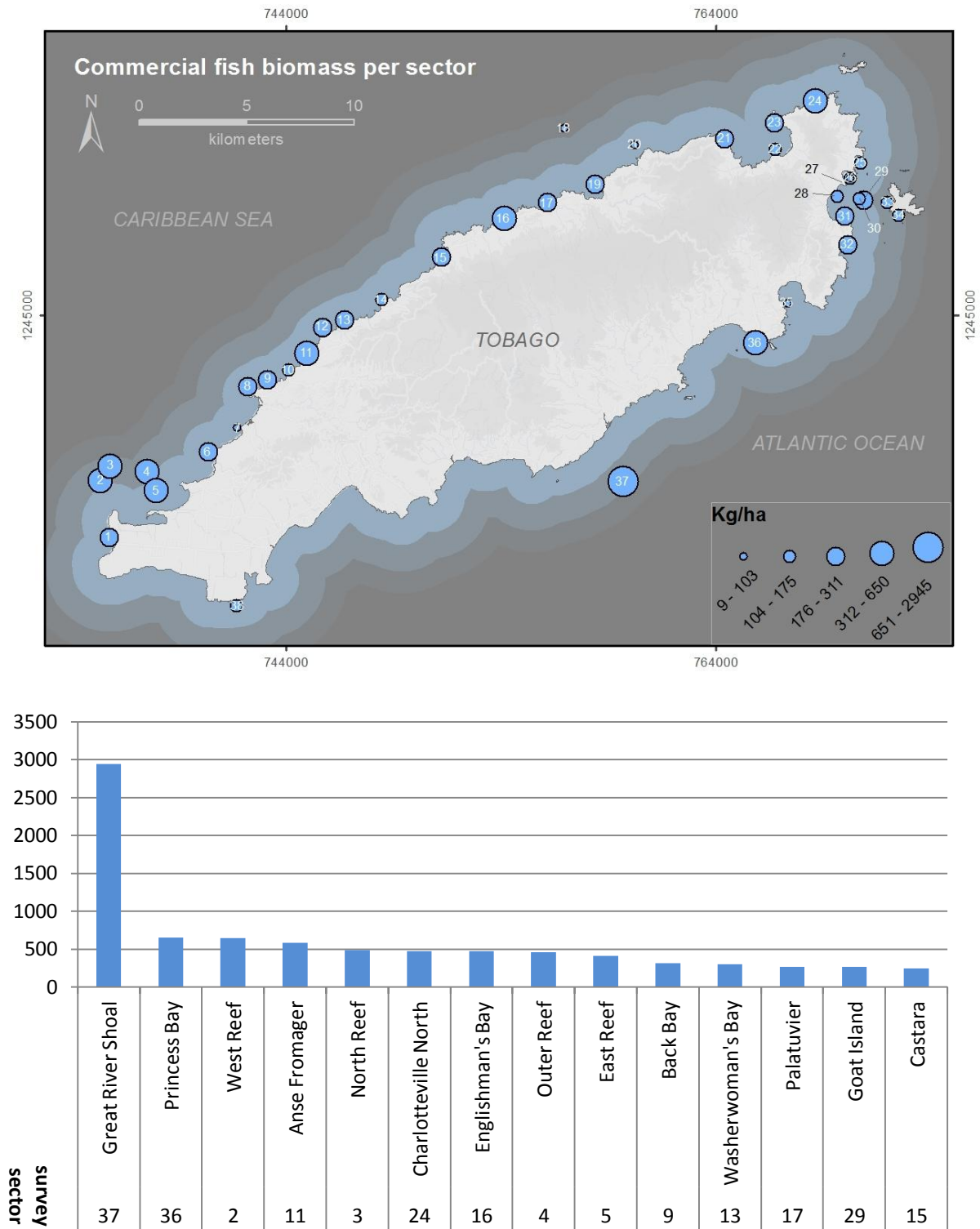


Figure 17 Commercial fish biomass (kg per hectare) for survey sectors around Tobago.

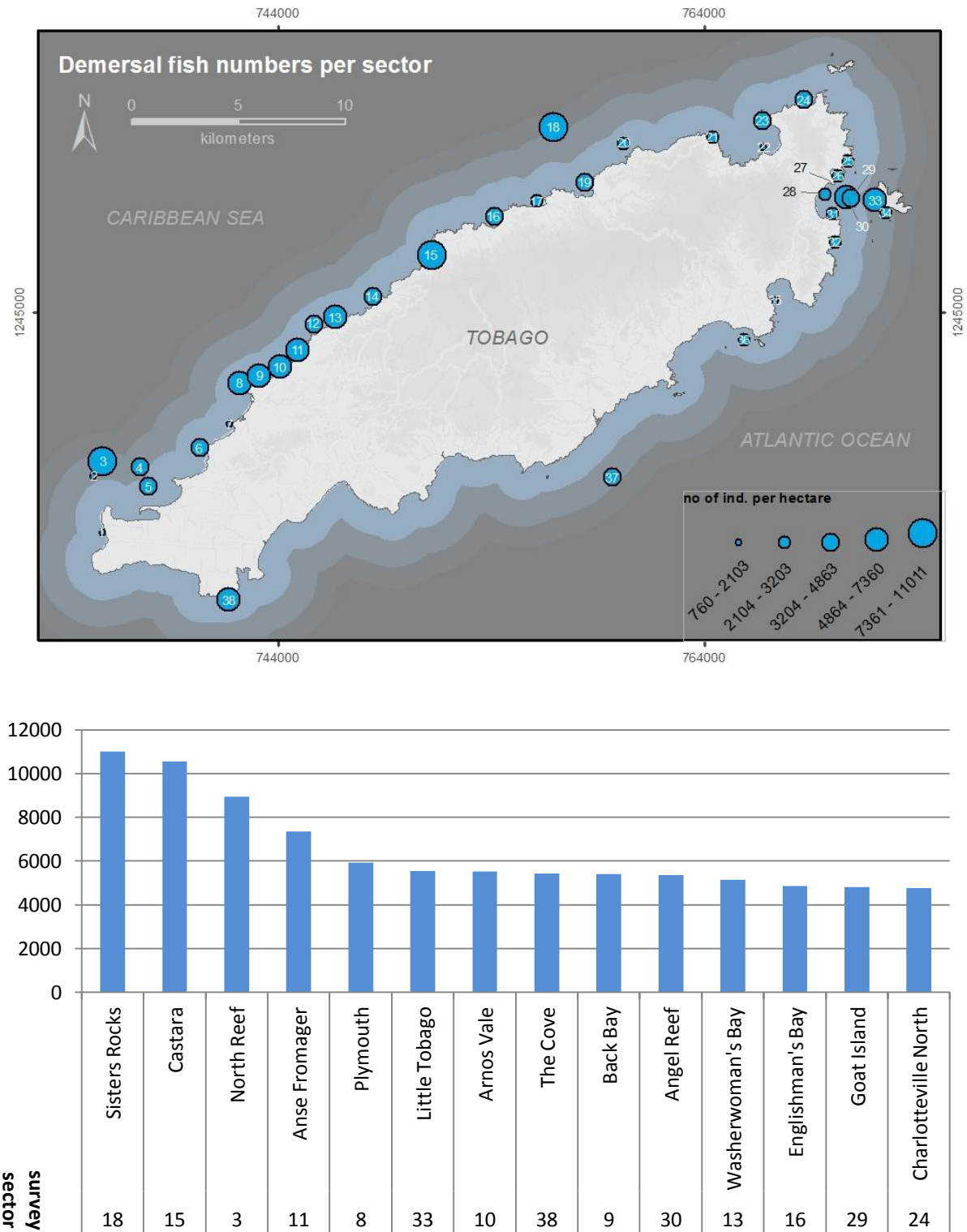


Figure 18 Demersal (reef associated) fish densities for survey sectors around Tobago.

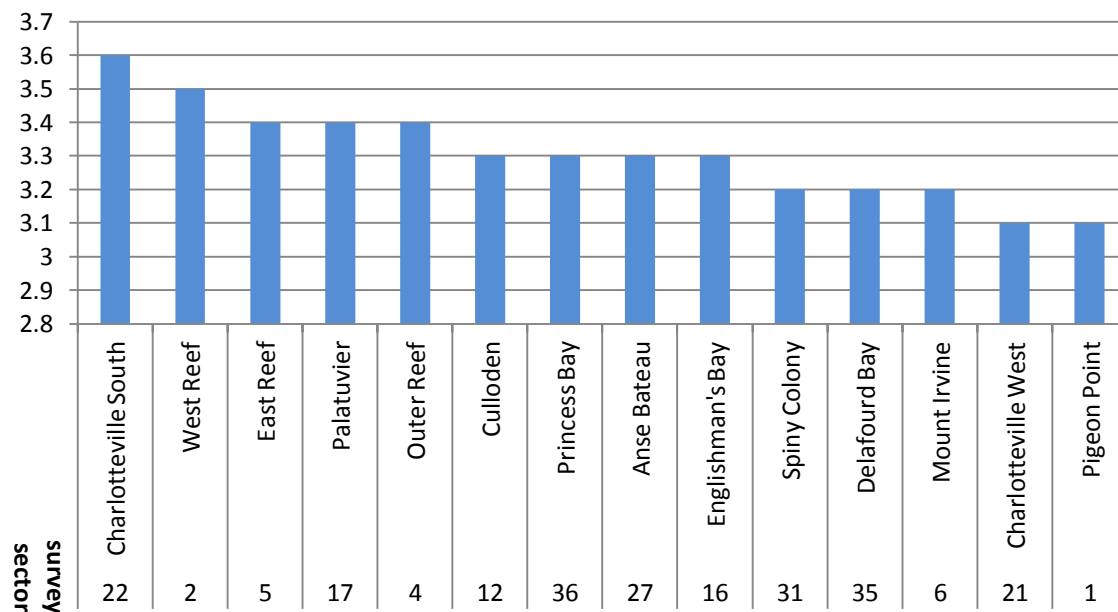
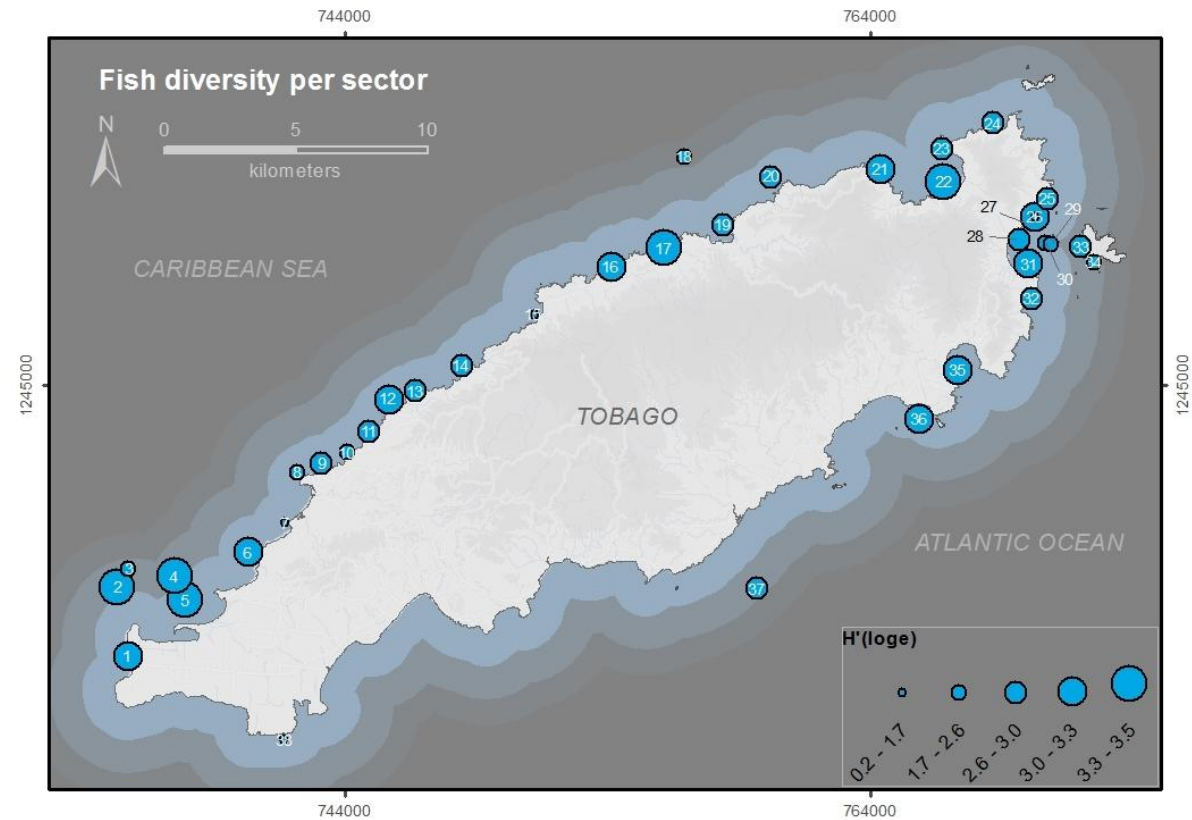


Figure 19 Fish diversity (Shannon-wiener Index) for survey sectors around Tobago.

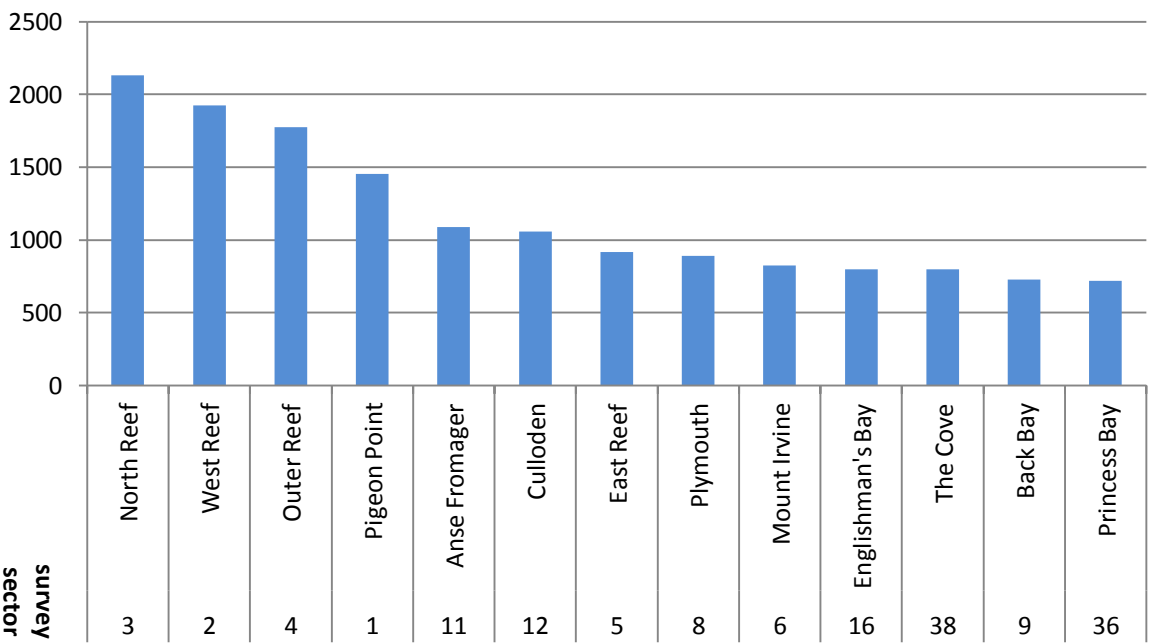
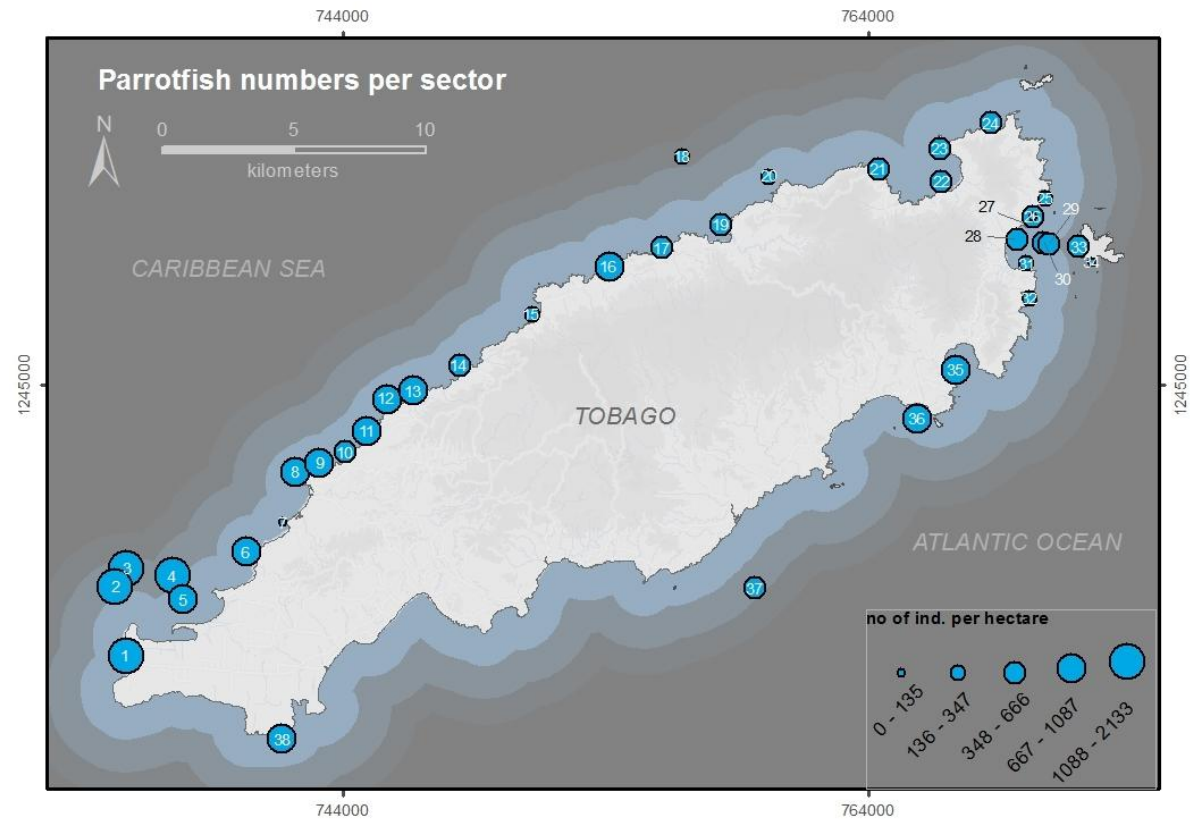


Figure 20 Parrotfish densities for survey sectors around Tobago.

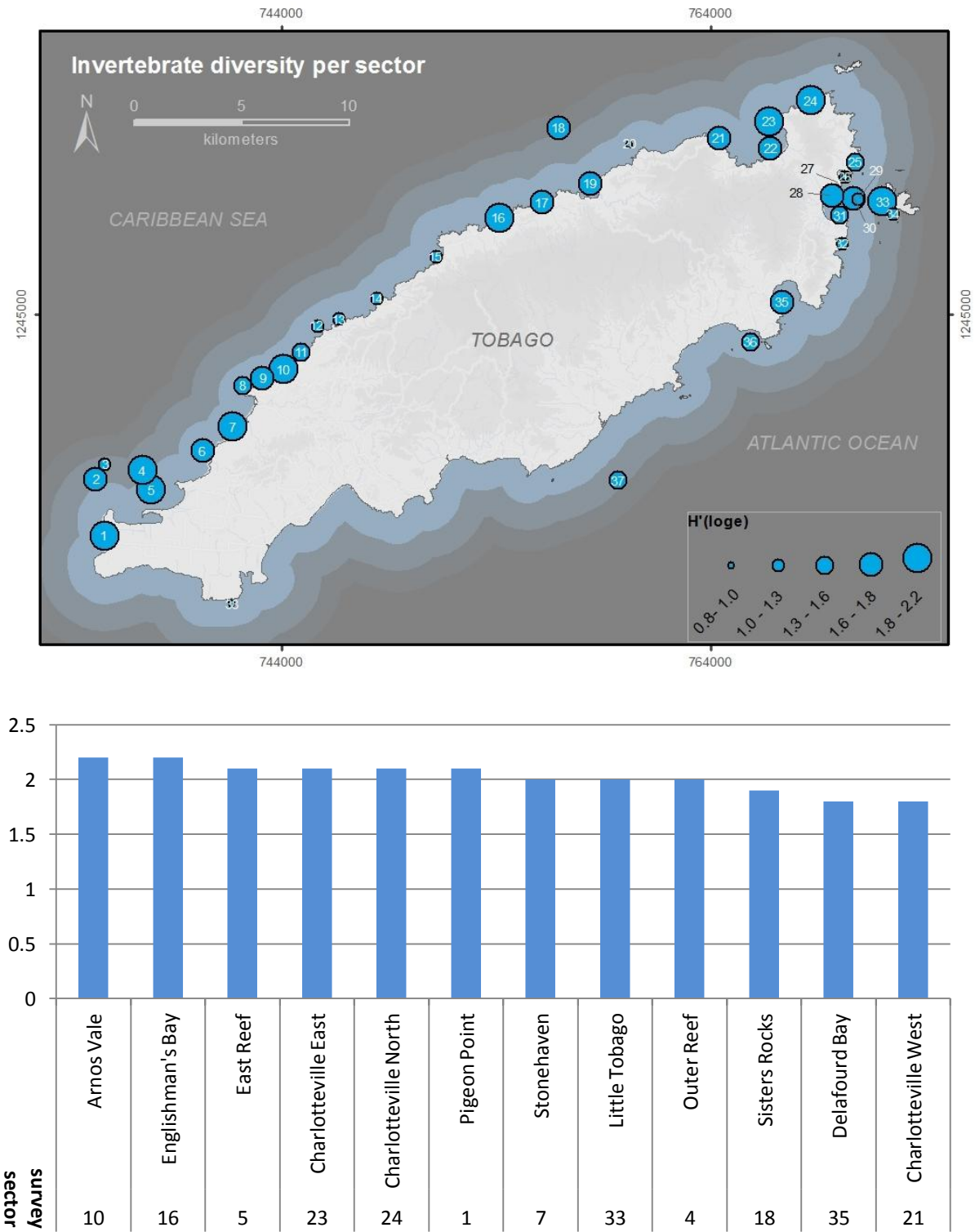


Figure 21 Invertebrate diversity for survey sectors around Tobago.

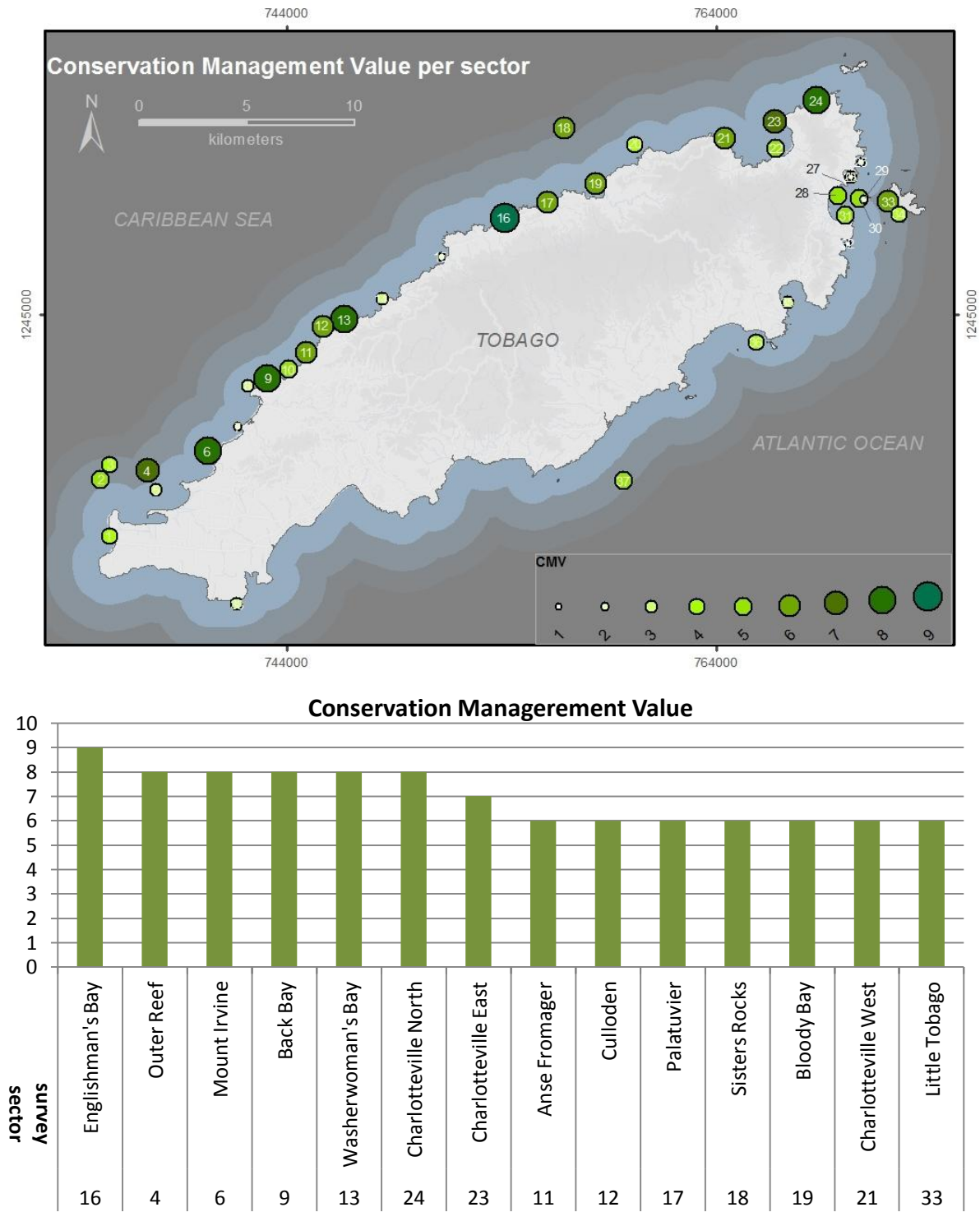


Figure 22 Conservation Management values for survey sectors around Tobago.

4.11 *Proposed no-take zoning plan*

Based on the Conservation Management Values presented above, we propose the designation of ten fully protected no-take areas, encompassing over 20 km² of coral reef, seagrass and mangrove habitats, in order to help ensure the preservation of Tobago's most diverse coastal resources (Figure 23, next page). The Buccoo Reef Marine Park (BRMP), Tobago's only marine park in existence, incorporates the Bon Accord seagrass beds and mangrove forests, which are likely to be an important nursery ground for many important fish and invertebrate species.

The plan we propose here secures some of the best and most diverse reef sites on both the Caribbean and Speyside reefs as well as over 300 hectares of the Great River Shoal on the Atlantic side of Tobago. These areas should be designated as fully protected, no-take zones if they are able to provide adequate potential for fisheries and coral recovery. Although limited recreational activities such as SCUBA diving and snorkeling should be allowed, any destructive practices including anchoring, trampling and removal of any species should be prohibited.

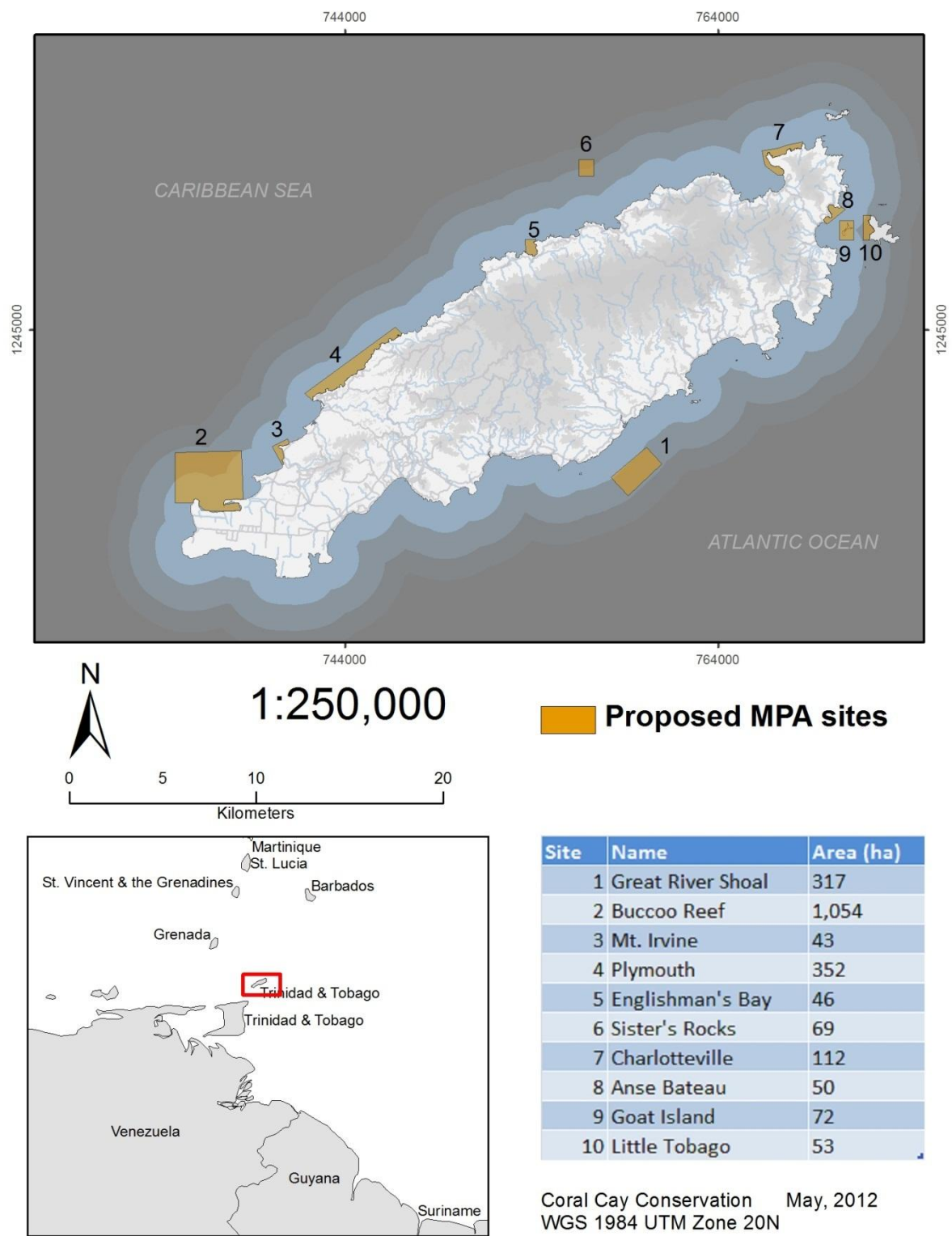


Figure 23 Proposed MPA sites around Tobago.

4.12 Coral Disease and Bleaching

Over the late summer of 2010 (July-October), a steady increase in Sea Surface Temperatures (SST) throughout the Caribbean led to surface water temperatures well beyond the normal threshold for the region (29.5°C). With SST's of over 31°C, coral colonies around Tobago started suffering from temperature and UV-induced bleaching. In Speyside, where SST's of 32°C were measured, some sites had 100% bleaching of all coral colonies (Figure 25). Elevated temperatures persisted for many weeks and helped fuel the most active Atlantic hurricane season on record and the most severe and extensive mass coral bleaching event ever observed in the Caribbean (Figure 24).

Selected sites surveyed by CCC during the 2005 mass-bleaching event were re-surveyed in 2010 in order to get an impression of changes in coral cover as well as bleaching and disease prevalence (Figure 25). An analysis was undertaken of 68 coral reef sites surveyed at 7 and 12m, along the north-eastern coast of Tobago between August and December 2010. These surveys were conducted in roughly the same locations in both monitoring periods.

Surveys conducted at the same reef sites in 2005 and 2010 showed a significant reduction in live hard coral cover from 27% in 2005 to 13% in 2010 at 12m (t-test, $P < 0.05$). At 7m, there was also a strong decline in coral cover from 24% in 2005 to 10% in 2010 (Figure 26). Sites on the Caribbean side experienced the most significant declines in coral cover over the 5 year period. This was reflected in the fact that coral bleaching levels in 2005 were particularly high along the Caribbean coast while sites in Speyside had lower bleaching levels. In contrast, the mass-bleaching event of 2010 saw Speyside reefs being severely affected by coral bleaching whereas Caribbean sites had lower bleaching levels compared to 2005, particularly at 12m depth.

On average, approximately half of the coral colonies observed were bleached (~56%). Furthermore, a third of these colonies suffered from one or more coral diseases (Figure 27). Approximately a third of sites visited had bleaching levels of 90% or higher with some sites such as Black Jack Hole, one of Speyside's prime dive sites, displaying coral bleaching across all coral colonies (Figure 29). Coral bleaching was significantly higher at shallower depths (regression analysis, $p < 0.05$) although there was no apparent correlation between coral disease prevalence and depth (Figure 27). Coral bleaching at 7m was slightly higher in 2010 than 2005 whereas bleaching at 12m was higher in 2005 (Figure 26).

Bleaching between coral species appeared indiscriminate with dominant coral taxa being *Montastrea spp.*, *Siderastrea spp.*, *Diploria strigosa* and *Colpophyllia natans*. Sites that suffered the highest coral bleaching also suffered from sponge necrosis. Sponge necrosis was particularly high on Speyside reefs amongst Barrel Sponges, *Xetospongia muta* and Yellow Tube Sponge, *Aplysina fistularis* colonies (Figure 30). Where sponge necrosis was witnessed, it started before the onset of coral bleaching and is likely to have been caused by the unusually warm SST's in the area. Sponge necrosis was not seen in 2005, indicating that the impact of the 2005 mass-bleaching event was particularly severe for the marine environment of Speyside.

Coral diseases became prevalent after the 2005 mass bleaching event. Coral colonies on the Caribbean side of Tobago were frequently infected with a variety of coral diseases,

particularly yellow band disease which was commonly found on *Montastrea* coral colonies. Other coral diseases that were seen included White Plague, Black Spot Syndrome and Aspergillosis (Figure 28). For a list and details of commonly found coral diseases in Tobago, see Appendix B. Coral Cay has submitted its coral disease data to the UNEP/WCMC website www.coraldisease.org. We also plan to publish the disease data in a journal paper.

Coral colony die-off following the 2005 bleaching outbreak was further exacerbated by hurricane Thomas which took place on the 29th of October, 2010. Shortly thereafter, there was a high influx of mud from land runoff, resulting in high sedimentation levels which lasted for weeks, particularly within the sheltered bays along the Caribbean coastline. There was also direct coral damage from debris hitting the reefs. Charlotteville in particular suffered from prolonged and unusually high sedimentation levels (Figure 31).

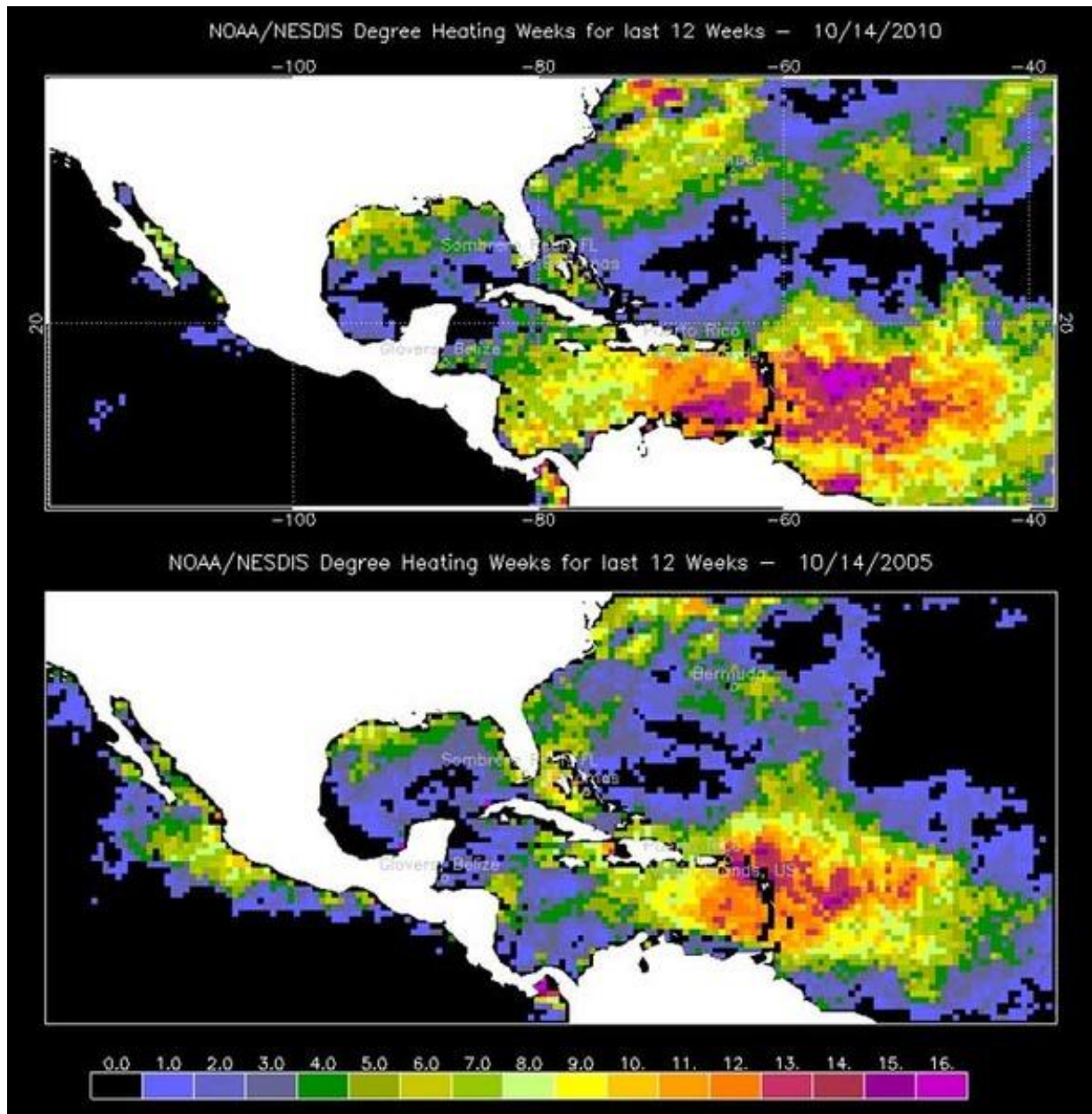


Figure 24 Extent and severity of the mass coral bleaching events of October 2005 and 2010, based on degree heating weeks (DHW). Values $\geq 4^{\circ}\text{C-weeks}$ typically result in significant bleaching; $\geq 8^{\circ}\text{C-weeks}$ typically result in widespread bleaching and significant mortality.

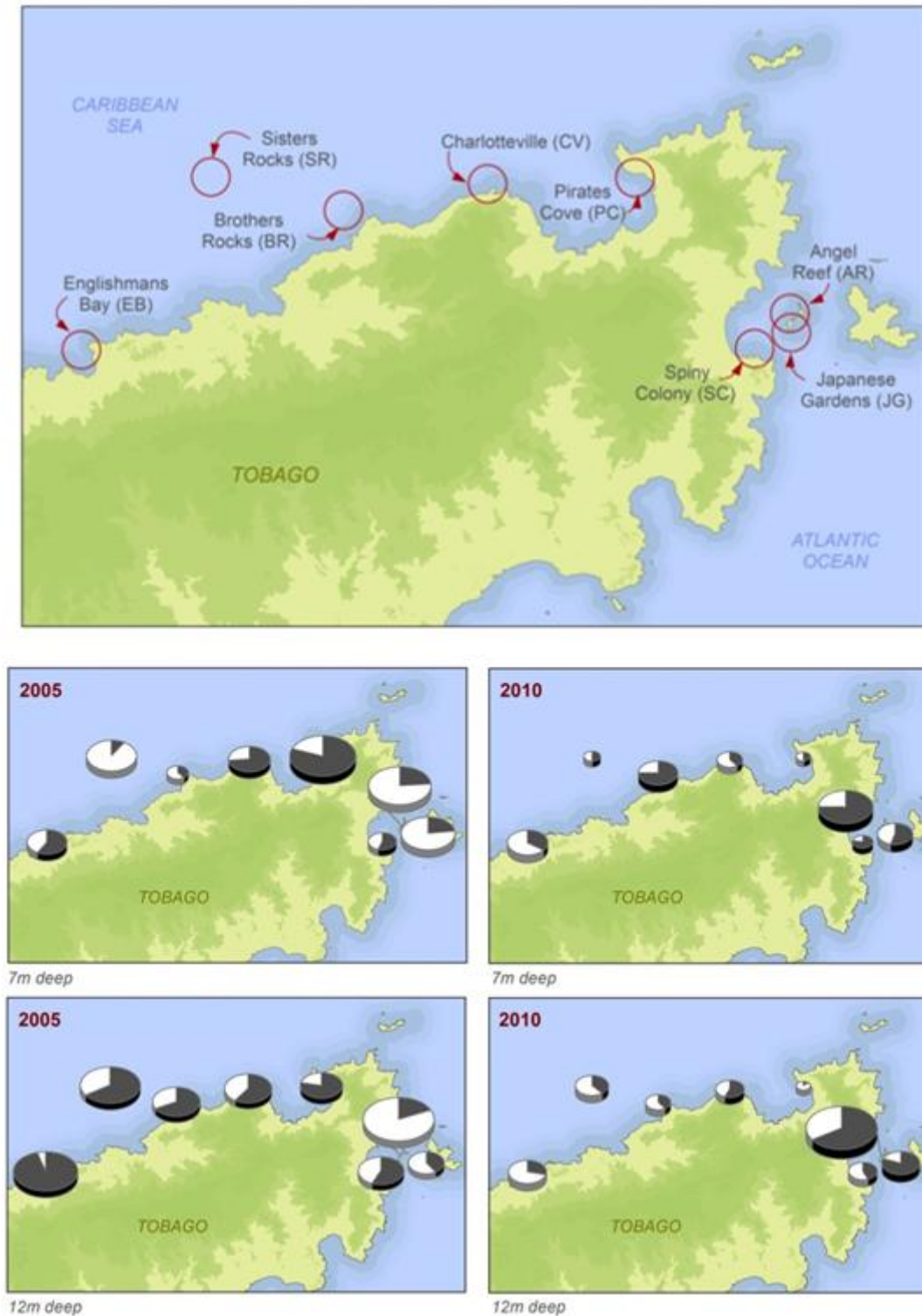
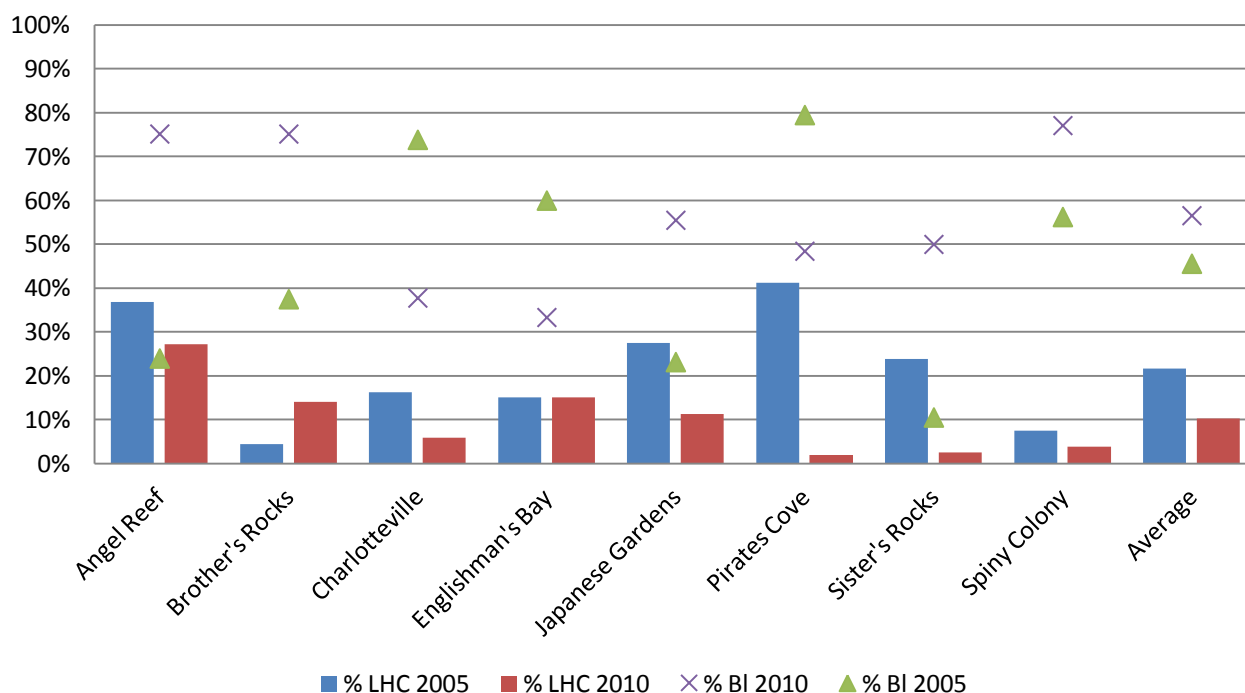


Figure 25 Locations of eight monitoring sites along the north-eastern coast of Tobago (above). Map below - Live hard coral cover (pie chart size) and bleaching prevalence (area in pie chart shaded grey) for two survey depths, 7m (above) and 12m (below) between 2005 and 2010.

Coral cover and bleaching 7m



Coral cover and bleaching 12m

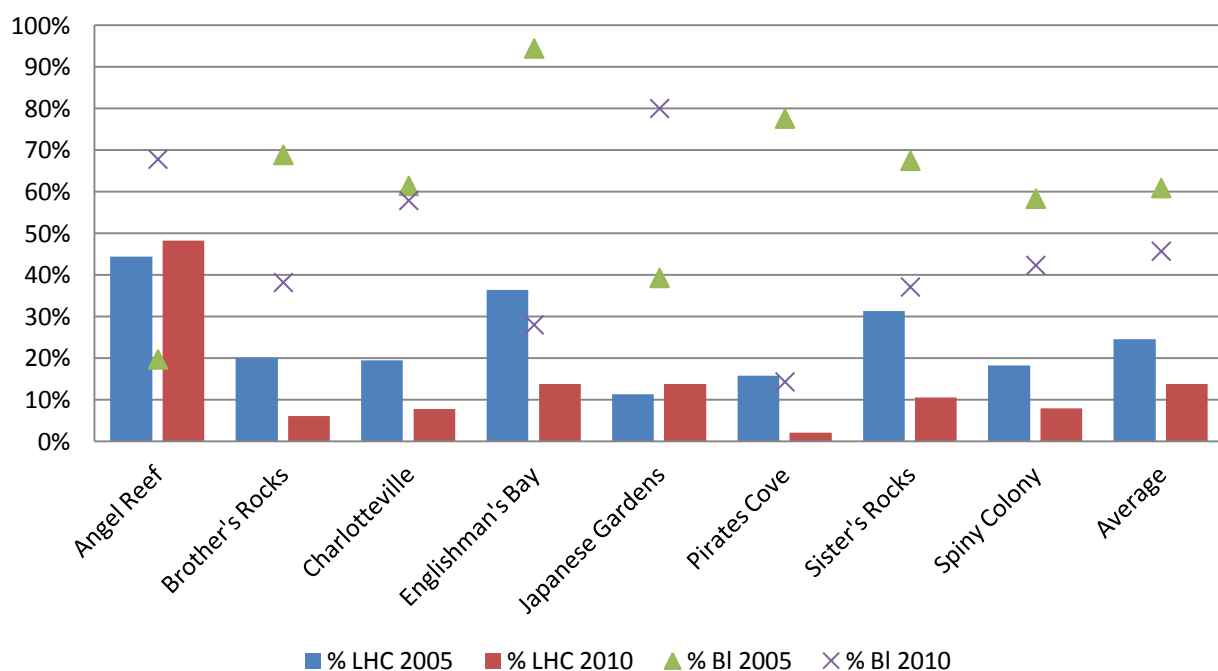


Figure 26 Changes in coral cover (blue and red bars) and coral bleaching (grey X and green triangles) levels at eight reef sites during the 2005 and 2010 mass-bleaching events at two survey depths – 7m (above) and 12m (below).

Hard coral cover and bleaching at four survey depths

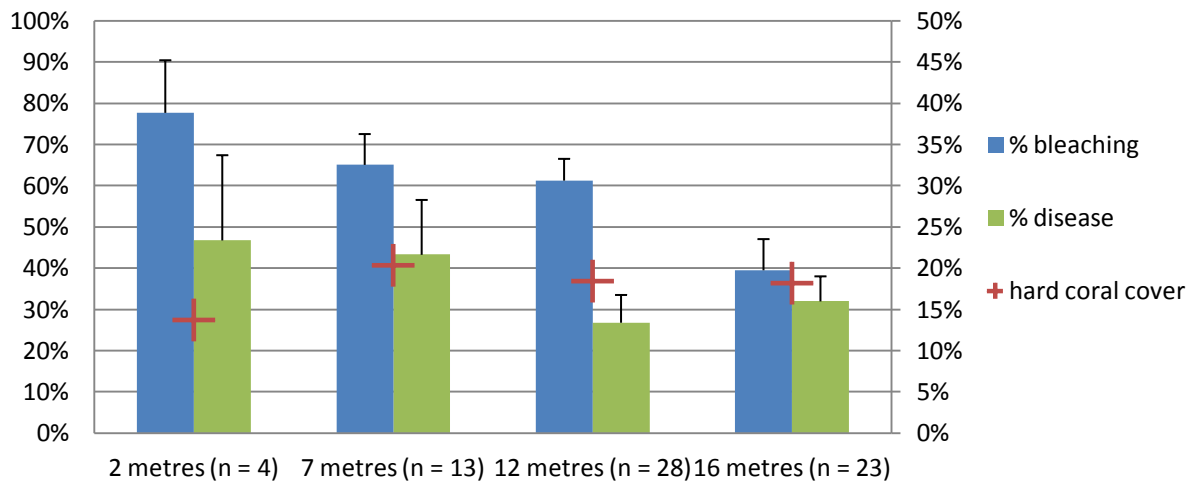


Figure 27 Coral cover (red cross), coral bleaching (blue bars) and coral disease prevalence (green bars) at four survey depths. Error bars indicate standard deviation from the mean.

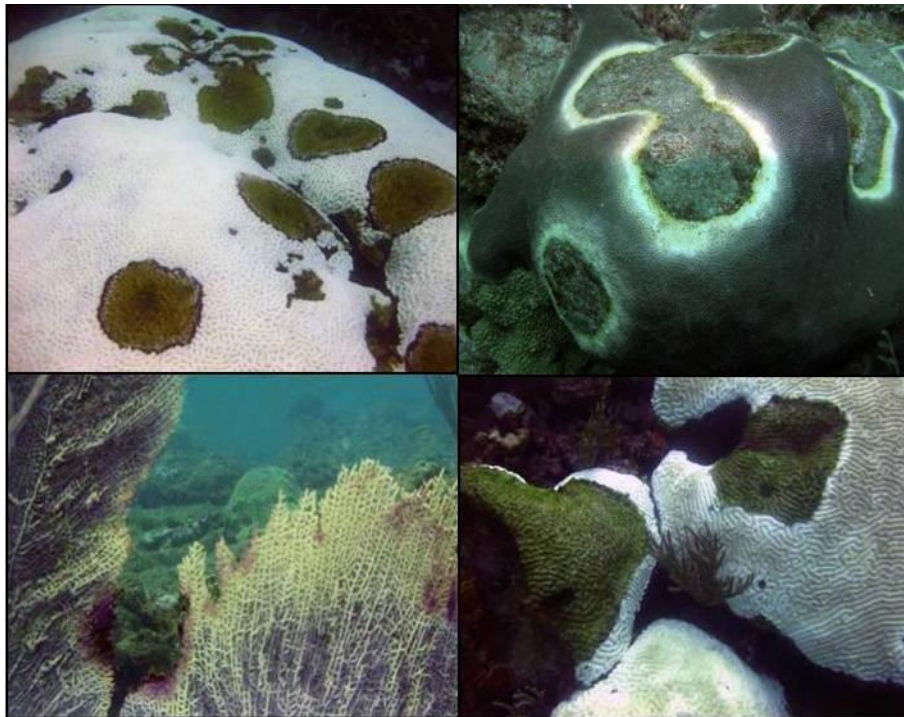


Figure 28 Coral diseases commonly seen on Tobago's reefs (clockwise): Red Band Disease on bleached *D. strigosa* colonies, Yellow Band Disease on a *Montastrea* coral, Aspergilliosis on a Seafan, White Plague disease on a *D. strigosa* coral.



Figure 29 Video still showing the extent of the mass bleaching event at Black Jack Hole, Speyside, September 2010.

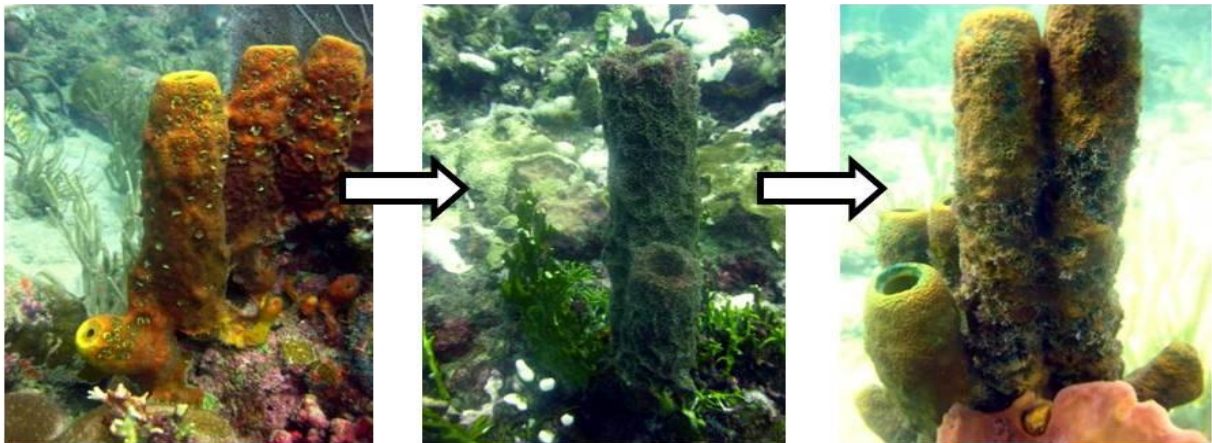


Figure 30 Progressive deterioration of yellow tube sponge, *Aplysina fistularis* due to heat-induced necrosis in Speyside, 2010.



Figure 31 Images taken before, during and after Hurricane Thomas. The resulting land run-off which washed into the sea killed off many coral colonies such as the large *Diploastrea Strigosa* colony on the right.

5. Discussion

The TCEMP project has been successful in providing an extensive baseline dataset in support of the implementation of an effective coastal management plan for Tobago. Between April 2007 and June 2011, CCC survey teams conducted 927 survey transects around the coastline of Tobago. Data derived from this effort provides a detailed baseline information dataset which is freely available to third parties for further research and monitoring purposes. The fact that all surveys are geo-referenced enables anyone to easily conduct follow up studies to assess changes in the health of particular reef sites. This provides a powerful meta-dataset which we hope will be used in support of the management and conservation of Tobago's coral reef resources in the future.

Since the project began in 2007, local awareness of coral reefs and other marine habitats has increased substantially amongst Tobago's residents, both young and old. Local capacity to improve the technical expertise and experience of managers has increased thanks to the scholarship programmes, provided throughout the duration of the project. In total, 64 Trinidad and Tobago nationals from various sectors received training in SCUBA dive and scientific monitoring techniques. The capacity that has been created through this effort should be utilised to continue to monitor the coral reefs as well as promoting the importance of their conservation for future generations.

The extent of the dataset means that an exhaustive analysis has not been carried out in this report. Rather, some general trends have been provided and used to support the main management recommendations provided in the next chapter.

5.1 Benthic cover and diversity

The dominant substrates found were sand, rock and coral. Living substrate was highest around the Speyside reefs. Additionally, relatively high coral cover was found at reef sites around Speyside, Sisters Rocks and sites on the Caribbean side of Tobago including Mt. Irvine and Washerwomen's Bay. The fact that Speyside has high biotic benthic cover puts it high on the list of sites in need of effective conservation management. Other sites, particularly around Castara and Buccoo Reef, showed signs of degradation and will need improved management and protection if they are to recover. Coral diversity varied greatly although relatively high coral diversity was found in Spiny Colony in Speyside. High coral diversity was also found on many of the Caribbean side reefs including Mt. Irvine and Washerwomen's Bay.

Corals were comprised mostly of massive framework builders, mainly *Montastrea spp.* (21%), *Millepora spp.* (14%) and *D. strigosa* (12%). *M. Mirabilis* was a dominant species on reefs around Speyside, particularly Angel Reef and Anse Bateau. *Acropora palmata*, once an abundant species in the shallows but now the first coral acknowledged by CITES as a threatened species, comprised less than 1% of hard corals seen on all surveys. Before the White-Band Disease outbreaks between 1977 and 1982, they were the dominant family of reef building coral on shallow water reefs (Wilkinson, 2004).

Live hard coral cover, an important indicator of reef health, dropped significantly between 2005 and 2010. At 12m, corals comprised 27% of the benthic substrate in 2005 and only 13% in 2011. At 7m, the loss of corals was even starker, from 24% in 2005 to only 10% in 2011. Furthermore, many sites previously known to have healthy reefs were now showing less than 5% live hard coral cover, placing them on the brink of collapse. This is likely to be a result of the mass bleaching event of 2005 and is exacerbated by the coral disease outbreaks and severe weather systems that followed. Land-based impacts, mainly the high levels of sedimentation that were seen, are also likely to have killed many coral colonies, particularly in the more sheltered bays such as Arnos Vale, Englishman's Bay and Charlottesville. These sites displayed low coral cover and diversity where there were once thriving reefs.

High macroalgal cover and overgrowth was identified around the Great River Shoal on the Atlantic coast, as well as sites on the western edge of Buccoo Reef. High macroalgal cover is a strong indicator of pollution and/or nitrification of surface waters. In the case of the Buccoo Reef area, where algal dominated reefs were found on the western side, there may be a link with the local sewage output from Bon Accord. This is in accordance with findings from Lapointe *et al.* (2010) who recommended better wastewater treatment in order to improve local reef health. Algae can also flourish in areas where there is high turbidity of the water due to sedimentation. In the case of the Great River Shoal, high algal cover may be linked to the annual Orinoco river outputs from the South American mainland rather than local impacts from Tobago.

There is a high availability of hard, bare substrates for corals to settle on although coral recruitment has not been observed on any significant scale (Mallela *et al.*, 2010). Rocky (dead) substrates were more common towards the western, Caribbean side of the island. Sites including Buccoo, King Peter's Bay, Culloden and Plymouth showed high bare substrate cover. This may be an indication of recent coral mortality as a result of the 2005 mass-bleaching event and follow up disease outbreaks that were particularly prevalent on the Caribbean side. In spite of relatively high bare substrate cover, these sites still maintained a level of structural integrity (reef complexity), providing potentially important habitats for fish and invertebrate species. Sites around Buccoo in particular, had high levels of dead coral, visible from the structural remnants of what were once extensive Elkhorn (*A. palmata*) coral stands. Once proper protection and management have been implemented, coral recovery and transplantation programmes would be an effective means to repopulate these reefs with previously abundant coral species, including Elkhorn corals. If these 'dead reefs' are not actively recovered and coral recruitment does not take place, natural bioerosion processes will significantly reduce the reef complexity and ability of these reefs to provide important ecological services such as shoreline protection and supporting healthy fish stocks.

5.2 Reef Fish and Invertebrates

Reef fish densities and biomass for a number of commercially fished families such as Groupers and Snappers and reef herbivores such as Parrotfish were low at all depths surveyed. Tobago's reefs have suffered from unsustainable fishing pressure. This is evident not only from the lack of fish on the reefs but also from the low proportion of adult size, commercially targeted fish groups.

In some areas, particularly Buccoo Reef, herbivorous fish species, mainly Parrotfish and Surgeonfish, were relatively abundant compared to other Caribbean Islands (see van Bochove *et al.*, 2008). The same holds true for another key reef herbivore, Long-spine, Diadema Sea Urchins. The relatively high abundance of reef grazers may explain the low macro-algal cover for most of the reef sites around Tobago. Phase shifts from coral to algal dominated reefs have been a big issue for other Caribbean nations such as Jamaica. The conservation of these herbivores is therefore essential to maintaining a high proportion of suitable substrates for the recolonisation of reefs around Tobago.

Commercially important fish were remarkably high around the Great River Shoal reef system on the Atlantic coast of Tobago. Although only limited surveys were conducted here, there are strong indications that the reefs here harbour significantly higher commercial fish populations than on the Caribbean side of Tobago. The reason for this is unknown but the exposure to Atlantic swells for much of the year could play a role in reduced fishing pressure. Sister's Rocks, Castara and the North Reef of Charlotteville had relatively high demersal fish populations. Sister's Rocks in particular, remains an excellent recreational dive location in addition to displaying low bleaching levels in both 2005 and 2010.

Overall, both fish densities and diversity varied enormously within and between sectors, making it difficult to draw conclusions. What can be distilled from the information is that the Buccoo Reef area has both high fish abundances and diversity, particularly for Parrotfish. This is likely to be a result of the (limited) protection it has received as a marine park in addition to its high availability of reef, mangrove and seagrass habitats, combined with a high reef complexity to provide suitable habitats.

Commercially harvested invertebrate species such as Queen Conch and Lobsters displayed very low abundances indicating severe over-harvesting. Queen Conch in particular, were encountered on less than 1% of all survey dives. These once abundant species would benefit from adequate protection in order to allow their stocks to recover.

5.3 Coral bleaching and disease outbreaks

Over the summer of 2010, Tobago was struck by the second mass-bleaching event in five years. Bleaching prevalence around the north-eastern side of the island was approximately 50% for both years. While coral bleaching levels were highest for the Caribbean side in 2005, the 2010 event seemed to indicate the opposite when the reefs of Speyside were particularly hard hit. At some sites around Speyside, nearly all corals suffered from prolonged bleaching at the peak of the event. This makes the 2010 bleaching event equally, if not more severe to the previous one.

At the time, the limited bleaching that took place around Speyside in 2005 was seen as an indication that Speyside reefs were potentially more resilient to warmer surface temperatures. It was hypothesised that the strong water currents that run past Speyside provided it with a buffer against prolonged warming of SST's (O'Farrell *et al.*, 2005). The mass-bleaching event that followed five years later indicates that all of Tobago's reefs, including Speyside, are vulnerable to bleaching episodes during periods of prolonged sea surface water warming. What is needed is a management plan that aims to tackle both local

water and land based issues in order to maximise reef resilience against future bleaching events that are likely to become a regular occurrence (IPCC 2007).

High levels of coral disease, particularly yellow band disease, have been observed at most reef sites along the Caribbean coastline of Tobago where over 30% of hard coral colonies suffered from a variety of diseases. Prevalence of these diseases was highly variable but some sites had over 50% of coral colonies infected with coral diseases. Massive, slow growing *Montastrea spp.* and *Siderastrea spp.* colonies were often the most severely impacted. Although no estimate can be given for coral mortality, many of the massive colonies displayed a reduction of over 75% in their live surface area and some were almost completely infected.

The prevalence of hard coral diseases in Speyside was significantly lower although this does not include anticipated disease impacts of the 2010 mass bleaching event. *Aspergillois*, a land-derived fungal disease, was particularly prevalent in Speyside, affecting over 60% of sea fans in the area.

The disease outbreaks are likely to be a consequence of the mass bleaching events that preceded these outbreaks. This was shown to be the case two years after the 2005 mass-bleaching event when coral colonies all along the Caribbean coastline were suffering from the prevalence of several diseases, mainly Yellow Band Disease and Dark Spot Syndrome. No coral diseases were observed prior to the mass bleaching event, providing a strong indication that coral diseases have started to proliferate since the event. Based on the disease outbreaks that followed in 2005, it is likely a similar aftermath will take place following the 2010 mass bleaching event. The Speyside area which had relatively low disease levels thus far may well see a sharp increase in disease prevalence. Follow-up monitoring will need to confirm this. Further information on coral disease prevalence and mortality will be presented in a subsequent paper.

5.4 Conservation Management Values

The CMV is an ecological value of each survey site relative to the other sites around Tobago. Areas with high CMV values should be considered priority sites for effective conservation management since they had above average values for many of the important criteria from which the CMV was produced. Sites with high CMV values included Englishman's Bay, Buccoo's Outer Reef, Mount Irvine, Back Bay and Washerwomen's Bay, all on the western Caribbean side. On the eastern side of Tobago, Charlotteville and Little Tobago in Speyside had high CMV values. All sectors round Charlettoville also scored highly. In spite of having high fish densities and biomass, sites on the Atlantic side generally had lower values, mainly due to relatively poor coral cover and diversity.

It is important to note that although the CMV value can be a good support tool for prioritising conservation sites, it is an arbitrary value which takes into account a high variation of factors and weighs them equally. Sites with high CMV values may not have the best reef diversity or cover for example. An effective management plan also needs to include a variety of reef and associated habitats such as seagrass beds and mangroves that have

crucial functions in terms of coastal protection and serving as a nursery ground for many fish and invertebrate species.

5.5 *General conclusions*

Our survey results over a three-year period indicate that there has been a significant deterioration in reef health for nearly all sites visited. However, there are still many good reefs found around and local efforts to better manage these sites provide room for optimism. Through the installation of several no-take zones and with careful management of the coral, seagrass beds and mangrove forests, coral reefs and dependent fish stocks can recover and continue to provide Tobago with an important source of income.

The installation of no-take areas is important as it will allow threatened fish stocks such as Groupers and Parrotfish to increase and recover over time. Eventually, there may even be a spillover of fish from protected areas to adjacent reefs where they can increase the abundances of fish to the benefit of local fishermen.

The duration of the project made it difficult to compare sites surveyed in year one and year three, due to the changes in reef health that are likely to have occurred over the three-year survey period. The high sedimentation levels, coral disease outbreaks and continuing stressors from local, anthropogenic impacts means that reefs around the island continue to deteriorate and a reef site surveyed in 2007 may look dramatically different two years later. To keep up with the rate of change that Tobago's reefs are experiencing, it is important to continue to monitor reef sites on a regular basis. This will provide crucial information on the rate of deterioration or recovery, pinpoint reefs of high resilience to stressors, and allow for adaptive management practices. Regular monitoring will also highlight the extraordinary rate at which Tobago's corals are disappearing, forcing policy makers to take notice and ensure remaining reefs are adequately protected from local stressors.

Healthy coral reefs are an essential part of Speyside's economy and efforts must be made to ensure that reef health is improved. Disturbingly, all of the reefs visited for surveys are showing some signs of stress. Although the signs vary, they generally include: high macro-algae cover, coral diseases, high sedimentation, low fish density and direct physical damage such as anchor and trampling damage. Whilst current reef health is a cause for genuine concern, it is likely that the reefs observed still retain the capacity to recover.

Although many of the triggers of bleaching are beyond the control of individual nations (such as increasing atmospheric CO₂ levels), the 2005 bleaching event creates an opportunity within Tobago and the wider Caribbean to explore links between the susceptibility of corals to bleaching with regard to additional stressors such as anthropogenic impacts. Steps towards mitigating these factors can (and must) be taken at a national and local level in order to reduce as much as possible the stresses to the reefs, if bleaching is not to severely threaten the long-term viability of the corals reefs of Tobago.

Most scientists agree that the capacity of corals to adapt to changes in environmental conditions will depend on the level of additional 'unnatural' stresses with which they have to contend. As Kinsey (1998) observes, corals can endure chronic stress, and even rebuff acute

stresses over a short period, but chronically stressed reefs are less likely to be capable of successfully moderating the impacts of acute stresses. It is likely that reefs that are not subject to local, anthropogenic impacts will be more resilient than those that are heavily impacted and will thus be less susceptible to, and more likely to recover from, acute environmental stresses such as bleaching events (Burke and Maidens, 2004; Buddemeier et al, 2004). In light of this, four key recommendations are presented here which, if implemented, will provide Tobago's reefs the best possible chance of recovering from recent impacts and enabling them to continue to provide valuable goods and services to the Tobagonian people who depend on them for their livelihoods, future prosperity and safety.

5.6 *Four key recommendations*

5. The creation of several no-take Marine Protected Areas as recommended in this report should be made a management priority. In close consultation with local communities, an appropriate management plan should be developed and implemented to secure areas of high biodiversity and "bleaching-resilient" reefs. These sites will help to increase commercial fish stocks, improve local fisheries through a spillover of recruits and act as a source of coral recruits to downstream reefs around Tobago and potentially its neighbouring islands.
6. Due to the likely increase in bleaching events in forthcoming years, there should be improved effort by the THA and developers to reduce coastal pollution from inadequately treated sewage effluent and sedimentation from land-based run-off of mud and silt. This will allow corals to recover from recent impacts and build the resilience of corals to future bleaching events. Particular efforts should be made to protect the upland forests and watersheds of Tobago to prevent siltation and pollution impacts on the surrounding reefs.
7. A long-term marine monitoring programme should be implemented that includes regular measurements of key parameters of environmental health (e.g. water quality, temperature, biodiversity, coral diseases, fish abundance) at fixed sites around Tobago's coastline. This data would be used to steer adaptive management practices and provide an important assessment of changes in the health of Tobago's coastal resources.
8. Continued community participation, education and capacity development will be important to improve awareness amongst Tobago's citizens about the benefits of well managed and protected coastal habitats to their livelihoods. Without this foundation of understanding and empowerment, it will be difficult to secure coral reefs for the future.

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Appendix A: TCEMP target species

FISH SPECIES				
#	CCC Category	CCC Name	Genus	Species
1	Angelfish	Cherubfish	Centropyge	argi
2	Angelfish	French	Pomacanthus	paru
3	Angelfish	Gray	Pomacanthus	arcuatus
4	Angelfish	Non-Target		
5	Angelfish	Queen	Holacanthus	cilaris
6	Angelfish	Rock Beauty	Holacanthus	tricolor
7	Bass	Blackcap	Gramma	melacara
8	Bass	Creolfish	Paranthias	furcifer
9	Bass	Fairy Basslet	Gramma	loreto
10	Bass	Greater Soapfish	Rypticus	saponaceus
11	Bass	Harlequin	Serranus	tigrinus
12	Bass	Non-Target		
13	Bass	Tobacco	Serranus	tabacarius
14	Batfish	Non-Target		
15	Big Eye	Non-Target		
16	Blenny	Non-Target		
17	Boxfish	Cowfish	Acanthostracion	
18	Boxfish	Non-Target		
19	Boxfish	Trunkfish	Lactophrys	
20	Butterflyfish	Banded	Chaetodon	striatus
21	Butterflyfish	Foureye	Chaetodon	capistratus
22	Butterflyfish	Longsnout	Chaetodon	aculeatus
23	Butterflyfish	Non-Target	Chaetodon	
24	Butterflyfish	Reef	Chaetodon	sedentarius
25	Butterflyfish	Spotfin	Chaetodon	ocellatus
26	Cardinalfish	Non-Target		
27	Cornetfish	Non-Target	Fistularia	tabacaria
28	Damselfish	Bicolour	Stegastes	partitus
29	Damselfish	Blue Chromis	Chromis	cyanea
30	Damselfish	Brown Chromis	Chromis	multilineata
31	Damselfish	Night Sergeant	Abudefduf	taurus
32	Damselfish	Non-Target		
33	Damselfish	Sergeant Major	Abudefduf	saxatilis
34	Damselfish	Sunshine Fish	Chromis	insolata
35	Damselfish	Yellowtail	Microspathodon	chrysurus
36	Drum	Hihat	Equetus	acuminatus
37	Drum	Non-Target		
38	Drum	Spotted	Equetus	punctatus
39	Eel	Conger		
40	Eel	Garden	Heteroconger	
41	Eel	Moray		

42	Eel	Non-Target		
43	Eel	Snake		
44	Filefish	Non-Target		
45	Filefish	Orange Spotted	Cantherhines	macrocerus
46	Filefish	Scrawled	Aluterus	scriptus
47	Filefish	White Spotted	Cantherhines	pullus
48	Flounder	Non-Target		
49	Flying Gurnard	Non-Target	Dactylopterus	volitans
50	Frogfish	Non-Target		
51	Goatfish	Non-Target		
52	Goatfish	Spotted	Pseudupeneus	maculatus
53	Goatfish	Yellow	Mulloidichthys	martinicus
54	Goby	Non-Target		
55	Grouper	Black	Mycteroperca	bonaci
56	Grouper	Comb	Mycteroperca	rubra
57	Grouper	Coney	Cephalopholis	fulva
58	Grouper	Goliath	Epinephelus	itajara
59	Grouper	Grasby	Cephalopholis	cruentatus
60	Grouper	Marbled	Epinephelus	inermis
61	Grouper	Nassau	Epinephelus	striatus
62	Grouper	Non-Target		
63	Grouper	Red Hind	Epinephelus	guttatus
64	Grouper	Rock Hind	Epinephelus	adscensionis
65	Grouper	Tiger	Mycteroperca	tigris
66	Grouper	Yellowfin	Mycteroperca	vemenosa
67	Grouper	Yellowmouth	Mycteroperca	interstitialis
68	Grun	Black		
69	Grun	Black Margate	Anisotremus	surinamensis
70	Grun	Bluestriped	Haemulon	sciurus
71	Grun	Ceaser	Haemulon	carbonarium
72	Grun	Corocoro		
73	Grun	Cottonwick	Haemulon	melanurum
74	Grun	French	Haemulon	flavolineatum
75	Grun	Grunts		
76	Grun	Latin	Haemuon	Steindachneri
77	Grun	Margate	Haemulon	album
78	Grun	Porkfish	Anisotremus	verginicus
79	Grun	Smallmouth	Haemulon	chrysargyreum
80	Grun	Spanish	Haemulon	macrostomum
81	Grun	Striped	Haemulon	striatum
82	Grun	Tomtate	Haemulon	aurolineatum
83	Grun	White	Haemulon	plumierii
84	Hamlet	Barred	Hypoplectrus	puella
85	Hamlet	Black	Hypoplectrus	nigricans
86	Hamlet	Butter	Hypoplectrus	unicolor

87	Hamlet	Golden Hamlet	Hypoplectrus	
88	Hamlet	Hamlet	Hypoplectrus	
89	Hamlet	Indigo	Hypoplectrus	indigo
90	Hamlet	Shy	Hypoplectrus	guttavarius
91	Hamlet	Yellowbelly	Hypoplectrus	aberrans
92	Hamlet	Yellowtail	Hypoplectrus	chlorurus
93	Hawkfish	Non-Target	Amblycirrhitis	pinos
94	Jack	Barjacks	Caranx	ruber
95	Jack	Blue Runner	Caranx	crysos
96	Jack	Horse-Eye	Caranx	latus
97	Jack	Jacks		
98	Jack	Palometa	Trachinotus	goodei
99	Jack	Permit	Trachinotus	falcatus
100	Jack	Scad spp		
101	Jack	Yellow	Caranx	bartholomaei
102	Jawfish	Non-Target	Opistognathus	
103	Lizardfish	Bluestriped	Synodus	saurus
104	Lizardfish	Non-Target		
105	Lizardfish	Sand Diver	Synodus	intermedius
106	Misc. Silvery	Barracuda	Sphyræna	barracuda
107	Misc. Silvery	Boga	Inermia	vittata
108	Misc. Silvery	Bonefish	Albula	vulpes
109	Misc. Silvery	Cero	Scomberomorus	regalis
110	Misc. Silvery	Chub	Kyphosus	spp.
111	Misc. Silvery	King Mackerel	Scomberomorus	cavalla
112	Misc. Silvery	Little Tunny		
113	Misc. Silvery	Mojarra spp		
114	Misc. Silvery	Needlefish		
115	Misc. Silvery	Non-Target		
116	Misc. Silvery	Saurcerye Porgy	Calamus	calamus
117	Misc. Silvery	Spadefish	Chaetopditerus	faber
118	Misc. Silvery	Spanish Mackerel	Scomberomorus	maculatus
119	Misc. Silvery	Tarpon	Megalops	atlanticus
120	Misc. Silvery	White Mullet	Mugil	curema
121	Parrotfish	Blue	Scarus	coeruleus
122	Parrotfish	Blue IP	Scarus	coeruleus
123	Parrotfish	Midnight	Scarus	coelestinus
124	Parrotfish	Midnight IP	Scarus	coelestinus
125	Parrotfish	Non-Target		
126	Parrotfish	Princess	Scarus	taeniopterus
127	Parrotfish	Princess IP	Scarus	taeniopterus
128	Parrotfish	Queen	Scarus	vetula
129	Parrotfish	Queen IP	Scarus	vetula
130	Parrotfish	Rainbow	Scarus	guacamaia
131	Parrotfish	Rainbow IP	Scarus	guacamaia

132	Parrotfish	Redband	Sparisoma	aurofrenatum
133	Parrotfish	Redband IP	Sparisoma	aurofrenatum
134	Parrotfish	Redtail	Sparisoma	chysopterum
135	Parrotfish	Redtail IP	Sparisoma	chysopterum
136	Parrotfish	Stoplight	Sparisoma	viridae
137	Parrotfish	Stoplight IP	Sparisoma	viridae
138	Parrotfish	Striped	Scarus	iserti
139	Parrotfish	Striped IP	Scarus	iserti
140	Parrotfish	Yellowtail	Sparisoma	rubripinne
141	Parrotfish	Yellowtail IP	Sparisoma	rubripinne
142	Pipefish	Non-Target		
143	Porcupinefish	Non-Target	Diodon	hystrix
144	Puffer	Bandtail	Sphoeroides	spengleri
145	Puffer	Non-Target		
146	Puffer	Sharpnose	Canthigaster	rostrata
147	Scorpionfish	Non-Target		
148	Seahorse	Non-Target	Hippocampus	
149	Snapper	Cubera	Lutjanus	cyanopterus
150	Snapper	Dog	Lutjanus	jocu
151	Snapper	Gray	Lutjanus	griseus
152	Snapper	Lane	Lutjanus	synagris
153	Snapper	Mahogany	Lutjanus	mahogoni
154	Snapper	Mutton	Lutjanus	analisis
155	Snapper	Schoolmaster	Lutjanus	apodus
156	Snapper	Snappers		
157	Snapper	Yellowtail	Ocyurus	chrysurus
158	Squirrelfish	Non-Target		
159	Surgeonfish	Blue Tang	Acanthurus	coeruleus
160	Surgeonfish	Doctor	Acanthurus	chirurgus
161	Surgeonfish	Non-Target	Acanthurus	
162	Surgeonfish	Ocean	Acanthurus	bahianus
163	Sweeper	Non-Target	Pempheris	schomburgki
164	Tilefish	Non-Target	Malacanthus	plumieri
165	Toadfish	Non-Target		
166	Triggerfish	Black Durgon	Melichthys	niger
167	Triggerfish	Non-Target		
168	Triggerfish	Queen	Balistes	vetula
169	Trumpetfish	Non-Target	Aulostomus	maculatus
170	Wrasse	Blackear	Halichoeres	poeyi
171	Wrasse	Bluehead	Thalassoma	bifasciatum
172	Wrasse	Clown	Halichoeres	maculipinna
173	Wrasse	Creole	Clepticus	parrae
174	Wrasse	Hogfish	Lachnolaimus	maximus
175	Wrasse	Non-Target		
176	Wrasse	Puddingwife	Halichoeres	radiatus

177	Wrasse	Rosy Razorfish	Xyrichtys	martinicensis
178	Wrasse	Slippery Dick	Halichoeres	bivittatus
179	Wrasse	Spanish Hogfish	Bodianus	rufus
180	Wrasse	Yellowhead	Halichoeres	garnoti

BENTHIC SUBSTRATE				
#	Category	CCC Name	Genus	Species
181	Rock	Rock		
182	Sand	Sand		
183	Silt	Silt		
184	Recently Killed Coral	Recently Killed Coral		
185	Rubble	Rubble		
186	Other Animal	Other Animal		
187	Micro-Algae	Cyanobacteria		
188	Green Algae	Green Filamentous		
189	Green Algae	Acetabularia spp	Acetabularia	spp.
190	Green Algae	Avrainvillea spp	Avainvillea	spp.
191	Green Algae	Caulerpa spp	Caulerpa	spp.
192	Green Algae	Halimeda spp	Halimeda	spp.
193	Green Algae	Codium spp	Codium	spp.
194	Green Algae	Neomeris spp	Neomeris	annulata
195	Green Algae	Udotea spp	Udotea	spp.
196	Green Algae	Ulva spp	Ulva	spp.
197	Green Algae	Sea Pearl		
198	Brown Algae	Dictyota spp	Dictyota	spp.
199	Brown Algae	Padina spp	Padina	spp.
200	Brown Algae	Lobophora spp	Lobophora	variegata
201	Brown Algae	Styopodium zonale	Styopodium	zonale
202	Brown Algae	Turbinaria spp	Turbinaria	spp.
203	Brown Algae	Brown Filamentous		
204	Brown Algae	Sargassum spp	Sargassum	spp.
205	Red Algae	Encrusting Coralline		
206	Red Algae	Galaxaura spp	Galaxura	spp.
207	Red Algae	Amphiroa spp	Amphiroa	spp.
208	Red Algae	Jania spp	Jania	spp.
209	Red Algae	Red Filamentous		
210	Red Algae	Sheet		
211	Red Algae	Wrangelia penicillata	Wrangelia	penicillata
212	Red Algae	Laurencia spp	Laurencia	spp.
213	Red Algae	Liagora spp	Liagora	spp.
214	Macro-Algae	Other		
215	Sea Grass	Sea Grass		
216	Sea Grass	Turtle	Thalassia	Testudinum
217	Sea Grass	Manatee	Syringodium	filiforme
218	Sea Grass	Halophila	Halophila	baillonis

219	Mangrove	Mangrove		
220	Sponge	Encrusting		
221	Sponge	Barrel		
222	Sponge	Vase		
223	Sponge	Tube		
224	Sponge	Branching		
225	Sponge	Ball		
226	Sponge	Rope		
227	Sponge	Lumpy		
228	Sponge	Red Boring	Cliona	delitrix
229	Sponge	Coral Encrusting	Cliona	langae
230	Other Cnidarian	Zoanthid	spp	
231	Other Cnidarian	Hydroid		spp.
232	Other Cnidarian	Corallimorph		spp.
233	Other Cnidarian	Encrusting Gorgonian	Erythropodium	caribaeorum
234	Tunicate	Tunicate		spp.
235	Bryozoan	Bryozoan		
236	Hard Coral	Lace	Stylaster	roseus
237	Hard Coral	Fire spp.	Millepora	spp.
238	Hard Coral	Staghorn	Acropora	cervicornis
239	Hard Coral	Fused Staghorn	Acropora	prolifera
240	Hard Coral	Elkhorn	Acropora	palmata
241	Hard Coral	Thin Finger	Porites	divaricata
242	Hard Coral	Branched Finger	Porites	furcata
243	Hard Coral	Clubtip Finger	Porites	porites
244	Hard Coral	Pillar	Dendrogyra	cylindrus
245	Hard Coral	Diffuse Ivory Bush	Oculina	diffusa
246	Hard Coral	Yellow Pencil	Madracis	mirabilis
247	Hard Coral	Eight-Ray Finger	Madracis	formosa
248	Hard Coral	Ten-Ray Star	Madracis	decactis
249	Hard Coral	Blushing Star	Stephanocoenia	intersepta
250	Hard Coral	Boulder Star Complex	Montastraea	spp.
251	Hard Coral	Lobed Star	Montastraea	annularis
252	Hard Coral	Mountainous Star	Montastraea	faveolata
253	Hard Coral	Boulder Star	Montastraea	franksi
254	Hard Coral	Great Star	Montastraea	cavernosa
255	Hard Coral	Smooth Star	Solenastrea	bournoni
256	Hard Coral	Knobby Star	Solenastrea	hyades
257	Hard Coral	Elliptical Star	Dichocoenia	stokesi
258	Hard Coral	Golfball	Favia	fragum
259	Hard Coral	Mustard Hill	Porites	astreoides
260	Hard Coral	Lesser Starlet	Siderastrea	radians
261	Hard Coral	Massive Starlet	Siderastrea	siderea
262	Hard Coral	Knobby Brain	Diploria	clivosa
263	Hard Coral	Symmetrical Brain	Diploria	strigosa

264	Hard Coral	Grooved Brain	Diploria	labyrinthiformis
265	Hard Coral	Maze	Meandrina	meandrites
266	Hard Coral	Rose	Manicina	areolata
267	Hard Coral	Boulder Brain	Colpophyllia	natans
268	Hard Coral	Sunray Lettuce	Helioseris	cucullata
269	Hard Coral	Lettuce	Agaricia	spp.
270	Hard Coral	Thin Leaf Lettuce	Agaricia	tenuifolia
271	Hard Coral	Other Agaricia	Agaricia	spp.
272	Hard Coral	Ridged Cactus	Mycetophyllia	lamarckiana
273	Hard Coral	Knobby Cactus	Mycetophyllia	aliciae
274	Hard Coral	Rough Cactus	Mycetophyllia	ferox
275	Hard Coral	Spiny Flower	Mussa	angulosa
276	Hard Coral	Smooth Flower	Eusmilia	fastigiata
277	Hard Coral	Orange Cup	Tubastrea	coccinea
278	Hard Coral	Scolymia spp	Scolymia	spp.
279	Hard Coral	Unidentified Live Hard		
280	Hard Coral	Low Relief Lettuce	Agaricia	
281	Hard Coral	Rough Star	Isophyllastrea	rigida
282	Hard Coral	Misc Cup		

Invertebrate species			
Category	CCC Name	Genus	Species
Annelida	Lugworm	Arenicola	cristata
Annelida	Xmas Tree	Spirobranchus	giganteus
Annelida	Feather Duster		
Annelida	Spaghetti		
Annelida	Fireworm		
Crustacea	Lobster		
Crustacea	Spiny Lobster	Panulirus	
Crustacea	Slipper Lobster		
Crustacea	Shrimp		
Crustacea	Mantis Shrimp		
Crustacea	Spider Crab		
Crustacea	Porcelain Crab		
Crustacea	Other Crab		
Crustacea	Batwing Coral Crab	Carpilius	corallinus
Crustacea	Yellowline Arrow Crab	Stenorhynchus	seticornis
Crustacea	Hermit Crab		
Crustacea	Banded Coral Shrimp	Stenopus	hispidus
Mollusc	Queen Conch	Strombus	gigas
Mollusc	Triton Trumpet	Charonia	variegata
Mollusc	Bi-valves		
Mollusc	Cowries	Cypraea	
Mollusc	Seahare		

Mollusc	Nudibranchs		
Mollusc	Flamingo Tongue	Cyphoma	gibbosum
Mollusc	Octopus		
Mollusc	Squid		
Mollusc	Other Snail		
Mollusc	Sea Slug		
Echinoderm	Feather Star		
Echinoderm	Sea Star		
Echinoderm	Brittle Star		
Echinoderm	West Indian Sea Egg	Tripneustes	ventricosus
Echinoderm	Long Spined Urchin	Diadema	antillarum
Echinoderm	Long Spined Juvenile	Diadema	antillarum
Echinoderm	Long Spined Adult	Diadema	antillarum
Echinoderm	Pencil Urchin	Eucidaris	tribuloides
Echinoderm	Sea Cucumber		
Flatworm	Flatworms		
Other Cnidarian	Jellyfish (medusa)		spp.
Octocoral	Common Seafan	Gorgonia	ventalina
Octocoral	Deepwater Fan	Iciligorgia	schrammi
Octocoral	Rod		spp.
Octocoral	Plume	Pseudopterogorgia	spp.
Octocoral	Red Sea Whip		spp.
Octocoral	Flat Sea Whip	Pterogorgia	spp.
Octocoral	Corky Sea Finger	Briareum	asbestinum
Black Coral	Black Coral Bushy	Antipathes	caribbeana
Black Coral	Black Coral Wire	Cirrhopathes	leutkeni
Anemone	Anemone (Sea)		
Anemone	Anemone (Tube)		spp.

Appendix B: Coral Diseases prevalent in Tobago

Coral Disease	Cause	Coral genus' affected	Prevalence in Tobago	Symptoms	References and other information
Yellow band disease	Bacterial: <i>Vibro</i> complex.	Most commonly affects corals from <i>Montastraea</i> genus. Other coral species rarely affected	High	- Multiple yellow or white rings, spots or bands. - Some show colour gradient across band.	Often confused with bleaching, other white syndromes, and predation. Prevalent during summer/autumn, but may extend through winter/spring.
White Plague	Bacterial: <i>Aurantimonas coralicida</i> .	Affects over 40 spp. of non-acroporid corals.	Medium	- White band starts advancing from sediment interface, crevices in the colony or from under <i>Halimeda</i> algal mats. - Advances quickly, with no tissue sloughing off. - Leaves sharp edge between infected and healthy tissue.	Often confused with bleaching, other white syndromes and invertebrate predation. Prevalent mainly during summer/autumn
Dark Spot Syndrome	Unknown.	Primarily affects: <i>Stephanocoenia</i> , <i>Montastraea</i> and <i>Siderastrea</i>	High	- Dark irregular or rounded spots. - Tissue is always present in these areas but the area is usually depressed.	Often confused with other compromised health problems. Most prevalent summer/autumn but may extend winter/spring.
Red Band Disease	Bacterial: Cyanobacteria (<i>Oscillatoria</i> spp.), and occasionally <i>Schizothrix</i> spp.	Commonly affects Octocorals (<i>Gorgonia</i> , <i>Plexaura</i> etc.) and also: <i>Agaricids</i> , <i>Meandrina</i> and <i>Mycetophyllia</i> hard corals.	Medium	- On seafans appears as a fussy red band. - On other octocorals and hard corals the red band may be more	Often confused with Black Band disease. Prevalent mainly during summer and autumn.

				compact and darker in colour.	
White Band Disease	Bacterial: <i>Vibrio charchariae</i> .	Only affects <i>Acropora</i> spp.	Low	- Wide, white band of bleached coral skeleton. - Separates areas of algae colonised tissue. - Tissue strings sometimes observed sloughing off.	Often confused with other white syndromes and predation from invertebrates. Prevalent in summer/autumn
Aspergillois	Fungal: <i>Aspergillus sydowii</i> .	Only found on Octocorals, commonly: <i>Plexaura</i> , <i>Plexaurella</i> , <i>Pseudopterogorgia</i> , and <i>Gorgonia</i> .	High	- Purple bands/patches around infected area. - Under close inspection, fungal hyphae maybe visible in infected tissue.	Prevalent all year.
References: Information in this table summarised from: - Weil, E. and Hooten, Anthony, A. J. (2008) <i>Underwater cards for assessing coral health on Caribbean reefs</i>. [online] Available at: http://coraldisease.org/diseases. [Accessed on 01/06/2012] Other useful information available from: - Raymundo, L. J., Couch, S. C. and Harvell, C. D. eds. (2008) <i>Coral disease handbook: Guidelines for assessment, monitoring and management</i>. [online] Available at: http://www.coraldisease.org/diseases. [Accessed on 01/06/2012] - Weil, E., Smith, G. and Gil-Agudelo, D. L. (2006) Status and progress in coral reef disease research. <i>Diseases of Aquatic Organisms</i>, 69:1–7.					