

**Developing marine management strategies
against regional eutrophication in Caribbean
small island nations with limited financial
and logistical resources**

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Declaration

I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where stated otherwise by reference or acknowledgement, the work presented is entirely my own.

Signed



Stuart P Wynne

September 2016

Executive Summary

Coral reefs are threatened globally, with habitat degradation and associated resource losses of primary concern. In the Caribbean region these losses have been increasingly well documented over the last forty years, but no clear consensus reached as to their cause. Over recent years however it has become generally accepted that it is multiple interacting factors behind the decline in coral reef health, including (but not limited to): over-fishing, climate change, and reductions in water quality. With climate change a regional stressor that can't be directly managed on a local level, management usually focuses on over-fishing and water quality. In the past, this latter factor was usually considered to be of a local nature and thus easily managed; that it was primarily caused by local sources of water pollution (such as sewage outflows, agricultural runoff, and industrial waste), and only affected the relatively limited surrounding geographic area.

Using the small, relatively undeveloped island of Anguilla as an example, this thesis set out to illustrate how habitat degradation is taking place in the Caribbean, even when local water quality stressor appear absent, and the implications of degradation for management. It is hypothesised that broad scale degradation may be due to fresh water river plumes that emanate from the Amazon and Orinoco, laden with nutrients from intensive farming in northeastern South America, entering the Caribbean basin via north Brazilian current rings. The nutrient levels within these plumes may have increased with deforestation of the Amazon Basin that accelerated during the 1970's. Since then, nutrients have been entering the Caribbean region, and via retention and recycling mechanisms, have been gradually building up ever since. These regionally sourced nutrients may be one of the main reasons behind the coral-algae phase-shift in the Caribbean; widely attributed to be causing the overall decline in habitat health throughout the region. It is proposed that the build-up of nutrients has now reached a level that is becoming more readily observable through signs such as the large regional plankton blooms (or Green Water Events) of 2009 and 2010 and the *Sargassum spp.* inundations of 2011 and 2014. Previously, without these unprecedented events, signs of eutrophication had been limited to the high abundance of macroalgae on Caribbean reefs, and discussions focused upon how much of this was due to the *Diadema antillarum* (Long-spined Sea Urchin) die off and/or over-fishing versus local nutrient sources.

If water quality is indeed a regional stressor in a similar way to climate change, management options within the Caribbean region become more limited. Focus now has to be placed on local fisheries management and minimizing any potential local sources of water pollution. Ecological assessments are essential when developing these management strategies, but they can be time consuming and expensive. Such resource constraints are often the limiting factor for many small island nations and one of the primary reasons for insufficiently managed protected areas around the globe. In an attempt to overcome this issue, an ecosystem health ranking tool was developed that uses only five ecological variables to ascertain habitat health, and allows managers to identify conservation priority areas. The most effective five variables to use were: percentage coral cover; percentage macroalgae cover; number of fish species; total fish count; and mean size of commercially/ecologically important fish species.

Ecological monitoring, while being the essential foundation work for any managerial regime, must be complimented with all necessary fishery information. Often much of this can come from literature reviews and employing the precautionary principle, but if knowledge gaps exist for any fisheries following this process, a full assessment is necessary to ensure correct management. Again, as with ecological assessments, fishery assessments can be time consuming and expensive. However, by employing the help of local fishers and retail outlets, methodologies are available that minimize these resource constraints. This was undertaken for the *Panulirus guttatus* (Spotted Spiny Lobster) fishery in Anguilla, and used a novel approach to assess both minimum maturity sizes and breeding seasons for the species. Based on the results of the assessment, it is recommended to introduce a minimum landing size of 52 mm carapace length in order to mitigate the potential of the hand-capture fishery capturing immature individuals, and a closed season of three months duration, January through March, to protect breeding females. By characterizing flaws in conservation managerial processes that often lead to stalling or insufficient management, a further critical stage that lies between these conservation assessments and management plan design was identified: deciding which stressors were influential; which can be managed against; and how best to conduct this management. In order to bridge this gap a model was developed that employed a threat assessment phase, where ecological monitoring data was used to identify stressors with management potential. This process used rapid assessment methodologies to examine stressors and the effectiveness and implication of stressor management. The culmination of the structured approach to integrating survey information and threat assessments is a more robust and realistic set of management objectives. This is illustrated in this thesis by a plan for marine conservation in Anguilla, which was subsequently accepted by the Island's government.

Chapter 1

The case for regional eutrophication in the Caribbean and potential impacts on coral reef ecosystems and their management: A literature review and observational account

Introduction

Habitat degradation in coral reef ecosystems has been well documented now for a number of decades (Goldberg & Wilkinson, 2004), with wide ranging causes that can all be traced back to an anthropogenic source. These causes (or stressors) are all ultimately derived from human population growth and the stress that trying to support such a population puts onto natural systems (Jameson, 2008). In terms of management, it is not possible in real time to address this ultimate cause, whether on regional or local levels, instead secondary or (more often) tertiary stressors are those that management must focus upon. Of these secondary stressors, eutrophication has been the subject of intense scientific debate over recent years (Szmant, 2002). Coral reefs are naturally oligotrophic systems, but when located near population centres or industry, nutrients invariably enter this system and cause nutrient enrichment (Angelo & Wiedenmann, 2014). It has been known for a number of years that this enrichment promotes algal growth, which itself can be viewed as one of the main tertiary stressors. It is at this level that multiple stressors may start interacting (for example: reduced numbers of herbivores) and all ultimately contribute, in this case, to coral reef habitat degradation (Hughes, 1994). The scientific debate has related to whether these nutrients also cause negative effects on coral physiology (Szmant, 2002). Recent evidence suggests that exposure of corals to increased levels of nutrients can induce a number of negative responses (Fabricius, 2005; Dunn *et al.*, 2012). Wiedenmann *et al.* (2013) suggest that past discrepancies are due to the negative physiological effects of increased nutrient levels on corals not always being witnessed by observers, as all essential nutrients were available at sufficient concentrations to ensure their chemically balanced growth; a situation that is rarely the case if an overall reduction in water quality occurs (i.e. nutrient levels not being the only variable in question). They also introduce the concept that nutrient starvation of zooxanthellae may result from accelerated growth at increased nitrogen levels.

In the Caribbean region this debate is of particular interest as coral reef degradation has been occurring at an alarming rate (Gardner *et al.*, 2003), with a well-documented 'phase-shift' in the coral-algae balance witnessed in many areas (Hughes, 1994). This phase-shift is particularly easy to observe in areas with a local nutrient source (Lapointe *et al.*, 1997; Goreau, 2008), and accentuated where fishing pressure is high (Angelo & Wiedenmann, 2014), and other herbivores lacking, for example the sea urchin *Diadema antillarum* (Lapointe, 1999). It is often observed that this phase shift is not as readily visible in areas at further distances from these local sources of nutrients and fishing pressure. Angelo & Wiedenmann (2014) point out this is due to nutrient

dispersal and that healthy coral reefs can exist over a broad range of natural nutrient environments at the lower end of the concentration scale. This does not appear to be the case in Anguilla, the most northerly of the leeward islands in the Caribbean (figure 1.1); a small low lying coralline island with a relatively small population, no concentrated urban centres, and little industry. Increasing levels of macroalgae have been recorded here since the 1990's (Oxenford & Hunte, 1990). Although some minor land-based nutrient sources are present, many of these are naturally occurring (i.e. salt ponds¹) and with very little farming taking place, overall nutrient input into the marine environment is considered minimal. Of the nutrient sources present, there is: a golf course whose incorporated salt pond has been connected to the sea; a landfill site that may leech into the ocean; and a small number of hotel developments and/or houses whose aging septic tanks may also leech into the sea. Coastal developments and removal of beach flora may also lead to increased run-off during times of heavy rain. High levels of macroalgae have not been recorded close to these sources, so although they ultimately need to be addressed, it is concluded that prevailing currents carry nutrients away relatively rapidly. Fishing is popular on the island and *D. antillarum* has still yet to fully recover from its die-off in the early 1980's (Lessios, 1988). These two factors, in combination with the (albeit limited) local nutrient sources, are those usually attributed to the high level of macroalgae observed in the surrounding areas. This conclusion has been backed up in the past by the fact that offshore areas away from mainland Anguilla often have lower levels of macroalgae, although this may be due to other environmental conditions or a general reduction in anthropogenic disturbance. Either way, the level of macroalgae found on most reef areas around Anguilla does not seem representative of local nutrient sources and instead suggests a general background level of eutrophication.

In the past, effects from nutrients originating from local sources were usually only recorded in enclosed bays or river catchment areas (Donnelly *et al.*, 1998). Here, blooms of phytoplankton were often the result, although the fast removal of nutrients suggested effects on coral physiology were limited (Szmant, 2002). Recent findings suggest otherwise with studies that demonstrate nutrients in flood plumes can be transported distances greater than 50km (Angelo & Wiedenamnn, 2014). Aside from direct physiological damage to coral however, the blooms themselves can travel large distances before reaching coral reefs, as was recorded in 2002 in the Florida Bight (Hu *et al.*, 2003; Hu *et al.*, 2004). Here, coral communities were impacted by the toxic decay products of the dinoflagellate *Karenia brevis* (during a so called 'red tide') and

¹ Shallow rain filled bodies of water usually close to the coast but separated from the ocean often by only narrow strips of land. Sea spray and storm inundations over the years have led to most being saline in nature, and in the past many were used to harvest salt.

resulted in increased coral mortality during its two month duration. This coincided with a 40% loss of hermatypic coral species after a relatively stable percentage cover of between 15-20% for the five previous years.

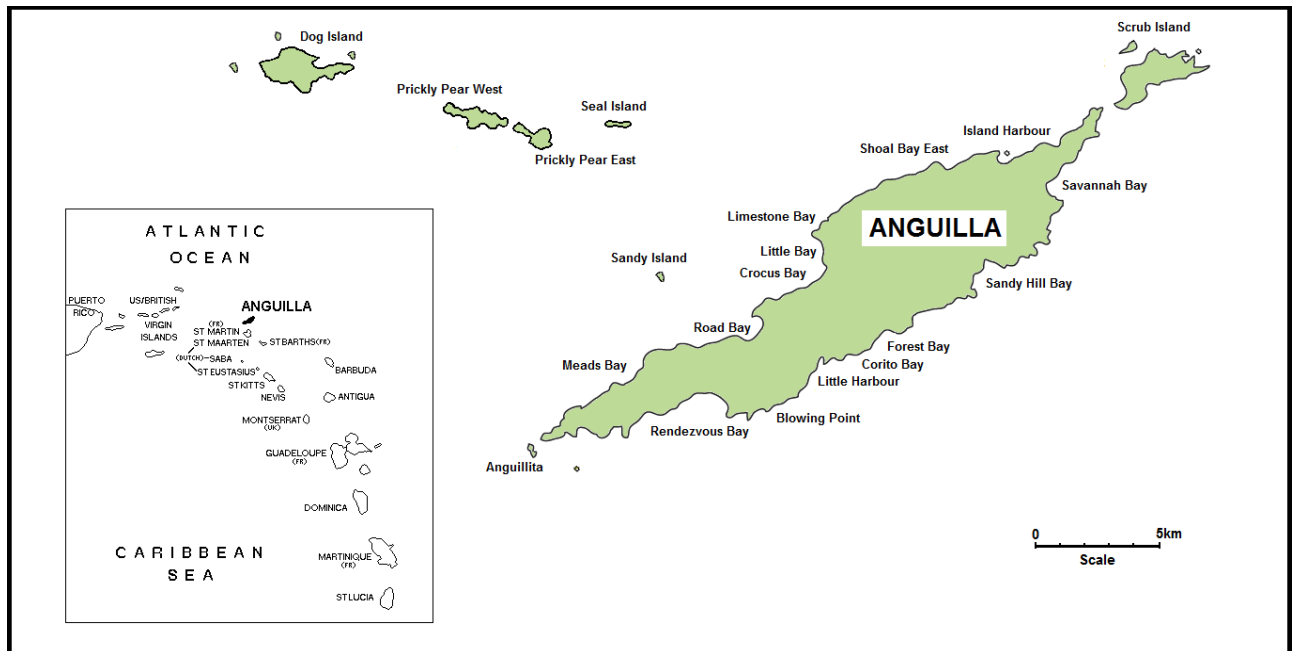


Figure 1.1: Map of Anguilla and its offshore cays, with its location in relation to other island illustrated in the inset situational map of the eastern Caribbean. Many of the locations referred to throughout this thesis have also been labelled.

Although coral mortality events cannot always be tied to phytoplankton blooms conclusively, the 2002 event in Florida does illustrate how an influx of nutrients can cause such a bloom, and how long this bloom is potentially able to last in the water column. Prior to this 2002 event, other less documented yet similar events occurred in the Caribbean region, although often their source was not established. Subsequently however two abnormally large blooms occurred in the eastern Caribbean during 2009 and 2010 that appeared to originate from the coast of South America's Orinoco and Amazon river plumes, spreading across the entire Caribbean Sea to Puerto Rico (Johns *et al.*, 2014). No direct detrimental effects have been reported for these two blooms, or 'green-water' events (due to the iridescent green colour water observed), although their occurrence is suggested here to represent evidence of an overall increase in nutrient levels throughout parts of the Caribbean, backed up by increasing signs of tertiary effects in areas such as Anguilla that are devoid of high levels of local nutrient sources.

Through river plumes and run-off, sediments and land based nutrients have historically entered the Caribbean basin at unquantifiable historical baseline levels, but increasing loads since the early 1980's continue to impact coastal ecosystems (Restrepo *et al.*, 2006). Industrialisation, intensive farming and deforestation have led to an increase in nutrient inputs (Heileman, 2007), likely originating in the Gulf States, and passing through the Florida Straits out into the Atlantic. Indeed, it follows that this flow and nutrients emanating from sources such as the Mississippi supply nutrients to the Sargasso Sea and help sustain the growth of Sargassum in the area. Another source into the region would have been from the South American coast and associated river plumes. Since the 1970's changing land-use patterns in South America's Amazon region have likely led to these river plumes having increased nutrient loads, with ocean currents pushing these nutrient rich waters into the Caribbean. Circulation patterns responsible for this are discussed later and include mechanisms that may trap nutrient rich water within the Caribbean basin, or recycle it back into the region from the Sargasso Sea. It is hypothesised that these mechanisms have led to a gradual increase in background nutrient levels in the Caribbean, and responsible for the tertiary effects observed in Anguilla. Even though inputs from the Amazon may no longer be increasing at the rate they did towards the end of last century, background levels may now be at a concentration that during times of high rainfall in the Amazon (i.e. during El Niño events), the mixing of the two water bodies can now produce these extended blooms (Johns *et al.*, 2014).

This thesis presents evidence of this regional eutrophication theory and illustrates it with examples of the observable secondary effects, together with suggested mechanisms behind nutrient input and retention in the Caribbean. Using Anguilla as an example, evidence is also presented supporting the case that these regionally influential sources are, on a local level, likely more detrimental in the long-term to coral reef habitats than moderate to low local point sources. Management against these tertiary effects will also be discussed.

REGIONAL EFFECTS OF EUTROPHICATION

Green Water Events

Early Reports: Although the earliest reports of actual large scale phytoplankton blooms were not made until the mid-late 1990's, the satellite image presented in figure 1.2 illustrates the plume of induced high productivity nutrient rich water emanating from the Orinoco River and along Brazil's north-eastern coastline from the Amazon River in October 1979. During the rainy season the fresh water from these rivers are carried by the predominant currents into and extending over much of the Caribbean basin. These river catchments encompass most of Venezuela, Columbia and northern Brazil. The river outflow is enriched in nutrients, and being less dense than seawater it remains on the surface, gradually breaking up into lenses of less saline water.

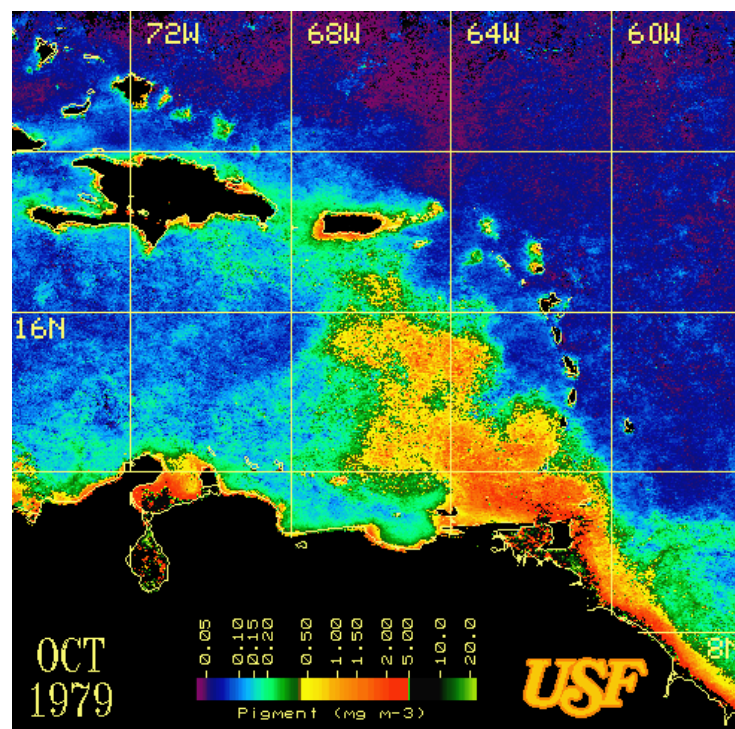


Figure 1.2: Composite image taken by the Coastal Zone Colour Scanner (CZCS) of the eastern Caribbean Sea for October 1979, showing the spatial extent of the Orinoco River plume of induced high productivity that occurs during the summer rainy season. (Image courtesy of Dr. Frank Muller-Karger, University of South Florida Remote Sensing Laboratory).

It would seem however that nutrient levels were not sufficient to induce algal blooms that could be sustained during the journey this plume makes across the Caribbean basin until recent years. Reports of green water events from the 1990's all stem from unknown or locally based nutrient sources. For example, one such event was documented to occur around the Florida Keys after the South Florida Water Management District released tons of dirty agricultural runoff from the Everglades agricultural area (Dr B.Lapointe, pers comm.). Although this event might essentially be considered as originating from a local point source, it was of sufficient scale to be considered of semi-regional significance. Other reports during 1991-1992 refer to sponge mortality during a cyanobacteria bloom caused by increased nutrient loading (Herrnkind *et al.*, 1995; Butler *et al.*, 2005; Stevenly *et al.*, 2010), with Peterson *et al.*, (2006) stating that these events have actually been occurring in Florida since 1987 and may be caused by lowering sponge populations and their filter feeding capacity similarly lowering. Peterson *et al.* states 'Some investigators have suggested that a new source of nitrogen or phosphorus is fuelling the elevated phytoplankton biomasses observed over the last decade in the north-central basins of Florida Bay. An alternative hypothesis is that the loss of the dominant suspension feeding grazer (i.e. sponges) from this area of Florida Bay has rendered a system-wide trophic dysfunction, resulting in the initiation and great magnitude of the phytoplankton blooms.' However, Boyer *et al.* (2006) presents evidence of dissolved organic matter being the source of these blooms in Florida, irrespective of whether a higher sponge population could mitigate against it. Similar localised events in Belize during 2011 reportedly killed off a significant portion of the sponge population. Wulff (2013) states 'The sponge mortality coincided with a clear environmental anomaly, an extremely dense phytoplankton bloom covering the entire southern portion of the Belize Barrier Reef for much of July–August 2011. Visibility at the census site was less than 30 cm for much of the monitoring.'

Most of these early and/or localised events usually fall into the broadly generalised category of a red-tide: blooms of often toxic dinoflagellates or other single celled algal species that discolour the water (Anderson, 1995). Actual 'green-water' events, where the water turns an iridescent green colour due to high levels of non-toxic phytoplankton were not reported until 2009, and again in 2010.

The 2009 & 2010 events: Satellite ocean colour images (figure 1.2) have illustrated since they were first produced in the early 1980's that productive water plumes deriving from the Amazon and Orinoco are delivered annually, on a strong seasonal cycle, to the western tropical Atlantic Ocean and eastern Caribbean Sea via prevailing currents. These plumes can be identified

travelling across great distances, eventually dissipating as they mix with the saline sea water. As described by Cherubin & Richardson (2007), and later Johns *et al.* (2014) after the peak of seasonal rain occurs during June/July in the north-eastern region of South America, freshwater plumes spread seasonally north-westwards across the Caribbean basin. These plumes are sustained by two main inflows from the North Brazil Current (NBC) and associated current rings (NBCR). The NBCR are created from the NBC as it turns offshore and flows east towards Africa as the seasonal North Equatorial Counter-current is established (figure 1.3). Of the two main inflows, one enters the Caribbean Sea as it passes south of Grenada to become the main branch of the Caribbean Current in the southern Caribbean, while the second passes northwards of St Vincent towards the Leeward Islands. As the NBCR stall and decay east of the Lesser Antilles they release fresh water into the northern part of the eastern Caribbean Sea as it merges with the inflow from the North Equatorial Current (Fratantoni & Richardson, 2006).

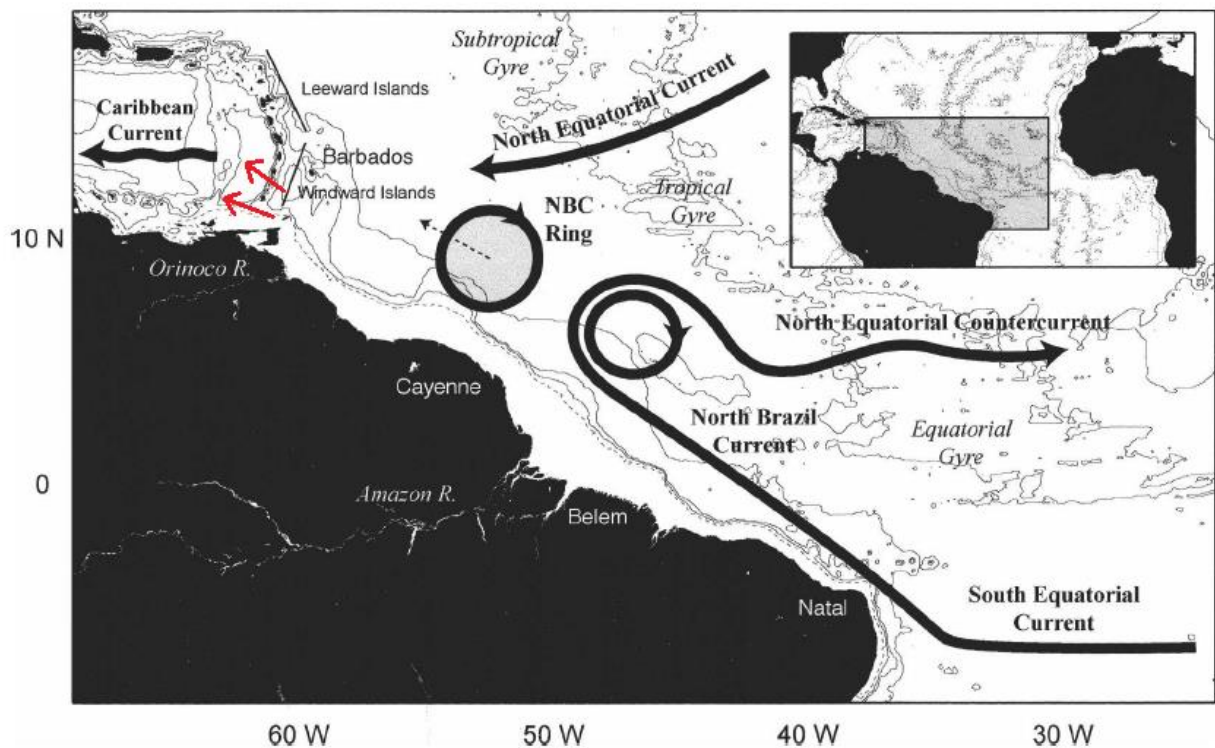


Figure 1.3: Circulation in the western tropical Atlantic Ocean showing predominant currents and the formation of North Brazil Current Rings. The 200m (dashed), 1000m, 2000m, and 4000m depth contours are shown (Fratantoni & Richardson, 2006). Two small red arrows have been superimposed to represent the current inflows into the Caribbean basin.

The dispersal of the Amazon River plume is difficult to discern completely as it varies from year to year in both size and location, and the input of the Orinoco directly into the Caribbean Sea means that the effect of each individual plume is hard to trace (Johns *et al.*, 2014). Normally however, these plume waters enter the Caribbean to the south between May and September, and then disperse widely throughout the region leading to slightly higher turbidity relative to the clearer oligotrophic waters naturally present in the area. However, in 2009 (and again in 2010) a major river plume event took place that was traced back predominantly to the Amazon, with addition of waters from the Orinoco, that caused extremely high levels of turbidity through heightened planktonic loads and associated chlorophyll-a concentrations (figure 1.4). Between April and June 2009 this water engulfed the Saba Bank, Virgin Islands and Anegada Passage, although it was not observed as far northeast as Anguilla (S.Wynne, pers. obs.). Based on the lack of previous reports it can be concluded that such a regionally dominating ‘green-water’ event had not occurred during the last 30 years. Johns *et al.*, (2014) who were conducting research in the area at the time studied this event and found that larval fish assemblages within the plume were significantly different from those of the surrounding waters, and from those encountered in the area in previous years.

Although the images in figure 1.4 could lead to the conclusion that the 2009 ‘Green Water Event’ (GWE) was part of the Orinoco plume, careful examination by Johns *et al.* (2014) of daily and weekly mean chl-a images from various sources painted a more complex picture. They put together a scenario showing that high chl-a water north of c.14°N immediately west of the Antilles is contained in boluses of Amazon water. These boluses moved across the island chain and started to travel rapidly north, with green water enveloping the Virgin Islands during the first week of April 2009. By May the plume had spread westward to 72°W and northward to 20°N into the Atlantic Ocean, although chl-a concentrations between 0.3 and 0.5 mg m⁻³ and higher remained in the vicinity of the Virgin Islands through June 2009. It is thought that this event took place due to increased NBCR activity, as seen by a second mass of Amazon River water observed to the east of the central Caribbean island arc. The NBCR’s finally dissipated by the end of September. Under less active conditions it is thought that the NBCR’s would dissipate before reaching the northern islands. As such any GWE would take place in the central Caribbean region away from any land masses as seen in figure 1.2. Johns *et al.*, (2014) states that based on monthly climatological data between 1997 and 2010, the extent of chl-a ≥ 0.7 mg m⁻³ does not normally exceed 14°N.

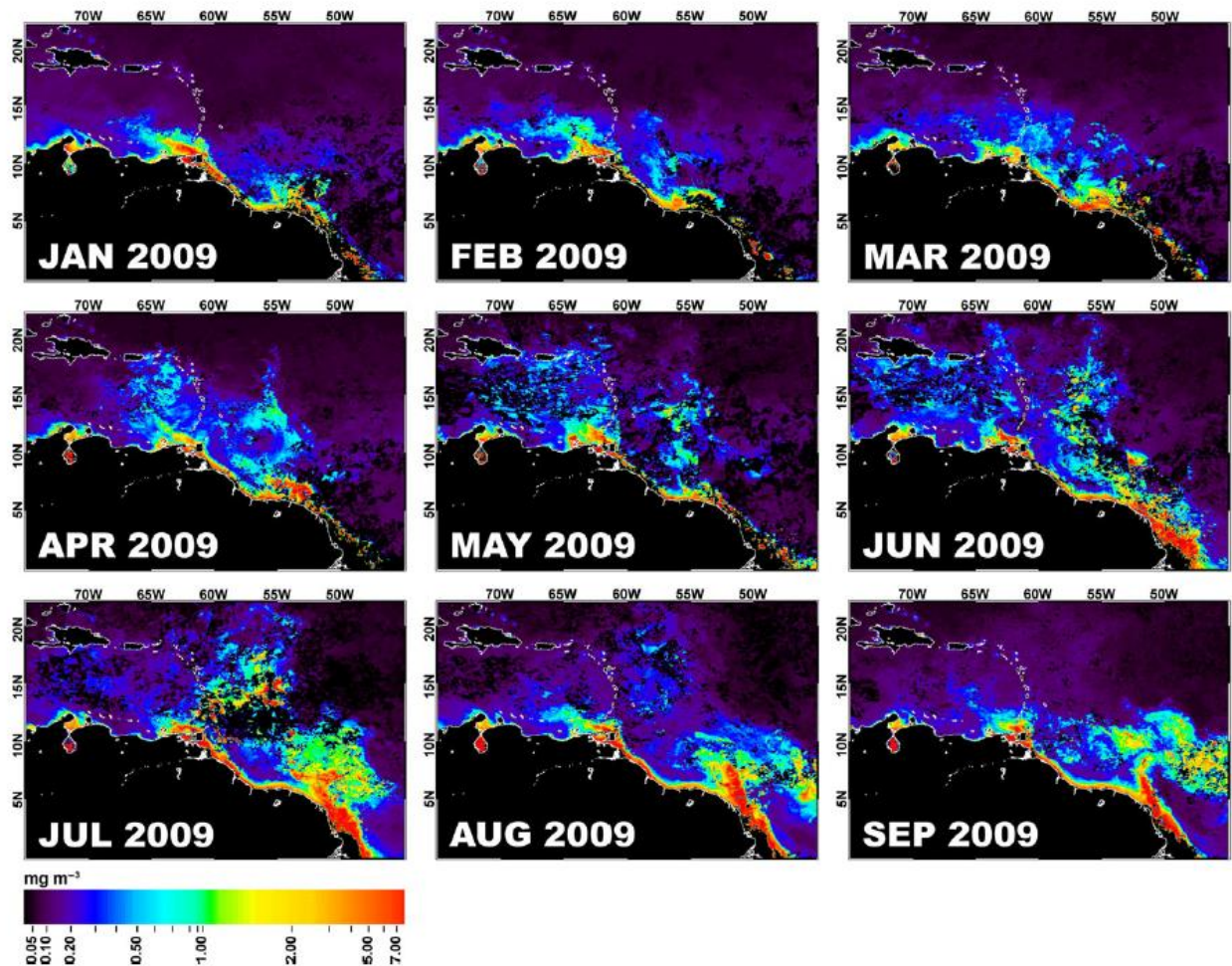


Figure 1.4: Monthly chlorophyll-a (chl-a) concentration (in mg m^{-3}) composite images derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra satellite sensor, January to September 2009. Images produced by the University of South Florida (USF) Institute for Marine Remote Sensing (IMaRS). Johns *et al.*, (2014).

Despite the normal southern limits of highly productive waters reported, an extreme plume event leading to another GWE again took place in 2010 (figure 1.5). This event, although not as widely studied as that in 2009, is considered to have been more extensive as it reached further northwest, partially enveloping Anguilla by the 7th of July 2010 (Wynne, 2010). Reports stated that ‘the waters were incredibly turbid with visibility at times lower than one or two metres’. Unfortunately a full study of this event in Anguilla was not undertaken as it was very short lived and conditions returned to normal after a couple of days. Furthermore the GWE seemed only to affect the eastern end of Anguilla around Anguillita Island and its surrounding waters. Western areas were not reported to be affected, and so it follows that Anguilla represented the north-western extent of the GWE and associated plume.

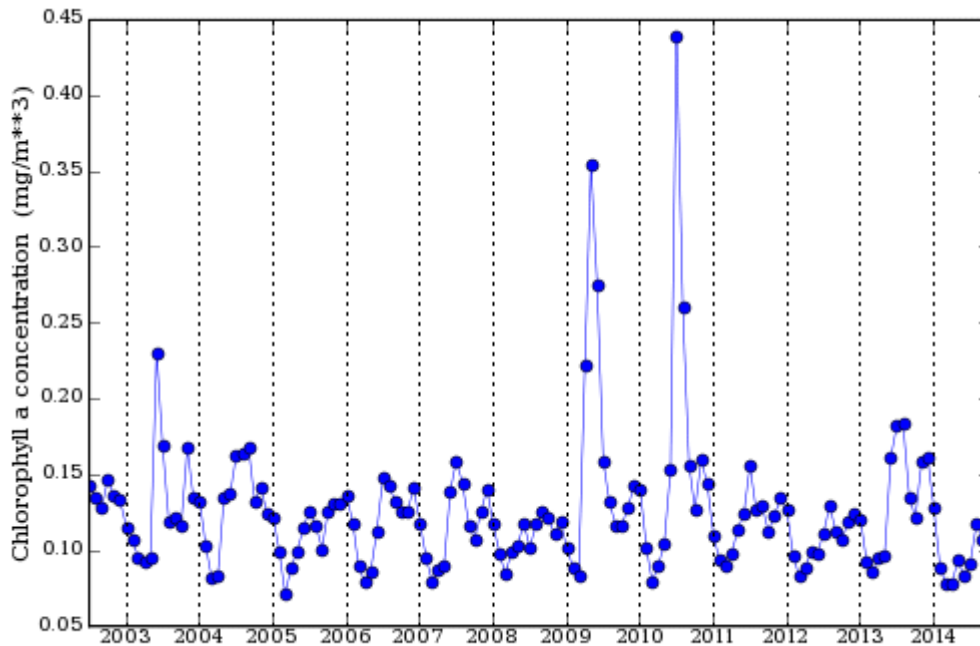


Figure 1.5: MODIS area-averaged time series for Chlorophyll-a concentration in the Caribbean (region covering 67°W-62°W, 17°N-19°N) illustrating peaks in 2009 & 2010, combined with smaller yet notable elevation in 2003. Data taken from <http://modis.gsfc.nasa.gov>. Other visualisations produced via data from the SeaWiFS sensor produce elevated peaks, with an additional elevation recorded for 2000. In these projections the 2010 chl-a peak surpassed the 2009 readings by nearly a factor of two (Johns *et al.*, 2014).

The Future: Precise reasons for the 2009 and 2010 elevations and associated GWE remain unclear and need further study. No strong correlations were found between the results presented in figure 1.5 and the North Atlantic Oscillation, El Niño/La Niña or rainfall means in the Amazon basin. For example, Brito *et al.* (2014) describes La Niña episodes in 2008 and 2011 where rainfall extremes increased, and El Niño years of 2005, 2007 and 2010 where rainfall extremes over the Amazon basin were reduced. It is probable that rainfall levels, which are influenced by these oscillation events, play a role in the amount of terrestrial nutrient runoff, but that this role is complex and in turn influenced by related factors such as increased freshwater dilution and climatic variations driving ocean currents and mixing. Nonetheless, based on older satellite imagery it is clear that these nutrient rich waters have been entering the region for many years (figure 1.2) but may have been overlooked as associated blooms might not have reached populated islands. Blooms of lesser extent than seen today would have been the dominating phenomenon due to the proposed ocean current recirculation mechanisms for regional

eutrophication presented later in this chapter. It is also possible that, combined with this regional eutrophication, blooms are increasing in extent due to (for example), changing land use patterns or drainage policies in South America. Although it is documented that deforestation rates are decreasing in the Amazon basin, increases in agricultural dependency on fertiliser use or changes in farming intensity or commodity (livestock vs arable) needs consideration. To reliably project future scenarios these factors need further study and more detailed models produced.

Sargassum Blooms

The Sargassum Event of 2011: Free floating species of Sargassum Seaweed² have been studied for nearly 200 years, and form extensive aggregations trapped in the North Atlantic Ocean gyre. This area, known as the Sargasso Sea is fed significant amounts of Sargassum that originates from the Gulf of Mexico (Gower & King, 2011). Surveys conducted using the global MERIS dataset (Gower *et al.*, 2006), and combined with later work conducted by Gower & King (2011) have shown an annual cycle of Sargassum distribution in the Gulf of Mexico and North Atlantic, with considerable inter-annual variation. This variation however does not usually extend to the Caribbean Sea where only small amounts of pelagic Sargassum are usually found. This changed in 2011 when a major ‘Sargassum event’ occurred in the Caribbean Sea bringing huge amounts of seaweed onto the beaches of many of the islands in the region (Gower *et al.*, 2013). This event had a significant effect on local tourism while also clogging bay areas and adversely affecting boat usage and therefore fishing. When washed up the rotting seaweed produced a pungent sulphurous odour and can entangle nesting turtles and other wildlife (figure 1.6).

Based on historical records initial suggestions as to the origin of the weed were the Sargasso Sea or the Gulf of Mexico, and the event attributed to changing currents and increasing variability of the Gulf of Mexico and North Atlantic annual cycle. The work conducted by Gower *et al.*, (2013) however suggests a new and alternative source. Through satellite observations this study presented evidence that the Sargassum event had its origin north of the mouth of the Amazon in an area not previously associated with Sargassum growth. Initially detected in April 2011 approximately 7°N and 45°W, by July it has spread to the coast of Africa in the east to the Lesser Antilles and the Caribbean in the west (figure 1.7). Gower went on to report that such large amounts of Sargassum were unprecedented even to the older inhabitants of the Lesser Antilles,

² ‘Sargassum Seaweed’ is the common name that relates to two species, *Sargassum fluitans* & *Sargassum natans*. For ease of reading this common name has been abbreviated to ‘Sargassum’ throughout.

who stated that it is common for a pile to wash up now and again for relatively short periods but ‘we have never in recent memory had so much of it for so long and seen such huge mats or lines of it from the air’.



Figure 1.6: Sargassum on the east coast of Barbados during the 2014/2015 inundation event. Photo courtesy of Hazel Oxenford, September 2014.

At the time the cause of this large shift in distribution was unclear, although Lapointe (1995) reported a possible connection between Sargassum blooms in the Gulf of Mexico and nutrient rich waters originating from the Mississippi plume. Gower *et al.*, (2013) suggest a similar link with nutrient laden waters from the Amazon River plume and above normal run-off ascribed to anomalous rainfall associated with La Niña could have been a significant source of nutrients to the equatorial Atlantic. The peak biomass that year was 200-fold higher than the previous eight years’ average biomass peak recorded in the Caribbean, and it was the first time that drifting Sargassum reached the coast of Africa (Smetacek & Zingone, 2013). By the end of the year however most of the Sargassum had dissipated and levels returned to normal after the nutrient reserves were presumably spent.

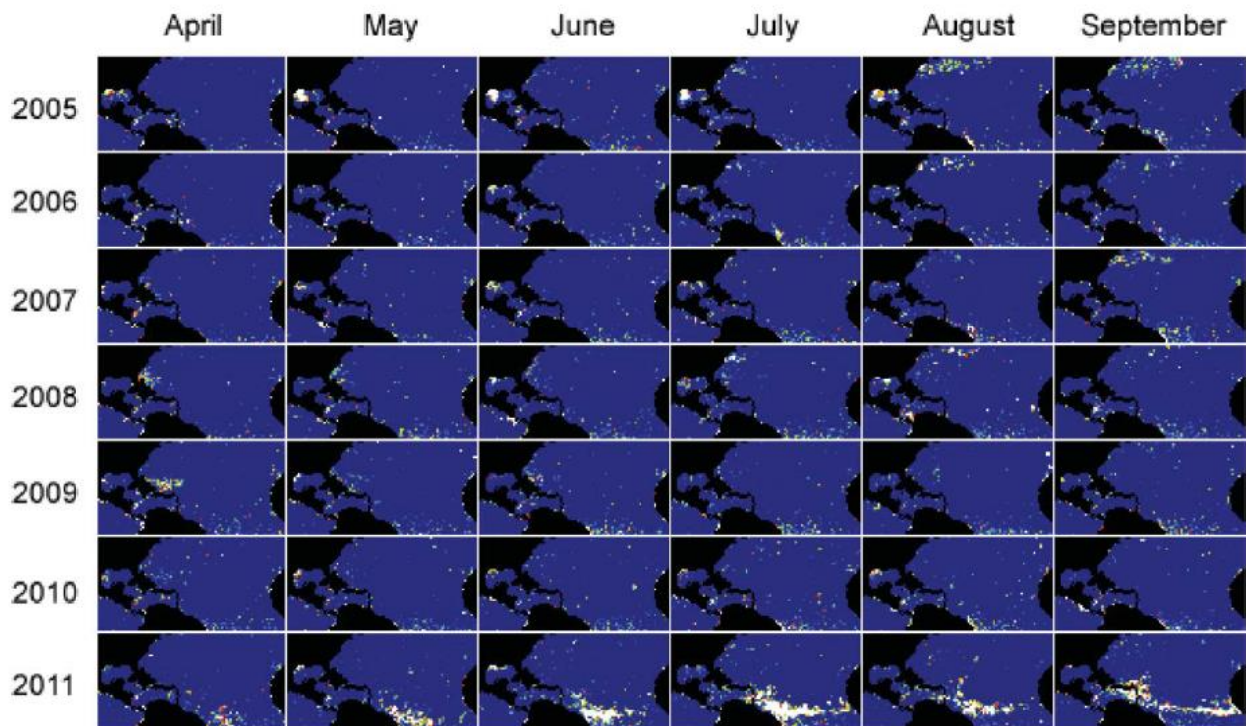


Figure 1.7: Monthly time series of MERIS between 2005 and 2011 of Sargassum detection counts for the area $0^{\circ} - 45^{\circ}$ N and $100^{\circ} - 10^{\circ}$ W covering the Gulf of Mexico, Caribbean and tropical Atlantic across to the west coast of Africa. Land is masked to black. The large area of high signal off northern Brazil shows white at the bottom of the lowest row and extends from the Caribbean to Africa in July and September 2011 (Gower *et al.*, 2013).

The Sargassum Event of 2014/2015: Following the 2011 Sargassum event, or ‘Golden Tide’ as it is sometimes referred to, sporadic reports came in of unusual amounts of Sargassum being deposited on beaches in the Caribbean Region (Moreira & Alfonso, 2013), although most were short lived and in areas where past deposits had been reported over recent decades. This changed during the latter half of 2014 however, when large amounts once again began washing up on beaches Caribbean wide, from Tobago to Antigua to San Andres Island (Gavio *et al.*, 2014). By the end of October that year seaweed drifts had built up as high as 3 to 4 feet, and once again began choking fishing ports and tourist beaches. The 2014 event did not dissipate towards the end of the year, with deposits continuing on into 2015. The latest reports, dating from early 2016 continue to describe large amounts of the weed washing up throughout the Caribbean. Most sources state that in their regions it has surpassed the severity of the 2011 event, most notably in peripheral regions that weren’t affected at all by the earlier event (Gavio *et al.*, 2014). Although

climate change is likely to be playing a role in the growth and distribution of the Sargassum (increasing sea surface temperatures facilitating rapid growth for example), nutrient rich water from the Amazon River is now widely attributed as the main cause of the 2011 event (Johnson *et al.*, 2013; Lum, 2014), with research on the current event ongoing (Koffi *et al.*, 2016).

Similar anomalous deposits have been observed in Anguilla during 2015, with some of the most prized tourist beaches being affected. One effect that has also been noted is the fact that the rotting Sargassum on the beach, when washed by waves appears to leach nutrients back into the bay and cause localised GWE. This appears to be further accentuated by Sargassum that has been washed back into the bay and floats around slowly decomposing on the sea floor. Waters around the island that were previously pristinely clear become more turbid under these conditions. It remains to be seen if this has negative long term effects on surrounding ecosystems.

The Future: With the 2014 event persisting into 2015, the future remains unclear. Many scientists agree that it is a sign of ‘a deep problem at many levels’ (J.Franks, pers. comm.), and a sign that the eutrophication of the Caribbean region is still increasing, with the Amazon and Orinoco river plumes responsible for carrying nutrient-rich runoff from land newly deforested in the Amazon for farming (Biggs *et al.*, 2006; Neill *et al.*, 2011). Whether this is a preview of what the oceans in the 21st Century after decades of pollution, overfishing and coastal development will look like remains to be seen, but it certainly is an indicator of regional eutrophication and an example of one of the negative economic effects such changes can bring about. Ecological effects of the Sargassum itself are uncertain but it does appear to act as a vector for nutrient transport across large distances of ocean: The nutrients absorbed and used for growth close to the Amazon are locked away until their ultimate breakdown when the seaweed is washed ashore and decomposes, and often being re-released back into the ocean. Although the removal of this material from the beach is controversial due to the loss of sand resources it can be advantageous as aside from entangling unsuspecting wildlife, stranding turtles, and offending local visitors it also has the potential to become a significant local point source of nutrients.

PROPOSED MECHANISM FOR REGIONAL EUTROPHICATION

The evidence presented above illustrates a complex situation, but one where regional eutrophication sources appear to play a greater role in overall Caribbean nutrient load than smaller local sources. Historically land-based nutrient inputs would have been on a relatively small scale and dissipated naturally or been carried out of the Caribbean via prevailing currents. For example, the Mississippi plume and other sources from the Gulf States would be transported through the Florida Straits and out into the Atlantic. It is in fact likely that these waters would have fed the Sargassum growing in the Sargasso Sea and become trapped in the North Atlantic Gyre. Some recirculation from this gyre back into the Caribbean basin does take place, but nutrient levels within it at this point will have dissipated to levels low enough to theoretically have minimal overall effect. As described earlier, waters from both the Amazon and Orinoco rivers enter the Caribbean via the North Brazilian Current on a seasonal cycle. Since deforestation and intensive farming in the 1970's, the levels of nutrients in these incoming plumes have increased dramatically (Santos *et al.*, 2008). A slowing rate of deforestation over the last ten years mean the rate of increase may be lessening, although as deforested land is turned over to agriculture and intensity of both arable and livestock farming practices increases, the extent of this lessening is questionable.

These nutrient rich plumes have been entering the Caribbean for generations, although presumably levels were not elevated enough to produce an algal bloom and so largely went unnoticed. Based on recognised prevailing currents, once the blooms have dissipated (or nutrients metabolised), these waters ultimately pass through the region and out into the Atlantic. However, recent studies have shown that anti-cyclonic recirculation of surface waters can occur during certain years that infuse the Caribbean with more nutrients from along the Venezuelan coast. This recirculation also produces gyres along the north edge of the Caribbean Current which inhibit the loss of productive waters to the Yucatan passage (Jury, 2011). Although this theory (Figure 1.8) requires further study as it may not occur on an annual basis, it does provide a potential mechanism where nutrients can be retained in the region and potentially build up over time.

This process would likely be gradual, as some of the nutrient laden waters would inevitably break off into prevailing currents and/or mix with nutrient poor water bodies. However, such a build-up would also explain why blooms may be becoming a more regular occurrence even if deforestation in the Amazon (for example) is slowing. A slowing rate of deforestation suggests a

similar slowing rate of increase in nutrient input via agricultural runoff (although as suggested earlier an increased dependency of agriculture on fertilizer use has the potential to counteract this). If a gradual build-up is occurring, even lower rates of nutrient inputs may be substantial enough when mixed with already nutrified regional waters to initiate a bloom. As highlighted by the conclusions of Jury (2011), more work is needed in studying the phenomenon, including (but not limited to) a comparison of local versus regional nutrification processes.

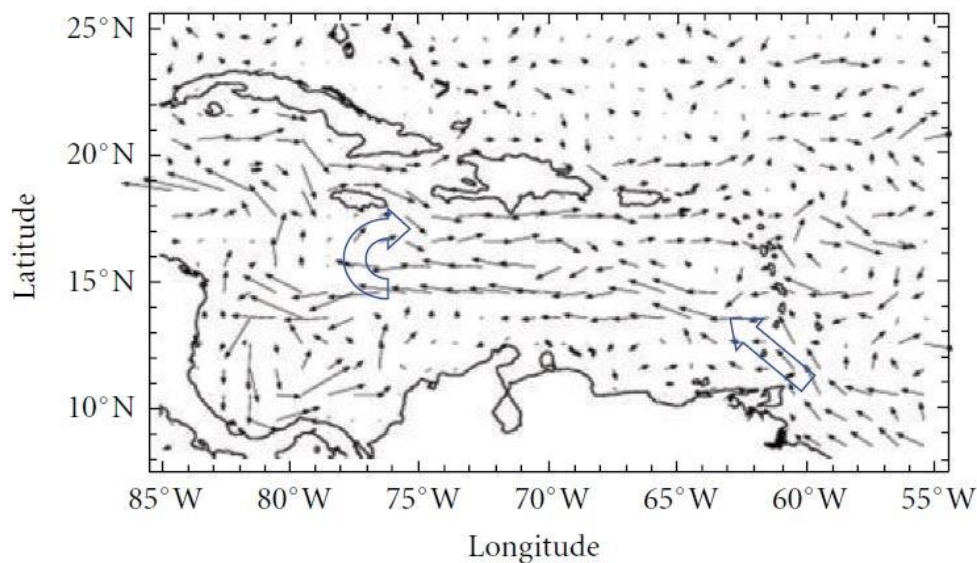


Figure 1.8: Map of 0-200m vector currents identified by Jury (2011) showing potential water current mechanism behind a nutrient build-up in the Caribbean basin. Large blue arrows depict main flow into the region and later back-cycling.

This process would likely be gradual, as some of the nutrient laden waters would inevitably break off into prevailing currents and/or mix with nutrient poor water bodies. However, such a build-up would also explain why blooms may be becoming a more regular occurrence even if deforestation in the Amazon (for example) is slowing. A slowing rate of deforestation suggests a similar slowing rate of increase in nutrient input via agricultural runoff (although as suggested earlier an increased dependency of agriculture on fertilizer use has the potential to counteract this). If a gradual build-up is occurring, even lower rates of nutrient inputs may be substantial enough when mixed with already nutrified regional waters to initiate a bloom. As highlighted by the conclusions of Jury (2011), more work is needed in studying the phenomenon, including (but not limited to) a comparison of local versus regional nutrification processes.

LOCAL EFFECTS OF EUTROPHICATION

Changes to Macro-Invertebrate Communities

Besides the controversy that surrounds the primary effects that nutrient enrichment has on invertebrate physiology (Szmant, 2002; Loya *et al.*, 2004; Fabricius, 2005; Dunn *et al.*, 2012) there are a number of reported effects at the community level. For example, the increased productivity caused by eutrophication might benefit certain coral species by increasing the availability of particulate matter that filter feeders rely on for food (Angelo & Wiedenmann, 2014). Such an effect has been suggested as the reason behind apparent increases in soft coral densities at a number of sites around Anguilla, British West Indies (S.Wynne, *pers. obs.*). These densities have reached such a level that in extreme cases they may shade and outcompete hard coral species.

Hard coral species can also be directly influenced by these primary effects either through smothering by sedimentation (Goldberg & Wilkinson, 2004), overgrowth by enhanced macroalgal vitality (Fabricius, 2005) or increased incidence or severity of disease (Bruno *et al.*, 2003). A number of hard coral diseases have been attributed to cyanobacteria growth which, as with macroalgae, is enhanced in eutrophic conditions. Incidences of coral diseases are high in Anguilla (Wynne, 2017), with the predominant cause observed to be through effects of cyanobacteria growth (figure 1.9).

As mentioned earlier, cyanobacteria growths have also been suggested to cause sponge mortality where widespread and persistent blooms coincided with the decimation of sponge communities over hundreds of square kilometres in Florida (Butler *et al.*, 1991, Herrnkind *et al.*, 1995, Stevenly *et al.*, 2010). This effect of the sometimes toxic 'red tides' can also effect higher community members (Trainer, 1999), not just macro invertebrates. However, as with the soft corals, most reports suggest that sponges benefit from most other primary effects of eutrophication - non-toxic plankton and overall increased particulate matter – and, as suggested also for soft corals, may even help to reduce suspended particles and act as bio-controls for phytoplankton blooms (Peterson *et al.*, 2006, McMurry *et al.*, 2015).

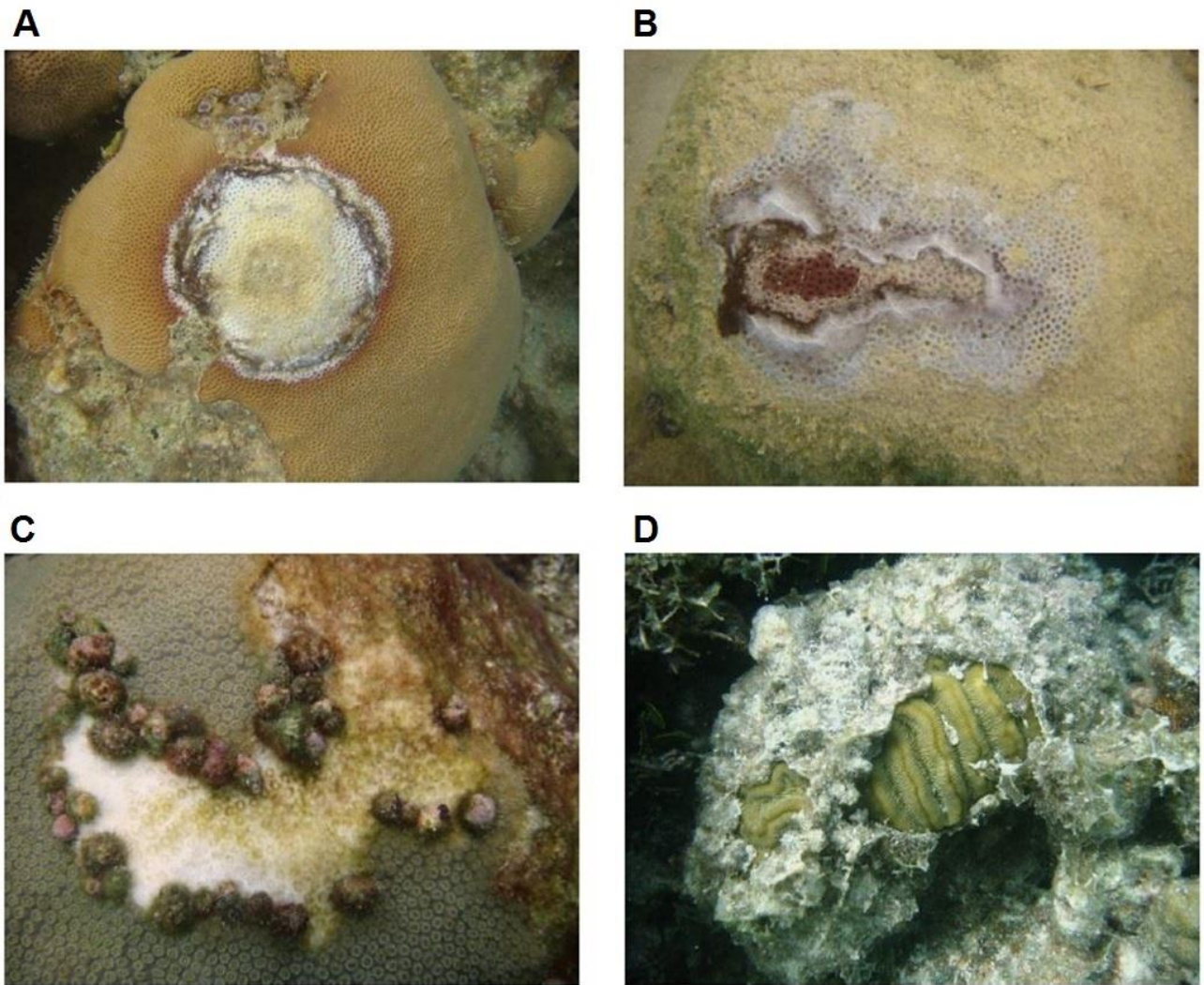


Figure 1.9: Images of cyanobacteria growth on hard corals in Anguilla: A & B - *Siderastrea siderea*; C - *Orbicella faveolata*; D - *Colpophyllia natans* (photographs by S.Wynne).

Changes to Vertebrate Communities

Aside from the toxic effects of red tides, the increased productivity that eutrophication brings has also been seen to effect fish abundances and species composition (Johns *et al.*, 2014). In the GWE of 2009 larval fish assemblages from the plume water were different from those in other water masses, where high abundances of pelagic and mesopelagic taxa were recorded. Reef and nearshore-associated taxa were lowest in the plume water, but it was suggested that they may have been displaced within the surface layers. Johns *et al.*, (2014) went on to conclude that if these events continue the ecological effects on the survival and recruitment of economically and ecologically important local reef fishes may be significant, although difficult to quantify at present.

The island of Barbados however, due to its closer proximity to the northern South America coast than the Lesser Antilles, is regularly surrounded by Amazonian plume water and so studied more extensively (Cowen, 2003). Observations showed that during some events larval fishes appeared to be rapidly advected away and resulted in a failure of larval settlement. Simultaneous changes were also observed in the vertical distribution of fish larvae. Larval fish encountering the plume waters were also seen to exhibit reduced growth rates and longer larval periods which was concluded to potentially reduce survival and ultimate recruitment success of coral reef fishes. It has yet to be established how much of these effects are caused by physical water properties versus the effects of the productivity within the waters. From other reports however, the effect of these productive waters is clear, as with the British Virgin Island reports from April 2009 (T.Baily, pers. comm.) where the GWE brought with it unusual fish assemblages, dolphins and large numbers of jellyfish.

Other reported, more obscure effects that increased nutrient levels can have on vertebrates include potential increases in cases of ciguatera poisoning and an increase in cases of fibropapillomatosis in Green Turtles (*Chelonia mydas*). In terms of the latter, parts of Florida categorised by habitat degradation and pollution have recorded a 200% increase in cases over recent decades (Foley *et al.*, 2005). Van Houtan *et al.*, (2010) reports elevated disease rates of *C. mydas* being clustered in watersheds with high nitrogen-footprints, both from natural and anthropogenic sources. It was concluded that this was due to invasive macroalgae and foraging ecology, where turtles now forage on invasive macroalgae that can dominate nutrient rich waters and affect production of the amino acid arginine. Arginine is known to regulate immune activity, promote herpes viruses, and contribute to tumor formation (Van Houtan *et al.*, 2014). These results have notable implications for understanding diseases in aquatic organisms under eutrophic conditions.

As for the biomagnification of the ciguatoxin produced by the dinoflagellate *Gambierdiscus toxicus*, a larger number of poisonings have been reported over the last five to ten years in Anguilla, with a wider range of species being linked to these poisonings (Sasso C, pers. comm.). Original reports of poisoning came from the consumption of barracuda (*Sphyraena barracuda*), but very quickly it became evident that it was also sensible to avoid larger species of jacks (i.e. *Caranx latus*), groupers (i.e. *Mycteroperca bonaci*) and snappers (i.e. *Lutjanus jocu*). Today, according to local reports, species of parrotfish (i.e. *Scarus sp.*) and surgeonfish (i.e. *Acanthurus coeruleus*) have also been responsible for incidents, which is especially interesting as these two

families are herbivores so should be less susceptible to biomagnification processes. Although no direct link to eutrophication has been established, dinoflagellates, along with cyanobacteria, can produce blooms and are known to sometimes be toxic.

Changes to Plant and Algal Communities

A Caribbean wide increase in macroalgae was initially attributed to the *Diadema antillarum* die-off in the early 1980's (Liddell, 1986; Lessios, 1988). It became problematic to corroborate this across the region as historical records are scattered, with only a handful of locations having data that reach back in the 1970's. After many years of study and deliberation it was ultimately concluded that *D. antillarum*, although a key grazing species, was only part of the picture (Lapointe *et al.*, 1997) and that other factors were also playing a key role in this 'phase shift'³ (Mumby, 2009). These factors include over-fishing of herbivorous fish (Angelo & Wiedenmann, 2014), and local sources of nutrient rich run-off and/or effluence (Lapointe 1999). As in other parts of the Caribbean, high levels of macroalgae were recorded in Anguilla twenty five years ago by Oxenford & Hunte (1990), a situation which continued for the next twenty years (Wynne, 2010) and is still gradually increasing to this day (Wynne, 2017). Here, *D. antillarum* numbers appear to be recovering in certain areas, but no clear associations with overall macroalgae cover have been observed (Wynne, 2017). As discussed later, the situation is highly complex, with other research reporting herbivorous fish to not influence macroalgae growth (Suchley, 2016), and others questioning the overall role that nutrients play and the validity of experimental results (Littler *et al.*, 2006).

This phase shift is generally considered to be one of the major factors contributing to the region-wide habitat degradation recorded in Caribbean coral reefs (Gardner *et al.*, 2003). It consists of algae out-competing reef building hard corals, leading to an algae dominated habitat rather than one dominated by Scleractinia. This happens via two main pathways: either algae directly overgrows small to medium sized colonies gradually smothering them as it spreads; or dead/diseased corals/bare rock are colonised by algae before the slower growing hard corals are able to establish. The latter is especially relevant to disturbance events which characterize coral reef ecosystems (i.e. storm damage etc), and their resilience to these events and the ability they

³ This term is popularly used to describe a shift in baseline conditions seen on Caribbean reef habitats, from one dominated by hermatypic coral species to that consisting predominantly of macroalgae. A discussion on the validity of this assumed phase shift can be found in Bruno *et al.*, (2014).

have to regenerate after disturbance is a crucial feature of coral reefs (Bellwood *et al.*, 2006). Aside from the dramatic disturbance events we see today this process is accentuated by increased incidence of coral diseases (as discussed earlier), and may be subject to synergistic interactions with other stressors (i.e. overfishing of herbivorous fish species) as will be discussed in the following subsection.

The effect eutrophication has on marine plants, unlike the rapid spread of macroalgae, is superficially considered positive. Seagrass for example, has been in decline not just in the Caribbean but world-wide (Waycott *et al.*, 2009) and increasing nutrient levels may in theory aid its growth. These plants are important food for manatees and turtles, habitat for juvenile fish and help stabilise the benthic substrate. This may be the case when nutrients are in relatively low concentrations, although what is being observed in Anguilla is decreased light penetration, increased epiphyte cover (most notably cyanobacteria) and the beginnings of a shift in community composition (Wynne, 2017): In some areas percentage cover of Fuzzy Finger Alga (*Dasycladus vermicularis*) has increased significantly, and the invasive seagrass species *Halophila stipulacea* has begun to dominate certain areas. However, *H. stipulacea* may in fact prove be beneficial as it grows rapidly and can colonise areas where other seagrass species (i.e. *Thalassia testudinum* and *Syringodium filiforme*) failed to establish, aiding sand stabilisation. *H. stipulacea* is also associated with larger fish and a more species rich fish community than *S. filiforme* (Rogers *et al.*, 2014).

Potential Synergistic Interactions

As mentioned in the previous subsection, complex interactions between multiple stressors have been theorised, and for more than a decade now have been the subject of considerable interest and study (Folt *et al.*, 1999). These interactions are generally placed into three categories: Antagonistic, where the combined effect of stressors is less than the sum of their individual effects; Additive, where the combined effect is equal to the sum of their individual effects; and Synergistic, where the combined effect is greater than the sum of their individual effects (Nicholas *et al.*, 2014).

There is growing concern that these interactions will occur synergistically and produce ecological surprises that may be more common than simple additive effects (Darling & Côté, 2008). Indeed, evidence for the existence of ecological surprises, events where the behaviour of

a natural system can dramatically deviate from that expected or historically observed, continues to mount (Lindenmayer *et al.*, 2010). However, meta-analytical studies over recent years have failed to find synergies between multiple stressors in coral reef ecosystems, even though there is evidence for them in freshwater and terrestrial systems (Darling & Côté, 2008; Nicholas *et al.*, 2014). Most synergies discovered have been during lab based experiments where variables can be tightly controlled (Crain *et al.*, 2008, Jessen *et al.*, 2014), although model based approaches have also been used in an attempt to uncover interactions that would be extremely difficult to study in the wild (Blackwood *et al.*, 2011). Direct field based experiments and analysis on coral reefs have yet to uncover synergies, and usually conclude effects are additive or antagonistic (Darling *et al.*, 2010). Recent studies have concluded that in systems as complex as coral reefs the lack of evidence for synergies is in part due to knowledge gaps for numerous stressor interactions and insufficient quantitative evidence (Nicholas *et al.*, 2014). It seems likely that such interactions exist, even on the simplest level where, for example insufficient top-down control may have catastrophic consequences for reef ecosystems as exemplified by the removal of grazers by overfishing or die-outs (Angelo & Wiedenmann, 2014), with ecological catastrophes discussed for over two decades (Hughes, 1994). Despite this such interactions are still a matter of much debate, with understudied complexities still confounding results (Suchley *et al.*, 2016), especially when discussing habitat destruction, overfishing, eutrophication and climate change (Momigliano *et al.*, 2015).

Even without direct evidence of synergies, it may be appropriate to assume it is only a matter of time until such evidence exists and thus proceed following the precautionary principle and manage systems in a way that attempts to mitigate against the most likely potential interactions. For example, it seems probable that eutrophication, overfishing and herbivore die-offs will have a greater than additive impact on overall habitat degradation when combined than when acting individually (Suchley *et al.*, 2016). In Anguilla much of the diverse coral reefs that once existed appear to be almost lost (Wynne, 2010) with most areas now dominated by 'survivor' species with stress-tolerant and weedy life histories, as was also observed to occur after stress events in Kenya (Darling *et al.*, 2013). It is not clear as to whether these areas can or will recover in the future (especially in light of regional stressors), but without the strictest possible management interventions it is almost a certainty that they will not. At the present time, due to uncertainties and a continued lack of direct scientific evidence, the outcome of such interventions remains unclear. However, by trying to address these issues holistically after assessing the local situation, ecosystem stability and the potential for recovery will be given the best possible chances of success.

LOCAL VS REGIONAL EUTROPHICATION & MANAGEMENT IMPLICATIONS

Following the *D. antillarum* die-off in the early 1980's the role that eutrophication plays in macroalgae growth promotion, combined with other ecological and physiological factors, became more extensively studied. When discussing eutrophication most reports give examples where the nutrients are coming from local sources, usually terrestrial run-off (including river plumes) or sewage outflows. Examples of such studies are: Algal growth in the effluent receiving area from a turtle farm in the Cayman Island (Goreau, 2008); wastewater discharge increasing dissolved inorganic nitrogen in southeast Florida (Lapointe, 1997); and groundwater inputs and sewage pollution at Discovery Bay in Jamaica (Lapointe *et al.*, 1997). Although the relevance of these local sources of nutrients should not be understated as they can heavily influence the nearby area and also add to regional levels of eutrophication, it is a main hypothesis of this thesis that equally, and in all probability more, important for Caribbean marine habitats as a whole are the larger sources of nutrients arriving from distant sources on ocean currents. As written about earlier in this chapter, the evidence for these sources as being a significant input of nutrients into the Caribbean has only recently begun to be collated, analysed and appreciated. These previously unappreciated sources of nutrients will have been adding to the local sources from before records began. This means that where local sources were once considered unimportant for the Caribbean as a whole as they were assumed to be diluted at a rapid rate, a bigger picture can now be painted of thresholds quickly being reached with potentially catastrophic near future consequences. This is particularly important for the relatively enclosed Caribbean Sea, especially for under populated and pristine areas that may have previously been considered safe from anthropogenic influence.

Anguilla is a case of such a relatively remote location with a comparatively small dispersed population. The lack of a large population centre or highly developed coastal areas means that the island doesn't fall into the usual model where significant pollution outflows exist. Furthermore, with little agriculture possible, nutrient rich terrestrial runoff is unlikely, with most collecting in salt ponds rather than flowing directly into the sea. The only identified local nutrient and/or pollution sources are: old and poorly maintained leeching septic tanks; intentional or natural connections made from salt ponds to the ocean; pollution (grey water or otherwise) from boat traffic; and leeching from the Corito Bay garbage dump located only a relatively short distance from shore. Some effects of local eutrophication can be observed close to some of these potential sources: for example poor water quality and sporadic algal blooms in

the port areas in Road Bay and Island Harbour. However, macroalgae levels around the mainland are high overall, and relatively uniform, showing no obvious link to these areas, and although offshore regions sometimes exhibit lower amounts of algal growth, generally levels are still high (chapter 2). Furthermore, water quality measures taken around the island found eutrophic conditions both near to shore and offshore (chapter 4). Additionally, there is some discussion as to what ‘natural’ levels of macroalgae are, and suggestions that current observations are being biased by lack of a coral canopy that previously existed, hiding such growths from view (Bruno *et al.*, 2014). This all represents a complex and interlinked situation, but one where regional sources of nutrients (i.e. the Amazon River plume) must play an important role in the present day ecology of the area. As management of regional nutrients is not possible without multi-national intervention, efforts should be focused on mitigating against effects at a local level.

Thesis Aims

- To conduct and analyse ecological data and develop a tool that can be used to rapidly assess habitat health and identify conservation priorities areas. This tool will be ideally suited to small island nations with limited financial and logistical resources (chapter 2).
- To give an example of a cost effective fishery assessment technique with an analysis that uses novel methods for establishing minimum size limits, breeding seasons and other managerially essential data (chapter 3).
- To produce a model that bridges the gap between collection of ecological data and the design of an information based management plan using threat assessment techniques (chapter 4).
- To develop an example management plan that brings together the techniques described in chapters 2-4 using the real world example of the Anguilla Marine Park System (chapter 5).

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Chapter 2

Collection of ecological data and the development of a study site ranking tool to identify conservation priority areas in Anguilla, British West Indies

Summary

Ecological monitoring is an essential precursor when developing comprehensive management plans for marine protected areas and their surrounding habitats. Without an historical baseline or ongoing monitoring programmes, and the associated lack of threat identification, paper park scenarios are common, with marine protected areas often existing under little or no effective management. This is often due to limited resources and other constraints. To address this, a ranking analysis tool was developed and analysed that assigned a relative health index (RHI) value to each study site, using ten, five and three ecological variables, and compared with best professional judgement (BPJ) scores. These methods were evaluated against a full suite of ecological variables to assess RHI or BPJ result validity. A close relationship between the ten variable model and BPJ was found, but neither correctly predicted overall ecosystem health due to conflicting variables and the inherently complex nature of coral reef ecosystems. Results using five non-conflicting variables gave the closest match to conclusions drawn when looking at ecosystem function as a whole. The five variables used for this model were: coral percentage cover; macroalgae percentage cover; total fish species count; total fish abundance count; and commercially/ecologically important fish size. It was concluded that the five variable version of the RHI tool was effective at ranking overall ecological health of a study site, and that these ranks could be used to produce 'health zone' maps. These maps will allow informed management decisions to be made when designating conservation areas and protection levels, in the absence of a full suite of ecological data, and when combined with BPJ rapid assessments will allow fast and reliable quantitative surveys to be conducted. If resources allow, it is not recommended that the RHI tool should replace full ecological monitoring as this information is essential when forming a robust baseline for future temporal change analysis. In the case of Anguilla, and due to theorised regional stressors effecting nutrient levels and other water quality variables, it is suggested that sites with the highest RHI rank should be afforded the highest level of protection. This will serve to preserve relic populations and potentially allow local mitigation measures to maintain these populations until a time when regional stressors begin to be effectively addressed by multinational/international policy agreements.

Introduction

Ecological monitoring is an essential part of the processes involved with managing marine protected areas, with effective management being crucial for sustainable ecosystems (McClanahan *et al.*, 2006; Mora *et al.*, 2009). It is often the case that such monitoring does not take place before marine protected areas are designated or management decisions are made (Friedlander *et al.*, 2003). This leads to the ineffective management of marine protected areas and their surrounding habitats, and the creation of so-called 'paper parks'. It is common in these areas that legislation is not enforced, resources are limited and/or management plans are poorly conceived. A global study (Kelleher, *et al.*, 1995) assessed 383 marine protected areas around the world and concluded that two thirds lacked effective management in this way. It is recognised that if management could be made more effective by identifying and addressing the threats that exist, paper parks would be changed into effective protected areas (Anon., 2001).

The Kelleher *et al.* report (1995) illustrated that this scenario is common among many small island nations where financial and logistical limitations restrict the initiation and continuance of ecological monitoring. It is therefore essential to build a programme around these limitations, as if they are not considered it is likely that the programme will ultimately fail. This appears to have been the case in Anguilla (British West Indies), where no long-term monitoring scheme had successfully been put into place prior to 2006, and all marine protected areas existed primarily on paper with no official managerial body.

In Anguilla (figure 1.1) during the late 1980's it was proposed to establish a number of protected areas, that later became known as the Anguilla's Marine Park System (figure 2.1). Prior to the official designation of these areas a study was conducted by the Bellairs Institute in Barbados (Oxenford & Hunte, 1990) that established monitoring sites in areas prioritised at the time for consideration to become part of this system. The study established permanent subsurface site markers, sediment traps and transect markers, with their locations identified via terrestrial reference points. Following the initial round of site set-up and data collection no subsequent visits to the sites have been documented. This is likely due to I) A lack of funding to allow subsequent visits by the Bellairs Institute. II) No on-island staff accompanying the initial researchers during survey work. III) A lack of sufficiently trained on-island staff at the time. IV) Insufficient on-island logistics at the time (research vessel, dive/survey equipment). V) Difficulty in relocating sites without the original researchers present.

Oxenford and Hunte (1990) did however yield data, which today represents the only known and/or surviving in-water ecological monitoring data for Anguilla prior to 2006. Following the publication of this work, five marine parks were established in 1993: Little Bay; Sandy Island; Shoal Bay-Island Harbour; Prickly Pear & Seal Island Reef; and Dog Island. A further area was designated (Junks Hole) to protect the wreck of a Spanish Galleon, together with one area considered to be under special management (Rendezvous Bay). Later, in 2010, Sombrero Island was also added to the system. The actual chronology of designation, and the legislation behind it, is poorly documented but a brief history is presented in chapter 5 based on available records and interviews with past officials. A management plan was drafted for the Anguilla Marine Park System (Hoggarth, 2006) but this was not based on any subsequent monitoring and was never officially adopted. Unfortunately Little Bay and Dog Island were the only designated parks that were surveyed during the Oxenford & Hunte (1990) study. This resulted in a disparity of data between parks as no further survey work was undertaken.

The paucity of data relating to the Anguilla Marine Park System, combined with the somewhat hap-hazard legislation, led to a period of managerial stagnation (1993-2005). This issue began to be addressed in 2006 when the Department of Fisheries and Marine Resources (DFMR), together with the Anguilla National Trust (ANT), conducted rapid assessments at thirty sites within the five marine parks (Wynne, 2007a). This not only provided much needed baseline data for the areas, but also allowed DFMR to: I) Ensure all research staff were properly trained. II) Begin the development of a methodology that would be feasible given financial and logistical constraints. III) Assess areas to prioritise for their proposed ecological monitoring. This monitoring would encompass not just the marine parks, but also their surrounding shallow water habitats. The ultimate aim for the proposed ecological monitoring was threefold: I) To establish a reliable baseline dataset for fifteen sites around the island that would permit future temporal analysis. II) To reignite managerial processes within the marine parks and surrounding shallow water habitats. III) To identify conservation priorities and any knowledge gaps that may inhibit managerial effectiveness.

Following the joint DFMR-ANT project it became clear that the sites studied by Oxenford & Hunte (1990) were not suitable for the proposed ecological monitoring. This was due to the fact that they were either no longer identifiable or in locations unsuitable to achieve current project objectives. The unsuitability arose as many sites were heavily degraded and/or in locations logistically problematic to monitor: Sea conditions at the Dog Island sites and some of those along the south coast were often severe, and this, combined with their distance from port, meant

their inclusion was not financially or logistically viable. Thus, following the rapid assessment and collection of baseline data, a pilot study was conducted to further develop and test methodologies while identifying sites most suitable for long-term monitoring (Wynne, 2008). Although an overall goal for the parks had long been identified (to protect fish, flora and fauna while preserving and enhancing natural beauty; Gov Axa c.1978), it remained clear that to enable Anguilla's Marine Park System to move past the paper park phase, the most important accomplishment for the present work would be collection of the baseline dataset. This could be used to make inferences into the health of, and areas of concern within, Anguilla's marine environment.

To facilitate these inferences a ranking analysis is developed in this chapter to identify conservation priority areas around the island that could later be used to help manage the existing marine park network. An assessment of site rankings was made using different combinations of ecological variables and subjective research diver observations. Using a tool such as this could make it possible for managers to employ a more rapid survey assessment of sites if they wanted to identify conservation priority areas, rather than having to undertake full ecological surveys. Depending on overall conservation goals, sites with the highest 'health' might be considered to be the most suitable for a high level of protection in order to preserve these areas for the future; or medium ranked sites may be seen as the most important to strictly manage in order to try and restore them to perceived past condition. It is the aim of this chapter to develop this ranking tool so that it may be applied to other small island nations in a similar situation to Anguilla. This tool will be especially important where the lack of historical data mean direct observation differences between temporal periods can not be made. Only later, if monitoring efforts continues on into the future, will trends be identifiable and rigorous long-term health projections be made possible (Shin *et al.*, 2005).

Methods

Protocol Development and Site Establishment

A survey protocol was developed for the long term monitoring of selected sites around Anguilla. This needed to harmonise three primary objectives: to be viable in the long term given constraints that exist for the research team; to collect data on the widest possible range of variables without compromising critical information; to produce a dataset that would be comparable with other datasets collected in the Caribbean region.

The protocol established was based upon methodologies developed both by the Atlantic and Gulf Rapid Reef Assessment (Kramer *et al.*, 2005); from the Survey Manual For Tropical Marine Resources (English, 2005); and through assessment by Schmitt *et al.*, (2002). Of primary concern was reproducibility of the survey protocol over time and not using an overly complex methodology that may affect surveyor accuracy (Darwall and Dulvy, 1996). Over thirty sites were initially identified based on the previous criteria. These were later prioritised and short-listed based on their overall representative nature when grouped with other sites (when, for example, considering geographical proximity to sites with similar known characteristics). Their importance to local decision-making processes was also an important consideration, for example, if they were close to existing or proposed developments, and if so, suitable undeveloped comparative sites would need to be identified also. Finally all thirty sites were rapidly assessed visually prior to short-listing using snorkelers towed in-water by a small vessel.

The initial year of this four-year study (2007) comprised a pilot season that tested the proposed methodology and completed field staff training. Special emphasis was put on training staff to correctly estimate fish sizes using ‘fish sticks’⁴. It was essential to ensure that staff would be able to continue monitoring and train future staff after the current four year study period was completed. For these reasons the pilot study itself does not form part of this chapter, instead being published separately by the Government of Anguilla (Wynne, 2008).

Twelve locations, marked with a subsurface buoy and recorded via GPS, were initially introduced in 2008 after the pilot study, and expanded to fifteen sites the following year. This yielded five seagrass sites and ten coral sites, the locations of which are illustrated in figure 2.1. It was elected to replace Dog Island from the survey schedule due to its distance from mainland Anguilla and the unpredictable and often dangerous conditions that persist there. Full site descriptions can be found in Wynne (2007b), together with detailed survey protocol. The basic framework of this protocol is described in the following paragraphs.

⁴ Pipe cut to known lengths and placed underwater

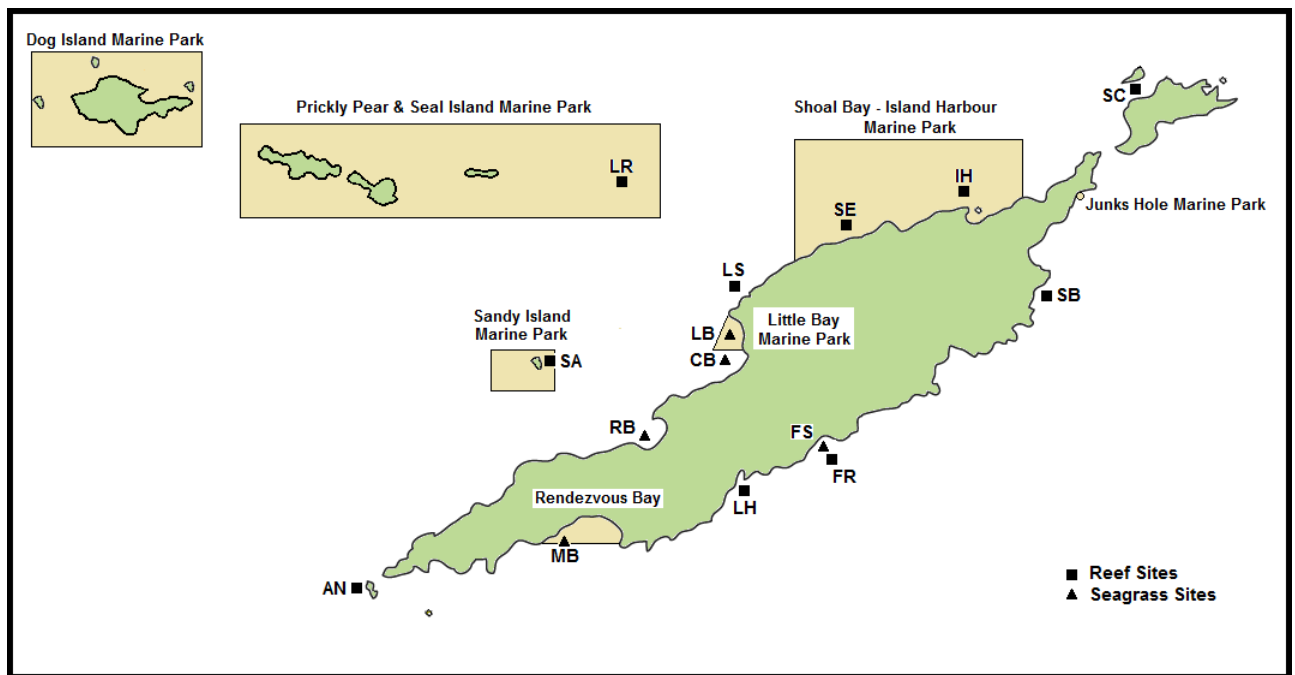


Figure 2.1: Map of Anguilla showing location of marine parks and study sites: Triangles represent seagrass sites (Anti-clockwise: LB=Little Bay, CB=Crocus Bay, RB=Road Bay, MB=Merrywing Bay, FS=Forest Bay); and squares reef sites (Anti-clockwise: SC=Scrub Island, IH=Island Harbour, SE=Shoal Bay East, LR=Long Reef, LS=Limestone Bay, SA=Sandy Island, AN=Anguillita Island, LH=Little Harbour, FR=Forest Bay, SB=Sile Bay).

Benthic Assessment Protocol

General habitat characteristics were assessed using 50 cm x 50 cm quadrats at five metre intervals along four 25 m transects. The transects were placed in a cross from a central permanent site marker, thus effectively forming two 50 m transects, one that lay perpendicular to the coast and one that lay parallel to the coast. Within each quadrat, variables recorded included (but were not limited to): coral species percentage cover and colony count; percentage cover of separate macro-algal genera; invertebrates present; predominating substrate type; and average quadrat depth as indicated by dive gauge. The relief of each quadrat was recorded as the greatest height difference measurable between opposing sides, and rugosity assessed using a link chain following methods set out by Risk (1972).

Each transect was further assessed as a line-intercept where coral species and health were of particular interest. Along the line-intercept changes in substrate were recorded until a coral

colony was reached at which point detailed measurements were taken relating to colony size and tissue health. This continued until the end of each transect. Certain key data collected using the line-intercept methodology could be combined with those from the quadrat surveys to provide a more robust outcome than by just using one survey methodology alone, such as overall coral percentage cover at each site.

Fish Assessment Protocol

To assess overall diversity of fish species present, two time and distance specific roving diver technique (RDT) surveys were conducted at each site. Surveyors completed a 25 m diameter circuit around the permanent central site marker while swimming at a constant speed of five metres per minute. All fish, recorded to species level, were counted within a five metre radius of the surveyor, with care taken not to record the same individual twice.

Along the transects placed at each site for the benthic surveys, fish of commercial and ecological importance were recorded to species level that were seen within a five metre radius of the surveyors while they swam at a constant speed of five metres per minute. Fish recorded were placed into 5 cm size classes. The species of particular interest were those belonging to Scaridae (parrotfish), Lutjanidae (snapper), Haemulidae (grunt), Carangidae (jack), Serranidae (seabass), Mullidae (goatfish), Holocentridae (squirrelfish), Balistidae (triggerfish), Acanthuridae, (surgeonfish), Pomacanthidae (angelfish) and Chaetodontidae (butterflyfish). Two replicates of each transect were undertaken.

Site Ranking Tool to Identify Conservation Priority Areas

Data collected during the surveying phase of this study were used to rank sites in relation to one another, and produce an overall 'ecosystem health' rank, where the highest ranking sites are concluded to be the most 'healthy' in relation to the sites ranking below them. A lack of historical data in Anguilla mean a 'health trend' is not identifiable, although if monitoring continues on into the future then this will be possible. The present work assessed various ranking models for their suitability, using best professional judgement (BPJ) to find a balance between model reliability and the least amount of variables needed to achievable this.

In order to conduct this assessment, the sites were initially ranked subjectively by research personnel and other professionals that had a detailed knowledge of the survey areas. Given the lack of historical data, these results were combined to produce a 'perceived' health rank for each site. It should be recognised that this ranking is only relative to other sites in the study, and so cannot be used as an indication of their 'absolute' health rank. This analysis was primarily conducted on the ten reef sites only, but once assessed, may prove viable for use on the seagrass sites also.

To conduct the assessment of the protocol ten ecological variables were chosen for analysis. Variables were chosen for inclusion if they may serve as an overall health indicator. For example, it is widely recognised that coral cover is a good indication of overall coral reef health, thus percentage cover of hard coral species was included in this protocol assessment. Similarly, macro-algae cover is also considered to be an indication of ecological health, where lower percentage covers represent a potentially 'healthier' reef ecosystem (Bruno *et al.*, 2014). After consideration, the ten variables chosen for inclusion in this assessment were: hard coral cover; hard coral health; soft coral abundance; fleshy algae abundance; bare rock/sediment/turf algae cover; sponge abundance; total reef fish species count (RDT method); total reef fish abundance (RDT method); commercially and ecologically important reef fish count (transect method); and commercially and ecologically important reef fish size (transect method).

The protocol follows a percentage weighting system where each variable at each site is calculated in terms of its value percentage compared to the site with the highest variable value. For example, the highest variable value seen across all ten sites is used as a maximum, against which all sites are compared. Thus, if the highest value for coral cover is concluded to be 15%, a site with 12% cover would be considered as 80% 'healthy'. This is conducted for all variables at all sites, and the percentages totalled up and divided by the number of variables in the analysis. This produces a final relative health percentage (RHP) for each site. This percentage can then be converted into a relative health index (RHI) based on their rank when compared to other sites. In this case, with ten sites, the RHI ranks will range from 1 (lowest overall RHP) to 10 (highest overall RHP).

After this initial assessment, further ranking analysis were conducted to examine the validity of included variables and explore the different outcomes when varying these variables: the aim being to establish if overall site health can be inferred by collecting a smaller number of variables. Overall, two reduced variable analysis were undertaken: one where five variables

were assessed after removal of potentially conflicting variables (for example, although bare substrate may be seen as positive in terms of macroalgae cover, it might conversely be seen as negative in terms of hard coral cover); and one that used only the three main fish variables (fish abundance, fish species count and mean fish size). This latter analysis was conducted to examine whether fish alone could be assessed to conclude overall ecosystem health, and to also explore the protocol's use as a stand-alone fish analysis tool

Finally, research staff and other local experts⁵ were asked to rank the sites from 1 to 10 in order of health, and the results compared to that from the three ranking models. The objective of this was to gain an understanding of how reliable subjective opinions are (BPJ) when compared to a more scientific analysis (RHI).

Using the results from the RHP analysis, and combining with BPJ of other areas outside of the monitoring sites, it is possible to map health zones around the island. Zone borders and cut-offs were established where observable habitat changes took place. This assessment also used observed historical inferences to grade the current habitats when combined with the RHP result for study sites: for example, did a 'healthy' reef area appear to have existed in the past (morphological remnants present) where now a more 'degraded' area exists. Only areas in water <10m were assessed, with health zones split into four categories: high level of degradation (RHP <60%); moderately high level of degradation (RHP 60-70%); moderate level of degradation (RHP 70-80%); and least degraded areas (RHP >80%). These percentage categories were arrived at based on the range of data.

Results

The scores of survey variables relative to the highest RHP values seen are shown in Table 2.1. High scores were spread across sites, with only Little Harbour and Shoal Bay East not obtaining a 100% RHI in any variable. Sandy Island and Long Reef both had the highest number of 'top three' RHP values, which leads to their top positions across variable treatments as illustrated in Table 2.2. Table 2.2 also illustrates how these scores are incorporated and totalled to arrive at a final rank, with comparison to that of best professional judgement (BPJ). Figure 2.2 presents a visual representation of these scores used when evaluating the ranking tool in the subsequent

⁵ The term 'expert' refers to non-research personnel with ecological knowledge of coral reefs and a level of familiarity with the study site area

discussion section, where rationale for removing variables is also discussed. From the results in table 2.2, figure 2.3 was produced to illustrate proposed ecosystem health categories (or zones) around Anguilla's coastal and shallow water areas.

Table 2.1: RHP for the ten variables included in the initial ranking analysis assessment across the ten reef sites surveyed. Values represent percentage 'health' in relation to highest value recorded (i.e. those valued as 100%) across all sites. CC = Coral cover, CH = Coral health, SC = Soft coral, FA = Fleshy algae, BS = Bare or sediment covered substrate, SP = Sponge, FAb = Fish abundance (RDT survey), FSp = Total number of fish species (RDT survey), FSz = Fish size (belt transects), FCt = Fish count (belt transects). Dark orange illustrates 100% RHP, mid-orange second highest RHP, and pale orange third highest RHP.

| Site | CC | CH | SC | FA | BS | SP | FAb | FSp | FSz | FCt |
|------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|
| SC | 31.42 | 96.6 | 39.53 | 84.07 | 78.3 | 26.74 | 100 | 93.15 | 100 | 46.55 |
| IH | 21.23 | 97.1 | 27.2 | 69.06 | 100 | 12.81 | 57.53 | 72.6 | 53.69 | 40.48 |
| SE | 59.39 | 86.4 | 53.49 | 81.95 | 82.02 | 4.53 | 66.36 | 93.15 | 52.35 | 39.68 |
| LR | 69.46 | 91.9 | 45.81 | 100 | 78.07 | 23.42 | 88.3 | 91.78 | 71.14 | 55.06 |
| LS | 37.08 | 98.2 | 100 | 80.02 | 84.65 | 100 | 62.34 | 89.04 | 55.7 | 29.15 |
| SA | 100 | 80.8 | 29.54 | 96.35 | 91.45 | 64.31 | 90 | 90.41 | 57.05 | 50.61 |
| AN | 23.92 | 97.4 | 65.81 | 98.88 | 42.98 | 51.93 | 70.84 | 100 | 92.62 | 19.84 |
| LH | 18.85 | 95 | 34.88 | 92.39 | 50 | 86.19 | 59.92 | 58.9 | 52.35 | 39.68 |
| FR | 17 | 98.5 | 6.28 | 82.66 | 59.43 | 0.55 | 48.49 | 72.6 | 67.11 | 100 |
| SB | 5.92 | 100 | <0.01 | 84.58 | 77.41 | 1.66 | 86 | 63.01 | 58.39 | 47.78 |

Table 2.2: Reef ranking analysis presenting final RHP values and RHI rank obtained from the health ranking analysis (Table 2.1) with ten, five and three variables across the ten reef sites. Sum Mean is the mean score across the three treatments. The latter column contains the results of BPJ based on observations in the field by research staff and other local experts. For each group RHP mean scores are presented in the left hand column and RHI rank position in the right hand column, with 10 being the most 'healthy' RHI and 1 the least 'healthy'. The five variable treatment uses: coral percentage cover; macroalgae percentage cover; fish species number; overall fish abundance; and commercially/ecologically important reef fish size. The three variable treatment uses the latter three variables only. Dark orange illustrates highest mean RHP/RHI, mid-orange second highest mean RHP/RHI, and pale orange third highest mean RHP/RHI.

| Site | 10 Variables | | 5 Variables | | 3 Variables | | Sum Mean | | BPJ |
|------|--------------|----|-------------|----|-------------|----|----------|----|-----|
| SC | 69.64 | 7 | 81.74 | 8 | 97.72 | 10 | 80.03 | 9 | 6 |
| IH | 55.17 | 2 | 54.83 | 1 | 61.28 | 2 | 57.09 | 1 | 1 |
| SE | 61.93 | 5 | 70.64 | 6 | 70.62 | 6 | 67.73 | 5 | 7 |
| LR | 71.5 | 8 | 84.14 | 9 | 83.74 | 8 | 79.79 | 8 | 8 |
| LS | 73.62 | 9 | 64.84 | 5 | 69.03 | 4 | 69.16 | 6 | 10 |
| SA | 75.05 | 10 | 86.76 | 10 | 79.15 | 7 | 80.32 | 10 | 9 |
| AN | 66.42 | 6 | 77.25 | 7 | 87.82 | 9 | 77.16 | 7 | 4 |
| LH | 58.82 | 4 | 56.48 | 2 | 57.06 | 1 | 57.45 | 2 | 5 |
| FR | 55.26 | 3 | 57.57 | 3 | 62.73 | 3 | 58.52 | 3 | 1 |
| SB | 52.47 | 1 | 59.58 | 4 | 69.13 | 5 | 60.4 | 4 | 3 |

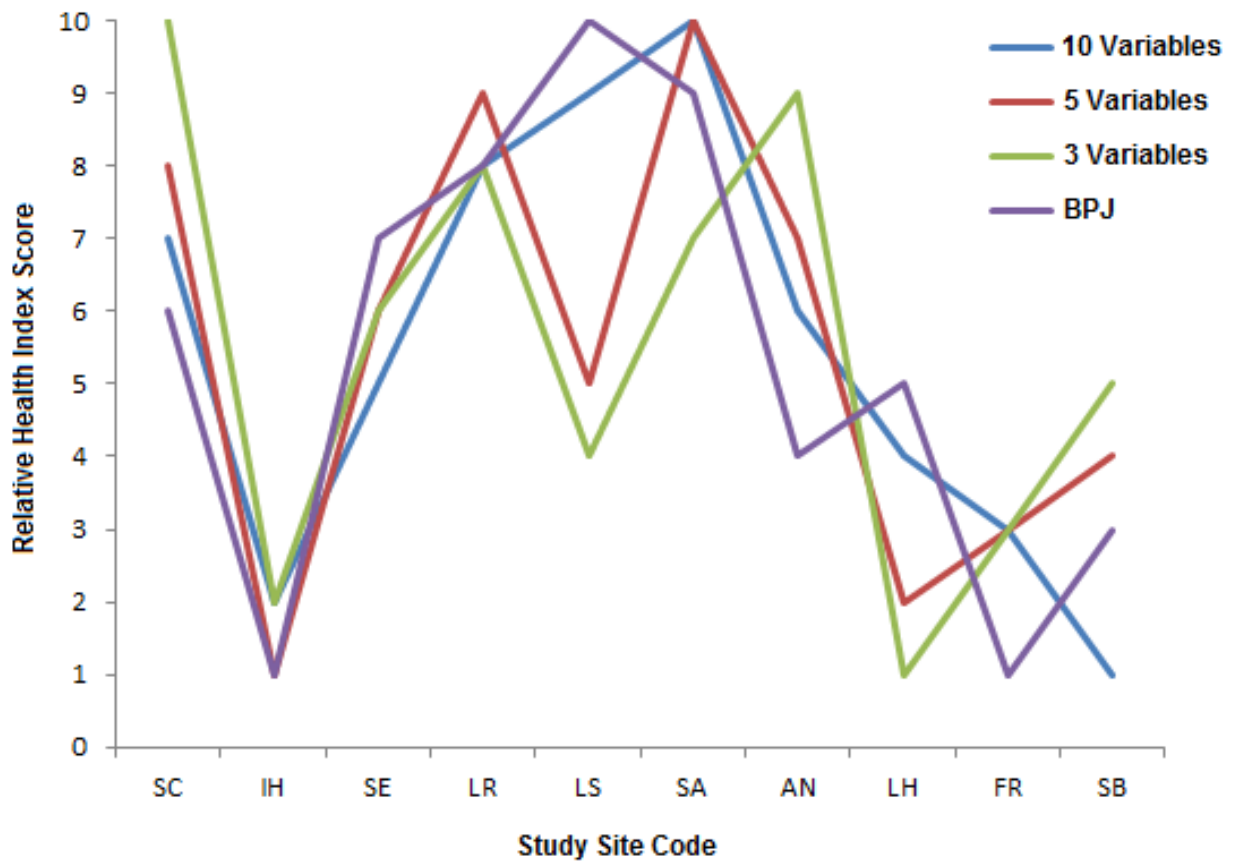


Figure 2.2: Relationships between variable treatments and BPJ. Generally correlations between treatments are high, but weakest were between 10 and 3 variables and BPJ and 3 variables. This illustrates confounding/conflicting information associated with increased number of substratum variables as discussed in the following ranking tool evaluation. The close association between 10 variables and BPJ is also likely due to this reason.

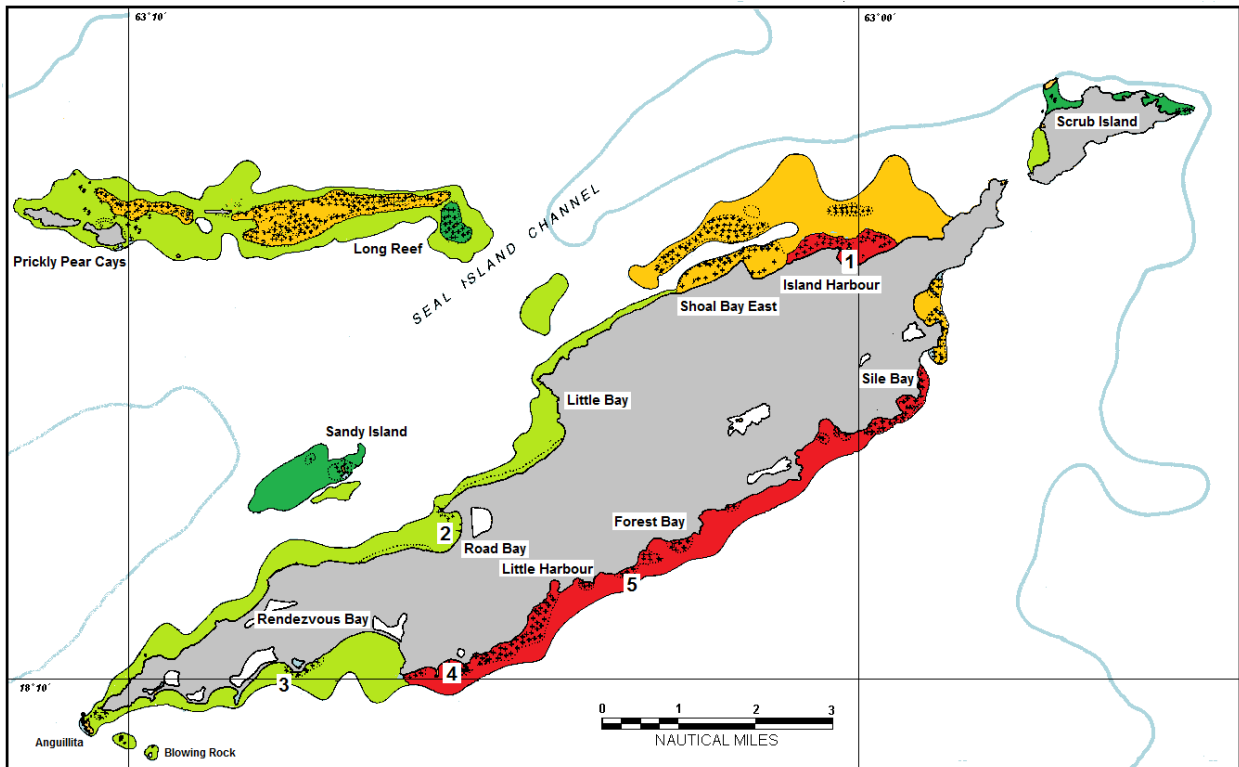


Figure 2.3: Ecosystem health zoning around Anguilla based on RHP analysis. Only areas in water <10 m were assessed, with health zones split into four categories: red - high level of degradation (RHP <60%); orange - moderately high level of degradation (RHP 60-70%); pale green - moderate level of degradation (RHP 70-80%); and dark green - least degraded areas (RHP >80%). The blue contour on the map details the 30m depth gradient. Numbered locations are (1) Island Harbour – fishing port and petrol station (2) Sandy Ground – commercial container port and fishing port (3) Cove Bay – fishing port and golf course salt pond pipe connections (4) Blowing Point – ferry port and fishing port (5) Corito Bay – petroleum port and landfill site.

Discussion

Ranking Tool Analysis Evaluation

While conducting the first stage of the ranking analysis assessment, it was quickly established that using ten variables was overly cumbersome, with many of the chosen variables potentially⁶ either: counteracting the effect of others (reason 'a'); producing conflicting results (reason 'b'); or were simply less effective an indicator as other variables included (reason 'c'). For example, it was concluded that 'coral health' was not a reliable indicator as sites with a very low coral cover would potentially be more likely to have fewer diseased individuals, especially if those species remaining were those that exhibit disease less frequently, for example *Porites astreoides* (reason 'a'). Similarly, soft coral and sponge diversity were both removed as although a good indicator of overall diversity, their proliferation can also sometimes signify higher turbidity which will likely negatively affect certain hard coral species (reason 'b'). Also sediment/bare substrate was removed as a lower cover does not necessarily indicate a 'healthier' system, it may simply be due to a higher cover of macro-algae (reason 'a' & 'b'). Finally, fish count (belt transect method) was removed as it was decided that overall fish abundance (RDT method) is a more robust variable (reason 'c').

Removing these five variables left: coral percentage cover; macroalgae percentage cover; fish species number; overall fish abundance; and commercially/ecologically important reef fish size. These variables seem reasonable in terms of habitat health and thus it was expected that using them would produce a value close to that obtained by BPJ. However, it did not, with the ten variable model a better predictor of an experts subjective habitat health assessment. Currently there is some controversy regarding the accuracy of using BPJ, with the ten versus five variable models appearing to illustrate this: it is generally considered that the validity of using BPJ depends on the overall complexity of the assessment being made (Thompson *et al.*, 2012; Teixeira *et al.*, 2010). In terms of a coral reef ecosystem, complexity levels are high, and if experts had been asked to assess each site purely upon its coral, algae and fish population structures they would likely have arrived at different ranking values. For example, Limestone Bay (LS) ranked 10 using BP, 9 using ten variables, and 5 using five variables: the high macroalgae at this site combined with low fish abundance, size & count compared to other sites

⁶ these are suggested relationships based on observations but not tested statistically

mean a ranking of 9 is not realistic. By examining raw data (not presented⁷) it was apparent that it only gained this rank due to high RHI values among confounding variables: coral health; soft corals; sponges; and bare substrate/sediment cover.

With similar situations noted within other sites' data it was concluded that the five variable ranking analysis was more robust and less likely to produce conflicting results. The ten variable model however closely resembles that of Best Professional Judgement (BPJ) for most sites, as illustrated see figure 2.2. This corroborates previous conclusions on the validity of using BPJ alone, although studies have concluded that agreement is better for samples at extremes of disturbance gradients (Teixeira *et al.*, 2010). Extremes of disturbance gradients will act in a similar way to reducing variable number, as BPJ was conducted visually on all variables, rather than asking experts to rank sites on certain variables only. Subjectively taking into account high soft coral cover and other potentially confounding variables essentially blurs these extremities making disturbance gradients more difficult to identify.

Also illustrated in table 2.2, an assessment of the three variable ranking analysis that utilised only fish variables, concluded that although it may be a useful tool to assess 'good' or 'bad' ecological health, finer scales could not be reliably identified. This is due to overall site ecology not being linked to all fish variables in their entirety, where high fish abundances and sizes might, for example, be due to where the site is located (close to a deep reef gradient, up-welling of nutrient rich water etc.). Instead, it is suggested that the three variable ranking analysis would be a useful tool for managers to use if they are solely interested in the overall relative 'health' of fish populations at a site. This might be of special interest in the case of Anguilla and the development of a management plan for its Marine Park System and associated shallow water habitats and fisheries. For example, identifying the sites with highest relative health of fish populations would justify the use of these areas as 'preservation zones', i.e. be afforded a high level of protection to provide important nursery habitats for the local area and seeding potential for the region. Furthermore, this tool may also allow a rapid 'fishing effect' analysis to be made at sites when surveyed during subsequent years, a measure that is notoriously problematic to assess due to associated changes in habitat health (Jackson, 2001; Paddock *et al.*, 2009). Such a tool provides a way for managers to easily combine multiple variables and reach managerial conclusions that may otherwise necessitate in depth statistical analysis, or, at the other end of the scale, single variable comparisons that do not represent a complete picture.

⁷ Full datasets can be obtained by contacting the author and will also be made available through <http://datadryad.org/>

Interestingly, in a similar way, the research staff and others familiar with the area could similarly only correctly identify 'good' or 'bad' health areas, with finer scales not being reliably identified. It is likely that this is due to a skewed idea of what constitutes a 'healthy' reef ecosystem, a subject that, despite the logic applied in this report, is still open to much debate. For example, it is likely that to research staff; high biota cover constitutes a 'healthy' habitat, compared to those seemingly more devoid of life. This may be the reason that Limestone Bay (LS) and Shoal Bay East (SE) were perceived as among the top 'healthiest' sites, as high covers of sponges, soft corals and even macro algae give the impression of a thriving ecosystem, even though coral cover and fish population indicators are relatively low. Similarly historical topological indicators may also be overlooked (evidence that points to significant habitat changes in an area over recent decades). Thus sites that appear today to not be 'thriving', might simply have been this way historically, and other less obvious but key indicators (coral cover, low macroalgae and larger, more abundant and diverse fish species) in actuality rank the site at the higher end of the scale. It is likely this reason that the research staff ranked Anguillita (AN) and Scrub Island (SC) lower than the RHP analysis did. This highlights the need for actual research and analysis to be conducted, and not just rely on researchers subjective opinions. It is hoped that the five variable RHI tool may be used in unison with BPJ and be useful for managers across the Caribbean. It can enable them to quickly and relatively cheaply conduct targeted research work, helping them to identify conservation priority areas without the explicit need for elaborate ecological surveys or long-term historical datasets.

Ecosystem Health Zoning

From the ranking analysis, and combined with BPJ from other areas around Anguilla's coastal zone, ecosystem health zones were identified as illustrated in the map presented in figure 2.3. From this, it is very clear that Anguilla's south coast is in a much more degraded state than the north coast, although certain areas in the north (for example Island Harbour) also fall into the lowest health category. This reflects observations over the last couple of decades, where anecdotal reports of decreasing health in south coast areas, combined with pockets of degradation in north coast areas have been made since completion of the Oxenford & Hunte (1990) study. Potential reasons for this require more study but the south coast sites are more exposed in nature than the north coast sites as the latter are afforded protection by a long barrier reef c.5km from shore. On the whole the north coast sites were more diverse with higher hard

coral cover and greater fish abundance. Fleshy algae percentage cover was high at all coastal sites suggesting some degree of eutrophication and/or paucity of key herbivorous species.

The sites along the south coast fringing reef seem to have suffered a severe mortality event in the past and have yet to recover. Without further research it is not possible to draw firm conclusions for the reasons behind this. It is suggested however that hurricane damage combined with white band disease was the initial destructive force. The continued presence of the disease, combined with a reduced resilience of corals to it and other stressors, is likely the reason for this. Coral recruitment levels are suspected to be low, again likely caused by multiple stressors. These stressors include (but are not limited to) sedimentation, eutrophication and associated algae growth (Babcock & Smith, 2000; Wolanski, 2003; ICRS, 2004; Birrell *et al.*, 2005; Lirman, 2008). A coral recruitment experiment is recommended to explore this (chapter 4). Overall, it is suggested that these environmental conditions and/or regional/geographical stressors are affecting the area and so recovery is unlikely at the present time. As previously stated, further studies are needed, but if this were to be the case it would be more prudent to focus management efforts on the northern coastal areas at the present time. Here, reef systems appear in better health, and with more diversity and associated resilience, successful protective management is more likely to succeed. Furthermore, this is the region the current marine protected areas are located, and thus there already exists good infrastructure for future legislation. It is recommended that these existing marine parks be used to preserve relic populations, with heavy restrictions applied to extractive and/or damaging practices.

The need to begin urgent protective management of the north coast is highlighted by the site at Island Harbour. In many respects, here the reef has begun to reflect the situation that is observed along the south coast: barren, dead *A. palmata* skeletal remains, little benthic diversity and relatively low fish abundances and size class structure. If this situation were to spread along the north coast it may not be long before few differences are observable between the two regions. Currently a number of the north coast sites seem in relatively good health (figure 2.3), and although they are likely to be under similar threats, it is suggested that these areas be those prioritised for management, whether or not they form part of a current marine park. Aside from generic management measures (such as restrictions on spear-fishing), it will only be sensible to turn attentions to the barren south coast regions when these currently 'healthy' areas are correctly managed.

The ecosystem health zoning map (figure 2.3) also highlights differences between sites located close to the mainland and those located further offshore. The offshore areas are generally less degraded than those closer to shore, with higher coral cover, lower fleshy algae cover, and larger, more diverse fish populations. Reasons for this have a probable anthropogenic source, as such stressors will be greater at the near-shore sites, and of these stressors fishing practices and coastal developments are likely the most influential. How these local stressors interact with other more regionally influenced variables might also be crucial. If regionally sourced eutrophication is playing a role, it is possible that the removal of herbivorous species might accentuate its impact on macroalgae growth, increasing stress levels to corals. Variations in fishing pressure thus lead to variations in macroalgae growth and coral cover, and if eutrophic conditions persist the overall effect is potentially exaggerated. Indeed there is an apparently strong relationship visible on figure 2.3 where near-shore north coast sites under high fishing pressure (Shoal Bay and Island Harbour) rank more highly in terms of degradation than offshore sites under lower fishing pressure (Sandy Island and Long Reef). Interestingly however trap fishing does still occur at these latter sites, but spear-fishing is more limited than at Shoal Bay and Island Harbour. This suggests that the unregulated practice of spear-fishing may play an important role in the observed results and thus needs the appropriate consideration in terms of new management (Frisch, 2012).

A further observation made was that near-shore north coast sites had higher sponge diversity and larger, more numerous soft corals than offshore sites. High sponge and soft coral diversity has been documented as a sign of high sedimentation rates (McClanahan & Obura, 1997). Although not directly recorded in this study, sedimentation is concluded to be higher at these near-shore sites based on visibility levels noted while conducting the survey work. Coastal development is common along the coastline in Anguilla with unregulated removal of materials very close to shore commonplace (S.Wynne, pers. Obs.). Such actions, especially following periods of torrential rain, can lead to greater rates of sedimentation. Interestingly, despite this sites on the south coast did not have a similarly high diversity of sponges or soft corals, although this may be due to increased wave action limiting their growth.

Conclusion

By using the tool described in this chapter and conducting a relative health index analysis, it is possible to identify areas with varying levels of ecosystem health and thus identify conservation

priority areas based on their rank. As the ecological situation around Anguilla appears bleak, and with local management only able to mitigate against region stressors such as nutrient enrichment (or reducing water quality as a whole), it is suggested that sites with the highest rank be afforded the highest levels of protection. This will serve to preserve relic populations and possibly allow local mitigation measures to maintain these populations until a time when regional stressors begin to be effectively addressed by multinational/international policy agreements.

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Chapter 3

Assessment of the Spotted Spiny Lobster (*Panulirus guttatus*) fishery in Anguilla, and the wider implications for management of Anguilla's Marine Park System

Summary

Financial and logistical limitations in small island nations often lead to restrictions in their ability to conduct fishery assessments. These assessments are needed in order to provide information that can be fed into the management decision-making process. The goal of the present study was to work within these restrictions in Anguilla, British West Indies and conduct an assessment into the Spotted Spiny Lobster (*Panulirus guttatus*) fishery. This fishery is currently only managed through legislation that also applies to the Caribbean Spiny Lobster (*Panulirus argus*) and generic fish pot minimum mesh size regulations relevant to all trap-fisheries, but for sustainable management, it will be necessary to establish a minimum landing size as already exists for *P. argus*. This assessment was undertaken between 2004 and 2008, with biometric and reproductive measurements collected from *P. guttatus* during fishing trips, and local restaurants, and during night-time snorkelling surveys. It was found that size at first physical maturity for male *P. guttatus* occurred at 51.3 mm carapace length (CL), whereas size at maturity for females in Anguilla was estimated at 46.0 mm CL (from 50% of sample egg-bearing). *P. guttatus* landed via traps were found to be significantly larger than those landed using the hand-capture method that is also common in Anguilla. *P. guttatus* of smaller sizes were seen to be less active on the reef than larger individuals. The results suggest that the *P. guttatus* trap-fishery likely captures only a relatively small number of immature individuals compared to the hand-capture fishery. Female reproductive activity increases from December to April, with highest levels between January and March. In view of these results, it is recommended to introduce a minimum landing size of 52 mm CL in order to mitigate the potential of the hand-capture fishery capturing immature individuals, and a closed season of three months duration, January through March, to protect breeding females. It is proposed that these measures be combined with a closed area in order to protect an entire portion of the local population from exploitation, thus providing over-spill to the surrounding fished areas and larval recruits to the regional pool. Further evidence was found of habitat degradation throughout the areas fished and a shift in areas targeted by fishers suggesting an overall depletion of resources. Of particular interest in terms of management were signs of lower reef fish abundances through spear-fishing and coral damage through trap fishing. Although not necessarily all directly related to *P. guttatus* fishing, these inferences are important when making decisions relating to the development of a management plan of Anguilla's Marine Park System.

Introduction

The degradation of coastal habitats and declining fish stocks have become an issue of growing concern for many decades (Turner *et al.*, 1999) with the collapse of various fisheries (Jahncke *et al.*, 2003 and Hutchings, 1999), and the loss of marine habitats (Munday, 2004) becoming a well documented phenomenon around the globe. The management of many of these fisheries and threatened ecosystems over recent years has achieved varying successes (Côté *et al.*, 2001). However, management interventions have been shown to arrest or reverse declines and are therefore frequently proposed as a necessary step in the sustainability of fisheries (Williams and Russ, 1995). It is widely documented that without effective management overfishing can influence settlement of hard corals and other invertebrates (Jessen *et al.*, 2014), cause trophic cascades (Daskalov, 2002), and may be responsible for the recent collapse of coastal ecosystems (Jackson *et al.*, 2001). In terms of the Caribbean lobster fishery, overfishing has been of concern for more than two decades, with reported annual catches in excess of 35,000 tons and widespread declines reported (CRFM, 2011). On a local scale, despite the reported resilience of the fishery (Pollock, 1993), continued reports of catch reductions (Gerwen, 2013) will lead to livelihood impacts and suggests an urgent need for local managerial changes to be made.

Successful management of these resources, involves a decision-making process that is based upon up-to-date and relevant field data. The collection of such data is often costly and labour intensive, and so small island nations can be faced with financial and logistical limitations that inhibit the necessary fisheries/habitat assessments essential for effective management (Carcamo, 2003). For small island nations this often means that management decisions have to be made on information collected in other regions that negates the possibility of geographic variation within a species/habitat. Furthermore, generic legislation sometimes exists for species within a genus (e.g. *Panulirus sp.*) that in fact share little in terms of life history or fishery structure due to different habitat preferences and foraging activity.

The Caribbean Spiny Lobster (*Panulirus argus*) and the Spotted Spiny Lobster (*Panulirus guttatus*) fisheries in Anguilla, British West Indies provides such an example. Both species form fisheries in their own right and yet the latter is only governed through generic legislation for *P. argus*: a minimum mesh size of 42 mm for lobster pots, the prohibition of fishing for lobsters using spear-guns, and further restrictions on landing freshly moulted lobsters or those bearing eggs or spermatophores. A minimum carapace length (CL) exists for *P. argus* but no such legislation exists for *P. guttatus*, and apparent geographic variation recorded for size at maturity

for this *P.guttatus* mean a significant knowledge gap exists. For example Briones-Fourzán & Contreras-Ortiz (Mexico 1997) estimated female size at maturity (50% of sample mature) at 56.4 mm CL, whereas Robertson & Butler (Florida Keys 2003) estimated it as 32 mm CL. For males, Sharp *et al.* (Florida keys 1997) estimated size at maturity at 48 mm CL, whereas Robertson & Butler (2003) estimated it at 36 mm CL, and Chitty (Florida Keys 1973) observed that males of 40 mm CL had viable sperm in their testes, although their small size may restrict their ability to mount receptive females. Robertson & Butler (2003) suggested that this variation might be caused by differences in methodology (i.e. Trap-based versus diver-based sampling).

Having identified both a legislative and local knowledge gap it was decided by the Department of Fisheries and Marine Resources (DFMR), Government of Anguilla to design a fishery assessment for *P. guttatus* that, due to financial and logistical limitations, was realistic to conduct using minimal resources. Previous research on *P. guttatus* in Anguilla (Wynne & Côté 2007) had recommended the possibility of a closed season for this species (as well as closed areas), but as further geographic variation in breeding seasonality appears to exist for this species (Briones-Fourzán & Contreras-Ortiz, 1997 & Robertson & Butler, 2003) it was decided that this should be an area that the assessment also focused on. A further study by Wynne (2004) addressed size at maturity for this species but it was also decided to expand on this data set in order to ensure that concerns relating to methodology biases raised by Robertson & Butler (2003) were addressed.

In Anguilla *P. guttatus* is primarily targeted using Antillean arrowhead traps although a significant hand-capture facet of the fishery exists that is becoming increasingly popular with opportunistic fishers. This practice is conducted by snorkelling at night with thick gloves and a forked stick that is used to pin down the foraging lobsters. By targeting the species in this manner, individuals of all sizes can be landed and so increases the need for a minimum legal carapace length to be established. By using data collected from both methods fishers use to target the species it is intended to avoid sampling biases that may exist (Robertson & Butler, 2003): for example, sampling from trap-catches only may produce bias towards larger individuals. Sampling in such a way also increases data robustness as survey effort will be spread across a greater variety of habitats that are under potentially varying levels of fishing pressure. Due to this increase in scope it is hoped that inferences will not only be possible for the *P. guttatus* fishery but also for the habitats that they are targeted in. In such a way, DFMR resources will be maximised to not only allow informed management decisions to be made for this fishery, but also for Anguilla's Marine Park System and other coastal areas.

Methods

In order to minimise financial and logistical constraints imposed when conducting independent trapping experiments, one field researcher accompanied local fishers on nine fishing trips between March 2007 and July 2008. The trips typically left Island Harbour jetty at 7.30am and returned at 12.30pm after visiting up to approximately one hundred traps. These traps had been set a couple of days earlier, usually in Shoal Bay-Island Harbour Marine Park and Prickly Pear-Seal Island Reef Marine Park. The traps were baited with cowhide and reef fish, the latter of which were often captured with a spear-gun by the fishers in-between trap-sets. The location, number and content of traps were recorded.

P. guttatus were individually assessed depending on sex. Both Male and Female CL was measured to the nearest mm using callipers, defined as the distance from in-between the two rostral horns to the posterior edge of the cephalothorax (figure 3.1). Once measured females were assessed for signs of reproductive activity, categorised as either: Egg bearing; with intact spermatophores; with egg or spermatophore remains; or showing no signs of reproductive activity. Female size at maturity was defined as the CL at which 50% of the population exhibit reproductive activity (Robertson & Butler 2003). To determine this value, females were divided into 5 mm size classes and the proportion of females exhibiting reproductive activity within each size class was calculated. Size classes were used rather than exact CL measurement as a paucity of smaller individuals would lead to less accurate percentage results in the lower size ranges. The smallest egg-bearing female was also recorded (Sharp et al., 1997, Robertson & Butler 2003). A quadratic regression analysis was conducted to ascertain size at 50% maturity⁸. Males were assessed by measuring the second segment of their second frontal walking leg (the meropodite, or merus – figure 3.1): when first physical maturity is reached the two frontal pairs of legs begin to grow at a faster rate in relation to their carapace, increasing their ability to mount receptive females, stay engaged, and deposit their spermatophores. The second frontal walking leg is chosen for the analysis as it undergoes the most pronounced growth increase. This is referred to as the period of allometric growth (Robertson, 1994; Evans *et al.*, 1995). As defined in Evans *et al.* (1995), the merus length (ML) can be plotted against CL to establish male size at first physical maturity. As set out in Evans *et al.*, (1995) the onset and subsequent

⁸ Although a logistic analysis would produce a more expected curve for maturity levels a lack of small female size classes due to the species cryptic nature meant this was not possible. This will not affect size at 50% maturity estimate.

cessation of this period was established by conducting regression analysis on multiple three way ML-CL data splits based on the lowest combined sum of squares of residuals. By solving pairs of equations simultaneously their intersecting values can be established.

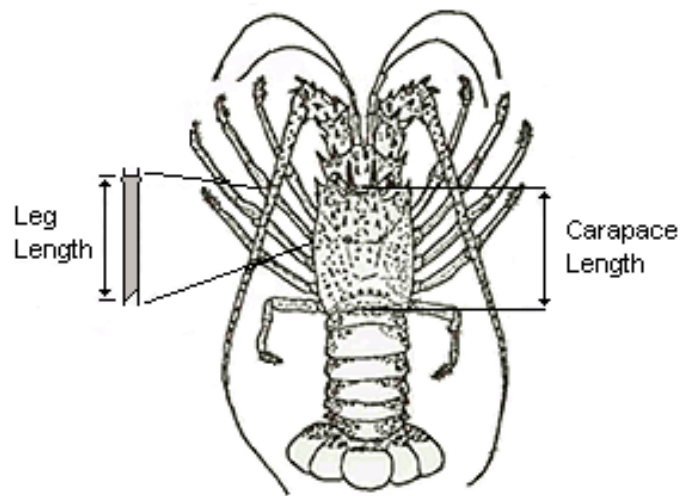


Figure 3.1: Diagram of *P. guttatus* illustrating location and measurement of both the carapace and the second segment of the second frontal walking leg (the meropodite, or merus).

Breeding seasonality was estimated by assessing female *P. guttatus* for the presence of eggs, which was taken to indicate reproductive activity. As intact spermatophores could have been placed by a male months prior to capture, and spermatophore or egg remains could have persisted for some time, these were not used as a positive sign of reproductive activity in this particular analysis. Further data were collected from *P. guttatus* landed through the hand-capture sector of the fishery, where variables were recorded for both sexes in an identical fashion to trap-caught individuals.

Also incorporated into this assessment were data collected in Anguilla previously for the species (Wynne 2004), which included five additional fishing trips, measurement and assessment of *P. guttatus* sold to local tourist restaurants, and timed nocturnal snorkelling surveys. These nocturnal surveys were conducted to assess populations on a variety of shallow reef habitats around Anguilla. During these surveys individuals were, where possible, sexed, their CL estimated to the nearest 5 mm and the location of the individual noted: Either foraging in the open or hiding in a protective recess. Temporal variations between the this and the 2007-2008 datasets were minimised by only combining results for female size at maturity analysis and not breeding season or hand versus trap-fishery analysis.

Results

Size at first physical maturity of males landed by trap and hand-fishing

Two hundred and thirty-nine (239) male *P. guttatus* lobsters from both trap and hand-fishing were measured and assessed to establish an estimate for size at first physical maturity. ML has been plotted against CL in figure 3.2. From this figure three distinct growth phases can be observed, and by solving their regression equations in pairs simultaneously intersect values can be obtained for each phase. This gives a CL of 51.3 mm for the start (onset) of allometric growth, which is therefore taken as the size at first physical maturity.

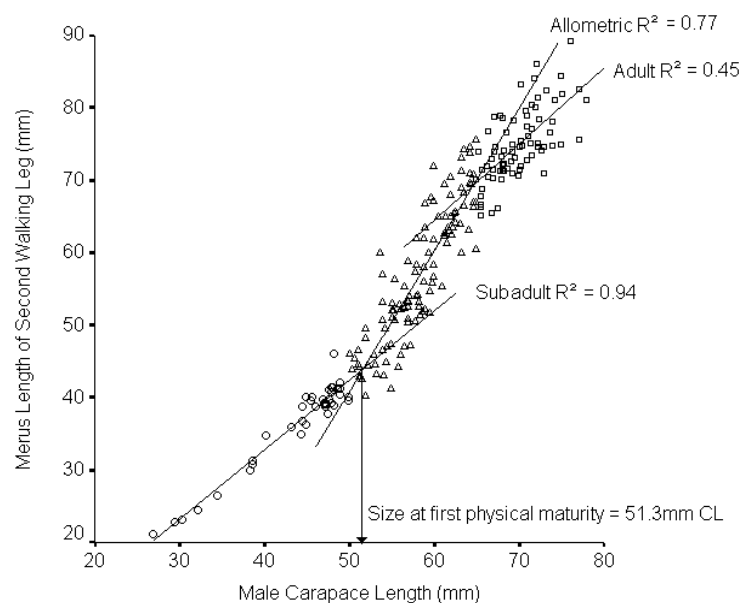


Figure 3.2: The relationship between male *P. guttatus* leg growth rates in relation to carapace length (n = 239). Three regression equations are obtained: Subadult (circles n = 38) $y = 0.959x - 5.574$, $p < 0.001$; Allometric (triangles n = 119) $y = 1.949x - 56.467$, $p < 0.001$; Adult (squares n = 82) $y = 0.894x + 12.028$, $p < 0.001$. These equations can be solved in pairs simultaneously to give intersect values for either variable. For example: Subadult and Allometric gives an intersect value on the x axis (carapace length) of 51.3 mm.

Female size at maturity of females landed by trap and hand-fishing

Four hundred and eighty four (484) females from both trap and hand-fishing were measured and assessed to establish an estimate for the size when 50% of the population exhibits reproductive activity. The percentages of each female size class (40 mm to 65 mm) exhibiting reproductive activity are plotted in figure 3.3, with quadratic regression analysis estimating that 50% of the population exhibit reproductive activity at 46.03 mm CL ($p < 0.001$, $R^2 = 0.974$). The smallest egg-bearing female had a CL of 39 mm.

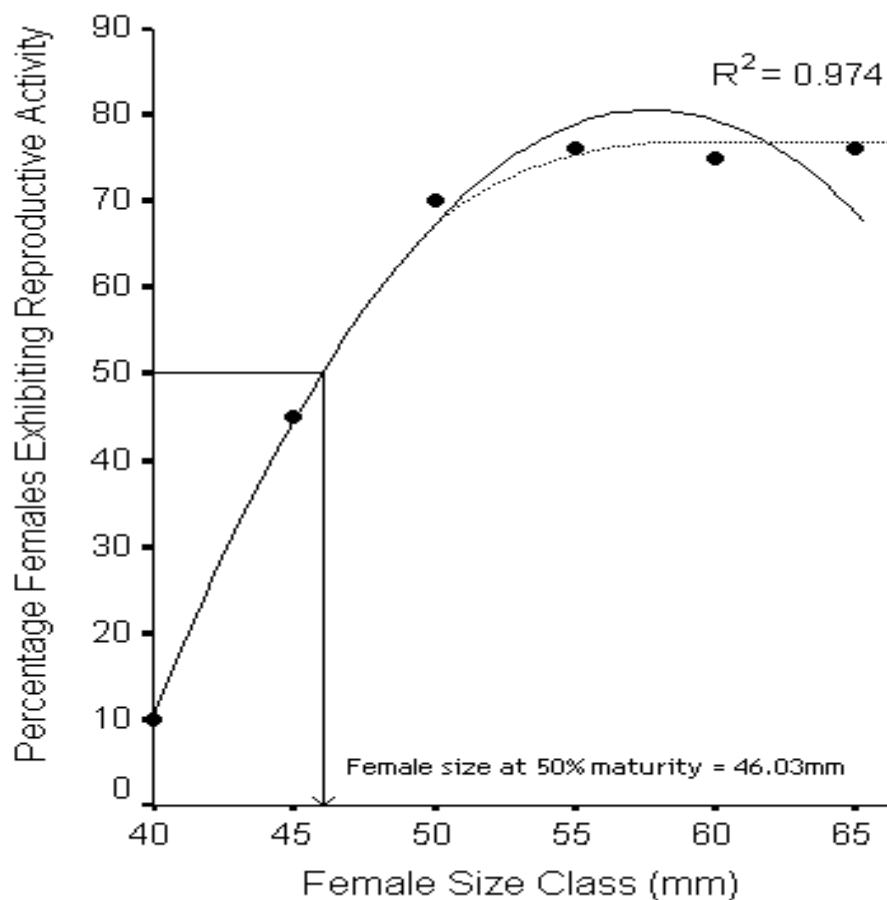


Figure 3.3: Percentage of female *P. guttatus* ($n = 484$) exhibiting reproductive activity within each 5 mm size class between 40 mm and 65 mm. Solving the quadratic regression equation $y = 25.77x - 0.2233x^2 - 663.07$ ($p < 0.001$, $R^2 = 0.974$) when $y = 50$ gives a value of 46.03 mm (CL). Dotted line represents likely logistic plateau of reproductive activity not represented by quadratic curve.

Breeding seasonality of females landed by trap-fishing

Two hundred and seventy seven (277) females, representing those that were landed by fishers via traps in the presence of the author, were assessed for reproductive activity. Females assessed within other aspects of this study that were not landed in the presence of the author could not be used in this analysis as their exact landing dates were not known. A peak in female reproductive activity was found to occur in February each year, with high levels of activity between December and April, as represented in figure 3.4.

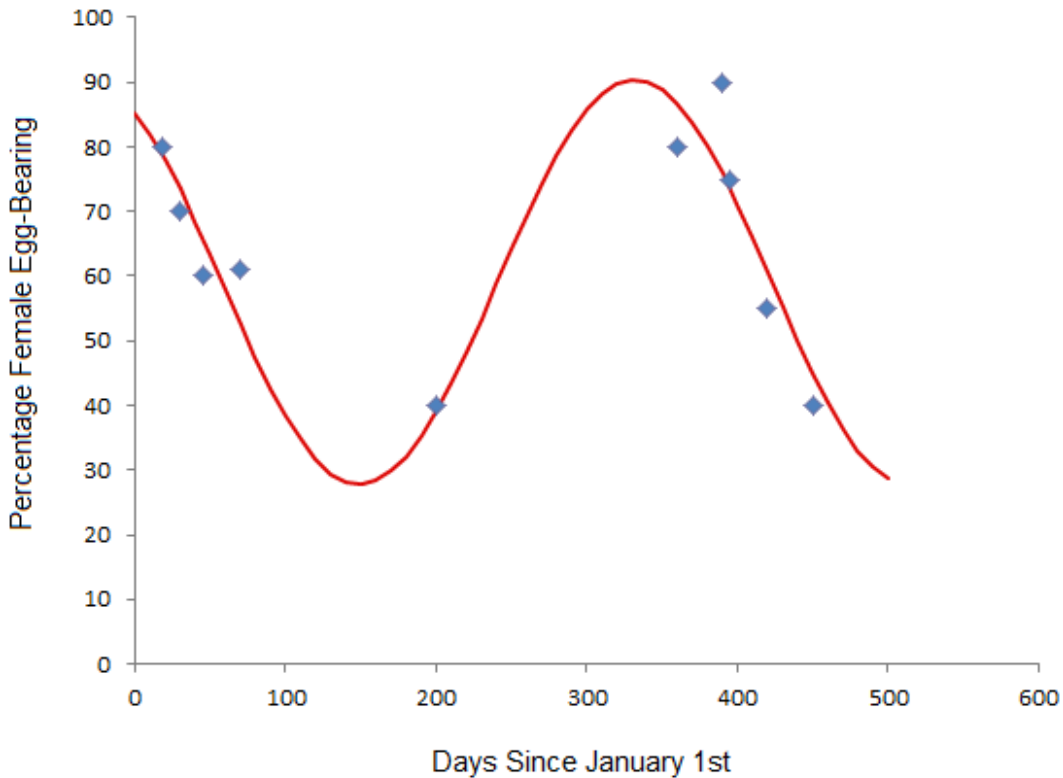


Figure 3.4: The percentage of female *P. guttatus* (n = 277) that were berried from each fishing trip. A similar graph is produced when plotting percentage of females that exhibited any reproductive activity, the only difference being percentages are higher. A 365 day sinusoidal function has been used to create the oscillated curve, which has an R^2 of 0.769.

Foraging habits from in-water surveys

Four hundred and forty (440) *P. guttatus* lobsters were observed during nocturnal snorkelling surveys. In total 237 (54%) were males and 173 (39%) were females and 30 (7%) were unidentified, with 256 individuals (58%) seen within protective recesses while 184 (42%) were seen foraging out in the open. Eighty-five per cent (85.2%) of male *P. guttatus* lobsters less than or equal to 45 mm CL were observed foraging in a recess, whereas eighty-four per cent (83.7%) of those greater than or equal to 50 mm CL were seen foraging out in the open (figure 3.5). Similar results were obtained for females, and both males and females found in a recess were significantly smaller than those foraging in the open ($t_{235} = 12.270, p < 0.001$ & $t_{171} = 4.568, p < 0.001$ respectively).

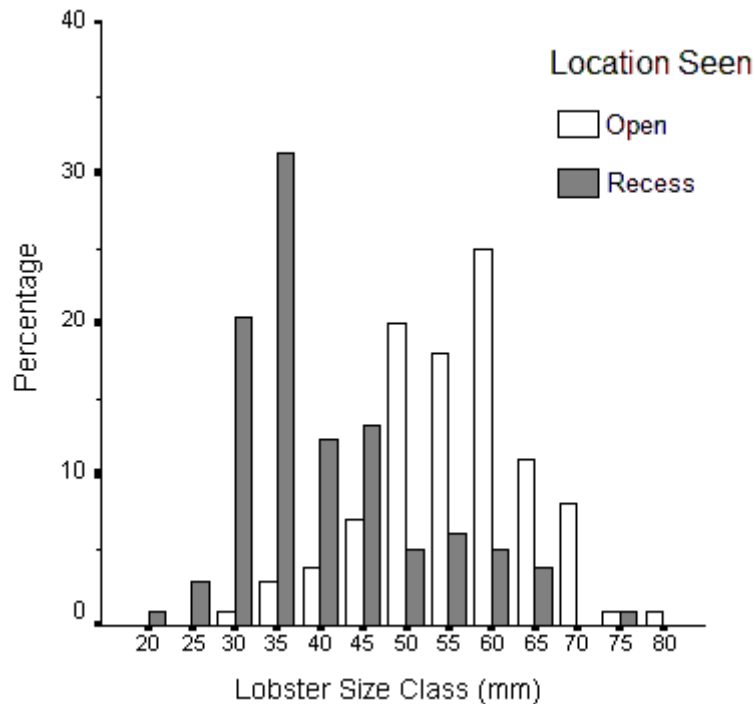


Figure 3.5: Male *P. guttatus* ($n = 237$) activity during timed nocturnal snorkeling surveys, split into whether individuals were seen foraging in the open or hiding in a protective recess. 83.7% of males seen foraging out in the open were greater than or equal to 50 mm CL, and 85.2% of those seen foraging within protective recesses were smaller than or equal to 45 mm CL.

Fishery selectivity from in-water surveys

Of the *P. guttatus* individuals sampled whose fishing method were known, the size class structure of those captured by trap (n=267) was significantly larger than for both hand (n=183) captures ($t_{448} = -9.264$, $p < 0.001$) and those observed during nocturnal snorkeling surveys (n=410, unsexed individuals excluded, $t_{675} = -15.921$, $p < 0.001$) - figure 3.6. The mode value for hand-fishing is the same as that recorded by surveying (50 mm CL) whereas trap-fishing has a mode value of 65 mm CL, hence hand-fishing fishes the natural nocturnal foraging population proportionally whereas trap-fishing targets the larger individuals.

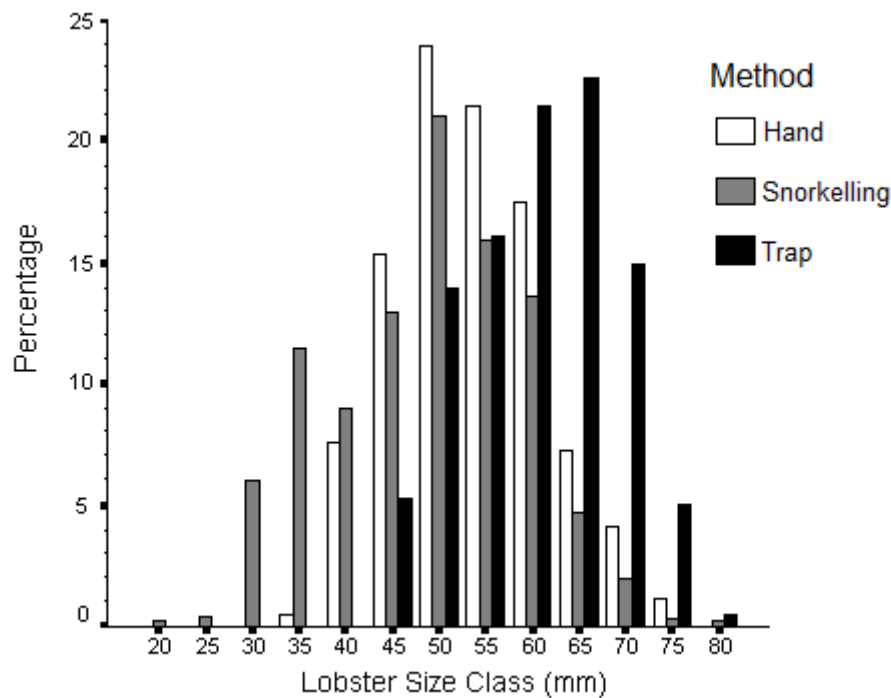


Figure 3.6: Percentage distribution of male and female *P. guttatus* (n = 860) size classes from the 2004 portion of the study as observed through timed nocturnal snorkelling surveys (n = 410), not including those unsexed); for those by hand-fishing (n = 183); and for those by trap fishing, (n = 267).

Changes in fishing practice

Based on observations made between 2004 and 2008, and through semi-structured interviews with fishers (mainly those operating from Island Harbour fishing port), it became clear why concerns exist in Anguilla regarding the sustainability of this fishery. In 2004 the fishing trips undertaken visited traps that had been set south of Prickly Pear East, along Seal Island Reef and on the reefs around Island Harbour and east of Shoal Bay East. By 2007 most of these areas were no longer visited as the fishers reported reduced catches. Instead efforts were concentrated west/central Shoal Bay East and north of Prickly Pear East. Of particular significance is the fact that Island Harbour reef become seldom visited, which, in terms of distance, is the closest possible reef for the fishers to reach. Also of significance is the fact that Seal Island Reef is seldom visited; this area was once the fishers primary source of *P.guttatus*. In interviews the fishers were very specific about this area stating that it was no longer “worth the effort” to visit (R.Webster pers comm).

Further changes were noted relating to spear-fishing for reef fish to use as bait. In 2004 between most trap-sets one of the fishers would snorkel with a spear-gun and return only minutes later with a rice sack full of reef fish, mainly large parrotfish (including, but not limited to *Sparisoma viride*, *Sparisoma aurofrenatum*, *Sparisoma chrysopterum*, *Sparisoma rubripinne* and *Scarus vetula*). The Stoplight Parrotfish (*S. viride*) was a particular favourite to target as the fishers believed it attracted more lobsters and took longer to rot in the bait cages. By 2007 spear-fishing was only seldom conducted during fishing trips and the fishers either went out separately, specifically to target bait, or obtained sacks of reef fish by-catch from fishers who operated significant distances (c.20km) from shore in an area known as Old England.

Hand-capture popularity was not seen to change over the study period although there were some reports that more opportunistic fishers were taking advantage of this efficient and cheap fishing method to supplement their income (H.Richard, pers comm). *P. guttatus* fishers only generally fish using this method if they have local restaurant orders to fill. Catch Per Unit Effort (CPUE) of the trap-fishery was not seen to have changed significantly over the years included in this study, although this may be due to fishers shifting their target areas. Historically, the species is not known to have been exported from Anguilla for sale.

Discussion

Fishery Assessment: Size at Maturity and Implications for Fishery Selectivity and Sustainability

From the results presented, and as illustrated in figure 3.6, where landed *P. guttatus* were significantly larger than in the observed natural nocturnal foraging population⁹, it seems clear that fishing solely via traps will remove the larger individuals from a population, an effect suggested by Wynne & Côté (2007). It is however unlikely that trap-fishing will remove all reproductively active individuals, because maturity begins in size ranges that are rarely caught by this method. Evans & Evans (1995) calculated that a 1.5 inch (c.40 mm) mesh has a mean retention size of 50 mm CL. This is very close to the legal mesh size in Anguilla of 42 mm, offering a reason why there are few individuals below this size landed via this fishing method. However, because only a small percentage of *P. guttatus* lobsters start foraging out in the open before they reach a size of greater than or equal to 50 mm CL, this behaviour will also play a significant role in limiting the sizes landed via traps. This is backed up by experiments conducted using traps with small mesh size (< 20 mm), where individuals captured were not significantly smaller than those landed with legal size mesh (Wynne, 2004); and by Robertson (1994) who states that *P. guttatus* is a highly cryptic species, the smaller size classes of which are rarely seen. Similar comparative use of small mesh traps in Bermuda by Evans (1989) resulted in catching only *P. guttatus* lobsters of a marginally smaller size than the size ranges caught by the standard Bermudan Antillean arrowhead (chevron) traps.

The hand-capture method however allows individuals to be captured even if they are within a protective recess, explaining why landed sizes via this method are significantly smaller than when using traps, and why the size class distribution of the natural nocturnal foraging population is almost identical to that captured using hand-fishing techniques. This explains why presently, with trap-fishing being the most historically popular method, fished populations are currently only showing reduced numbers of larger individuals, rather than a statistically significant effect of fishing (Wynne, 2004). Furthermore it illustrates why management measures are urgently needed with hand-fishing increasing in popularity, a trend that is highly likely to further increase if trap-fishers begin to suffer a reduction in CPUE.

⁹ that recorded during night-time snorkeling surveys

Closed areas have already been recommended as a management measure by Wynne & Côté (2007), and the present study agrees with this conclusion as it affords year-round protection to larger individuals that have the potential to produce larger brood sizes. These areas are valuable as they have the proven potential to seed the region through widespread larval distribution (Cudney-Bueno et al., 2009), and it is also reported that despite the longevity of the lobster pelagic larval phase, such protection may lead to increased adjacent populations through overspill (Kelly, 1999). Networks of no-take closed areas have proven potential to be used as a double-edged tool for marine resource management and marine conservation, e.g. Spiny Lobster Fishery, Leigh, New Zealand (Kelly, 1999), as restrictions on fishing also protect the reef from damage that can occur when traps are placed directly on it. Such intrusive trap placement occurs frequently in Anguilla when reef dwelling species such as *P. guttatus* are targeted (Wynne, 2004). These closed areas also restrict the likelihood of damage via boat collisions to the reef that occur regularly while fishers negotiate the shallow areas that are targeted (S.Wynne, pers. Obs.).

However, closed areas are often hard to police, especially in small island states like Anguilla who have limited resources, and a close-knit local population. For this reason it is suggested that the closed area be established in the lesser accessible offshore shallow reef areas, as closing these areas will cause the least local resistance. There are a number of marine parks in Anguillan waters, and provisions are already in place in the existing legislation for these parks to become closed areas to fishing. As three of these parks encompass shallow reef regions it is recommended here that the one most distant from the mainland (known as Prickly Pear and Seal Island Marine Park), be used as the initial closed area. Furthermore, this area would also be an ideal location for beginning similar management measures relating to other local fisheries. Further management measures for the more accessible mainland near-shore regions should be collaboratively developed and implemented subsequently with the fishers. This would be the case if the practice of v-notching were to be introduced here: it has been seen to be a highly effective conservation tool in the United States but does require a high level of cooperation with local fishers (Acheson & Gardner, 2011).

A closed season for the mainland near-shore regions is suggested in order to better protect the reproducing *P. guttatus* population, as protecting egg-bearing females alone is difficult to survey and enforce. Any person landing an individual during the closed season would instantly be

recognised as infringing regulations, and vessels could also be easily spotted and identified from the shore. No in-water surveillance would be needed. As *P. guttatus* breed all year it is important that the protection of egg-bearing females via generic legislation continues (Ye et al., 2006). However, it is known that even if egg-bearing females are returned to the water by fishers, the molestation they suffer while being handled beforehand increases mortality rates (Evans and Lockwood, 1994). Such molestation also reduces their chances of spawning optimally due to an increase in stress levels that induce tail-flicks and dislodge eggs, thus reducing brood size. Limbs are also often lost while being handled - reducing female reproductive fitness and potentially effecting fecundity - especially if the lost limbs are those the female uses to tend her eggs. Displacement while being removed from the trap and returned to the water will also increase stress and the likelihood that tail flicks will dislodge and damage the female's brood. However, Lozano-Álvarez *et al.* (2002) demonstrated that *P. guttatus* have a strong homing and orientation ability that will allow them to return to their dens even after significant displacement. In light of this, and based on the results from the present study, where a peak in breeding activity occurs between January and March, the period between 1st January and 31st March each year is recommended as a closed season. As adverse sea conditions often limit fishing activity during this time it is believed any negative effects to local livelihoods will be limited. This will in turn increase the likelihood of compliance. Although the suggested closed season period may seem an ineffective measure due to a lack of intensive fishing during this period, it does 'softly' introduce the concept of such seasons as currently none exist in Anguilla for any fisheries. It also protects against any future changes in fishing habits, especially if hand-fishing efforts were to increase during this time as they are less affected by sea conditions.

It is recommended to set a minimum landing size in order to regulate the hand-capture part of the fishery. If time is allowed to pass without proper management, it is predicted that trap-fishing will reduce in popularity as increasing fuel costs and reduced catch make its economic viability unattractive as a livelihood. At the same time, tourism, which drives the market, is predicted to increase, and as such demand for *P. guttatus* lobsters will do so also. This is set to increase the frequency of hand-fishing, which has already been growing in popularity for a number of years. It has been established by the present study that hand-fishing targets a size class structure almost identical to that of the natural nocturnal foraging population, thus if unregulated and intensified this method of fishing has the potential to do great damage to the production of new fishery recruits through the overfishing of all mature size classes. This would mean that closed seasons become redundant as there would be very few reproducing adults present in the remaining population, and it would impact the trap-fishery by removing the majority of individuals that are

trappable (> c.50 mm CL). Setting a minimum landing size will address this issue for the hand-capture fishery.

Setting a minimum landing size should be sympathetic towards local livelihoods while protecting *P. guttatus* up until the point that they have a chance of reproducing at least once. Although a larger minimum size would promote the protection of larger individuals that have the potential to produce more eggs, leniency is both important and possible because the proposed closed areas will already protect larger individuals in designated areas of shallow reef habitat. With this in mind, a minimum landing size of 52 mm is recommended as this is larger than the onset of male allometric leg growth at 51.3 mm CL and also the 50% female maturity size of 46.03 mm CL, while only representing 2.5% of the catch landed via traps. In other words, trap-fishers will only have to discard 2.5% of their catch due to it being of sub-legal size.

It is essential that any new management measures are complimented by continued compliance by fishers to existing generic legislation relating to minimum trap mesh size and the returning of berried females, or those with spermatophores, to the sea. It is also essential that surveillance and enforcement back up all management measures and as such assure this continued compliance. The sharing of these results and conclusions with the key marine stakeholders, and collaborative development of the proposed fisheries management measures with the fishers, would promote a sense of ownership of the management framework and enhance surveillance and compliance, aided by observation and reporting by the small and close Anguillan fishing communities.

Fishery Assessment: Wider Implications for Marine Park Management

Results collected while conducting this study, as discussed above, point to the need for a minimum landing size for *P. guttatus*, potential viability of a closed season, and the need for consideration to be given to using some of Anguilla's marine parks as closed areas for the species. However it is also possible to draw conclusions on other management facets by combining this this information with that collected indirectly during the course of fishing trips and other field excursions.

Over the study period it was noted how originally fishers often spear-fished for bait, with parrotfish appearing to be preferred species, especially Stoplight Parrotfish (*S. viride*). However,

as the years progressed this practice became less and less prevalent. Instead fishers would either only bait their traps with cow hide, or use in combination with reef fish that they had obtained by other means; that being caught while spear-fishing along the coastal zone while not lobster fishing, or caught as by-catch by fishers working further offshore and given to lobster fishers after returning to shore. This suggests that spear-fishing in areas where *P. guttatus* are targeted started giving limited returns and therefore that reef fish abundance, especially of larger individuals, was being detrimentally affected in these areas. This points to a need for management measures that will address the targeting of reef fish in areas fished for *P. guttatus*. Such measures might include the consideration of minimum landing sizes for certain species of reef fish and limiting spear-fishing as a whole that is currently permitted throughout Anguillan waters.

To further bolster this observation further ecological studies should be conducted to assess the abundance of reef fish throughout Anguillan waters. Although historical data are limited for Anguilla it was decided to conduct such assessments and use the precautionary principle based on their results (chapter 4). As reef fish are targeted intensely throughout the island, not just for lobster pot bait but also as a fishery in their own right (spear-fishing, trap-fishing, hook & line-fishing and trolling) it is highly likely that they are in need of urgent management attention.

Inferences can also be made on the overall ecological health of the areas targeted. Over the study period areas targeted by fishers shifted markedly, specifically from areas along Seal Island Reef to more northerly areas of Prickly Pear, and from east of Shoal Bay East and north of Island Harbour to more central and western parts of Shoal Bay East. Both these observations reflect reduced *P. guttatus* landings in these areas, and as such suggest a reduction in overall ecological health. Furthermore traps are sometimes set directly on the reef, which is well documented to cause coral damage, and over a period of time will have a negative cumulative effect on reef health. Although these observations do not necessarily indicate a certain reduction in reef health it does point to the need of more detailed ecological assessment of these areas, and illustrates how a fishery assessment can highlight areas to prioritise for further study.

Conclusions: Fishery Assessment

Size at maturity combined with a minimum mesh size of 42 mm mean the *P. guttatus* trap-fishery may not lead directly to recruitment over-fishing, although it will likely lead to the removal of larger size classes from fished populations. This may ultimately severely influence recruitment.

Under the current management framework, as larger size classes diminish, it is possible that the trap fishery would become no longer economically sustainable and that most or all *P. guttatus* landings would eventually occur via the already popular hand-fishing method. Hand-fishing targets smaller individuals than those caught through trapping, and, as population size classes diminish, landed size classes would follow suit. As the hand-capture fishing method is nocturnal in nature and as such limited in potential special scope, certain areas may remain unaffected.

Closing certain offshore shallow reef areas to all *P. guttatus* fishing is recommended to protect entire populations, hence promoting local and regional stock recruitment while reducing trap and boat induced damages to the reefs physical structure. It is suggested that Prickly Pear and Seal Island Marine Parks would be ideal for this purpose, with the potential to compliment future management measures for other local fisheries.

As *P. guttatus* is suspected to be sensitive to external stresses and because it is difficult to police the landing of berried and/or spermatophore-bearing females, a closed season is also suggested to promote the fishery's sustainability. To best protect spawning populations, and also to minimise livelihood impacts, this closed season is suggested to occur January 1st to March 31st each year, although some consideration will have to be given to the fact that this is also peak tourist season and so may have some livelihood impacts.

Based on size at maturity studies for both sexes a minimum landing size of 52 mm is recommended that will have little livelihood impact on trap-fishers, but will protect immature individuals that can be targeted by hand-fishing, so that they can have greater chance of survival, mating and growth. It is recommended that surveillance and enforcement, particularly in regard to the minimum landing size and the hand-capture fishery, be enhanced, for example by 1) regular random patrols and 2) by encouraging active involvement of the fishing community by creating a fishers organisation. The promotion and creation of a fish market, a facility that Anguilla currently lacks, would further benefit both management and livelihood aspects of this

fishery by facilitating surveillance efforts while at the same time opening up co-operative potential and increasing consumer accessibility to this much sought after resource.

These measures, together, will provide significant protection against recruitment over-fishing and also allow the *P. guttatus* lobsters to grow to a more marketable and valuable size, so that Anguilla's crayfishers enjoy greater returns for their effort, enhanced livelihood and a sense of ownership of a sustainably managed resource.

Conclusions: Wider Implications for Management of Anguilla's Marine Park System

Aside from the recommendation of a closed area for *P. guttatus* fishing, other fishing restrictions are suggested to be considered for marine park areas and coastal regions. Spear-fishing should be limited within the Anguilla Marine Park System, and consideration be given to doing so in all shallow coastal reef areas.

Minimum landing sizes are suggested for certain key reef fish species, for example the Stoplight Parrotfish (*Sparisoma viride*). A full list of key species should be compiled and full literature reviews conducted to establish if geographical variation exists within these species in relation to size at maturity and overall population structure. If no significant variation exists then fishery assessments would not be a priority, and legislation could be updated based on literature alone.

Traps set directly on the reef seem likely, over time, to cause significant damage to reef structural complexity. Reef complexity is essential for overall ecological health and as such it is recommended that legislation be updated to restrict traps being set directly on the reef, and so limited to sand patches adjacent to the reef structure. In order to be able to survey compliance and enact enforcement it is further recommended that trap surface marker buoys be marked with the fishers licence number and fisheries officers be given the authority to confiscate and impound equipment as necessary.

Ecological assessments should be conducted to look into those areas of concern identified by this fishery assessment. Given financial and logistical constraints a methodology needs to be developed that is viable within these restrictions. Reef fish abundance, diversity and size class distribution are essential data to be collected, as are variables relating to overall ecological health of reef areas. This assessment and conclusions drawn will be the subject of chapter 4.

Finally, this study has shown how financially and logistically viable studies are achievable for certain species, although first an important knowledge gap needs to be identified, and a methodology built that works within known limitations. Where possible, it is prudent to choose priorities where past research has been conducted, or encourage independently funded research before investing significant resources. One such method of achieving this is for managerial bodies to encourage postgraduate study on identified topics by providing in-country support to visiting students. This has taken place on Anguilla for a number of years now and has provided managers with important baseline information that can be built upon as needed.

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Chapter 4

Using threat assessments to bridge the gap between ecological monitoring and marine park management plan design in Anguilla, British West Indies

Summary

Marine managers often stall in the decision making process between collection of ecological data and implementation of successful management measures. This stalling can either take the form of introducing management plans that are unrealistic in terms of financial and logistical limitations, or not being able to decide and agree on which management measures would be most suitable and beneficial. This process usually occurs due to incomplete understanding of the data collected, or an incomplete understanding of the processes involved in producing interpretations from the data. This paper sets out to design a process by which this gap can be bridged, and provide managers with guidelines to follow to achieve this. A four stage management process has been identified: area designation (stage 1); ecological monitoring (stage 2); threat assessment (stage 3); and adaptive management (stage 4) that involves initial management plan design and implementation. This chapter uses four case studies that became part of the threat assessment (stage 3) process in Anguilla, British West Indies: a coral recruitment study; a water quality pilot study; a Long-Spined Sea Urchin (*Diadema antillarum*) translocation feasibility study; a comparative rapid assessment of available historical data; as well as a fishery legislation review. The results and conclusions of these case studies illustrate the importance of a threat assessment taking place prior to management plan development. The threat assessment helps identify which stressors can be most effectively managed, and feeds these conclusions into the design of the management plan, which itself becomes the integral facet of the adaptive management stage. Without this threat assessment it becomes clear why many protected areas do not move beyond the first stage of management (area designation - the paper-park level of management), or do so in an unsuccessful manner.

Introduction

Coral reefs around the world, in particular those in the Caribbean region, have undergone a period of serious decline (Gardener *et al.*, 2003). This has been characterised by significant loss of coral cover and diversity, combined with increased levels of macroalgae and an overall phase shift in community composition (McCook, 1999). This is the primary motivation behind the creation of many marine protected areas in the Caribbean region. In some cases, when effectively managed, marine parks have had well-documented positive effects on associated fisheries (McClanahan & Kaunda-Arara, 1996) and larval sources (Cudney-Bueno *et al.*, 2009). Interventions have been identified that may reverse this so called 'phase-shift', although their benefits have been documented to maintain overall coral cover (Selig & Bruno, 2010).

Reasons for the lack of documented successes are complex and wide ranging, with multiple stressors at play and multiple effects that are both primary and secondary in nature (Ban *et al.*, 2014). Indeed, in many cases the situations are so complex that it soon becomes problematic to discern the difference between stressors and effects, as effects become stressors and result in a new level of effect. For example, nutrient enrichment can increase the severity of coral diseases (Bruno *et al.*, 2003), and thus, in combination with bleaching events and predator outbreaks, increases the amount of substrate open for settlement. The increased capacity for macroalgae growth in a nutrient enriched environment (Lapointe, 1997) mean they out-compete corals for space and smother existing colonies. This growth can abound in an uncontrolled manner when key herbivorous species are removed from the system through fishing (Hughes, 1994) or disease (Miller *et al.*, 2003). Further stressors include sedimentation and particulate input from African dust that may be partially responsible for the initial introduction of certain coral diseases in the first place (Shinn *et al.*, 2000). Sources of nutrients include regional sources, for example large scale fresh water interactions in the Caribbean region from the Orinoco and Amazon (Cowen *et al.*, 2005; Chérubin & Richardson, 2007), and local sources from waste outflows and terrestrial runoff (Fabricius, 2005). The nature of these stressors are inherently difficult to manage, and as such mitigation measures are often the best option for managers.

Before the introduction of mitigation measures it is essential that ecological monitoring takes place in order to identify the threats that exist in a certain area. This step in the managerial process often does not take place sufficiently leading either to the paper-park scenario, or areas that are managed under measures inappropriate to its specific needs (Barbour *et al.*, 2006). Furthermore, managers can be in full possession of a complete habitat dataset but stall at the

management decision stage due to not fully understanding the implications of these data or other residual uncertainty (Biber, 2013). Additionally this sort of stalling is likely to be under-reported as a lack of regular monitoring means failures are not well documented except in the broadest sense of readily observable indicators (WWF, 2015). Even if this stalling process does not occur, management measures can still fall short of their proposed goals due poor data interpretation or lacking information. For example (table 4.1): A stressor is working alongside or interacting with other stressors (i); or a stress is being managed by an untested measure that is ineffective for the proposed situation (ii); or management is being attempted against a stress that can't be realistically managed (iii); or a stress being managed at the primary level when in fact it is a secondary effect (iv). The solution being proposed here is a secondary level of monitoring and experimentation that takes place once initial ecological monitoring is completed but prior to the development of a management plan for the area. Data collected can be fed back into the management system (figure 4.1) and allow more informed decisions to be made.

Table 4.1: Four suggested scenarios where management measures may seem realistic due to results from ecological monitoring, whereas in fact they are ineffective due to unforeseen or unknown stressors or effects of stressors.

| <i>Category</i> | <i>Description</i> | <i>Example</i> |
|-----------------|--|---|
| (i) | Interacting stressors, only one of which is being managed | Potential synergism between herbivore reduction and nutrient enrichment. Managed via fish catch limits on herbivorous species, but restrictions not enough to make a difference due to the effect of eutrophication. |
| (ii) | Stress being managed by an untested ineffective measure | Algal overgrowth being due to low <i>Diadema antillarum</i> numbers and management measure is to transplant <i>D. antillarum</i> from healthy populations into areas lacking. In fact, <i>D. antillarum</i> may not be possible to effectively transplant through cost effective means. |
| (iii) | Stress management attempted for a stress that isn't possible to manage | Attempt to manage eutrophication through tight control of potential local sources of nutrients. Though may prove ineffective if the stress is from regional and uncontrollable nutrient sources. |
| (iv) | Stress being managed at inappropriate level | Reduction of coral recruitment managed through coral nursery and plantation efforts, whereas low numbers of recruits aren't due to low numbers of potential recruits, it is instead (for example) disease or other stress through eutrophication inhibiting coral recruitment. |

This extra level of data collection prior to management plan development can be inhibited by cost, especially in small island nations such as those that exist in the Caribbean region. For this reason it is essential that initial ecological monitoring successfully identifies existing threats, and cost effective methodologies developed that also take into account other limitations of the managerial entity. This situation exists in Anguilla (British West Indies), where a marine park system was created but monitoring methodologies that were originally developed did not match the resource limitations on the island. Two and a half decades passed before a monitoring scheme was developed to address this issue. The latter was conducted over a four year period and resulted in a robust baseline dataset for fifteen sites around the island (chapter 2).

The initial ecological dataset identified a number of areas of concern that the proposed management plan will set out to address. Prior to its development however it is essential to identify which stressors are likely most significant, which of these stressors can realistically be managed and/or monitored, and which management measures would be most effect against them. Using Anguilla as an example, presented here is a model that managers can follow to guide them through this process, from initial identification of the proposed protected areas to development and assessment of the completed management plan and subsequent adaptive management (figure 4.1). The approach ensures the correct identification and designation of protected areas (stage 1) is followed by ecological monitoring (stage 2), and that these data are used effectively through a threat assessment analysis and management plan development (stage 3). Following the completed threat assessment and management plan, a final and repetitive stage is reached (stage 4) where results from activities laid out in the current management plan (including continued collection of ecological data) are fed back into the system, and a subsequent version of the management plan is produced. This cycle may repeat annually or biannually, but for successful implementation of the adaptive management concept, periods greater than three years are not recommended. At all stages of this process, public consultations and stakeholders meetings should be held to ensure community participation and understanding of the process, and increase the likelihood of local support. These meetings, as they should occur at regular intervals throughout the process, are not illustrated in figure 4.1.

Marine Park Designation and Management Procedure

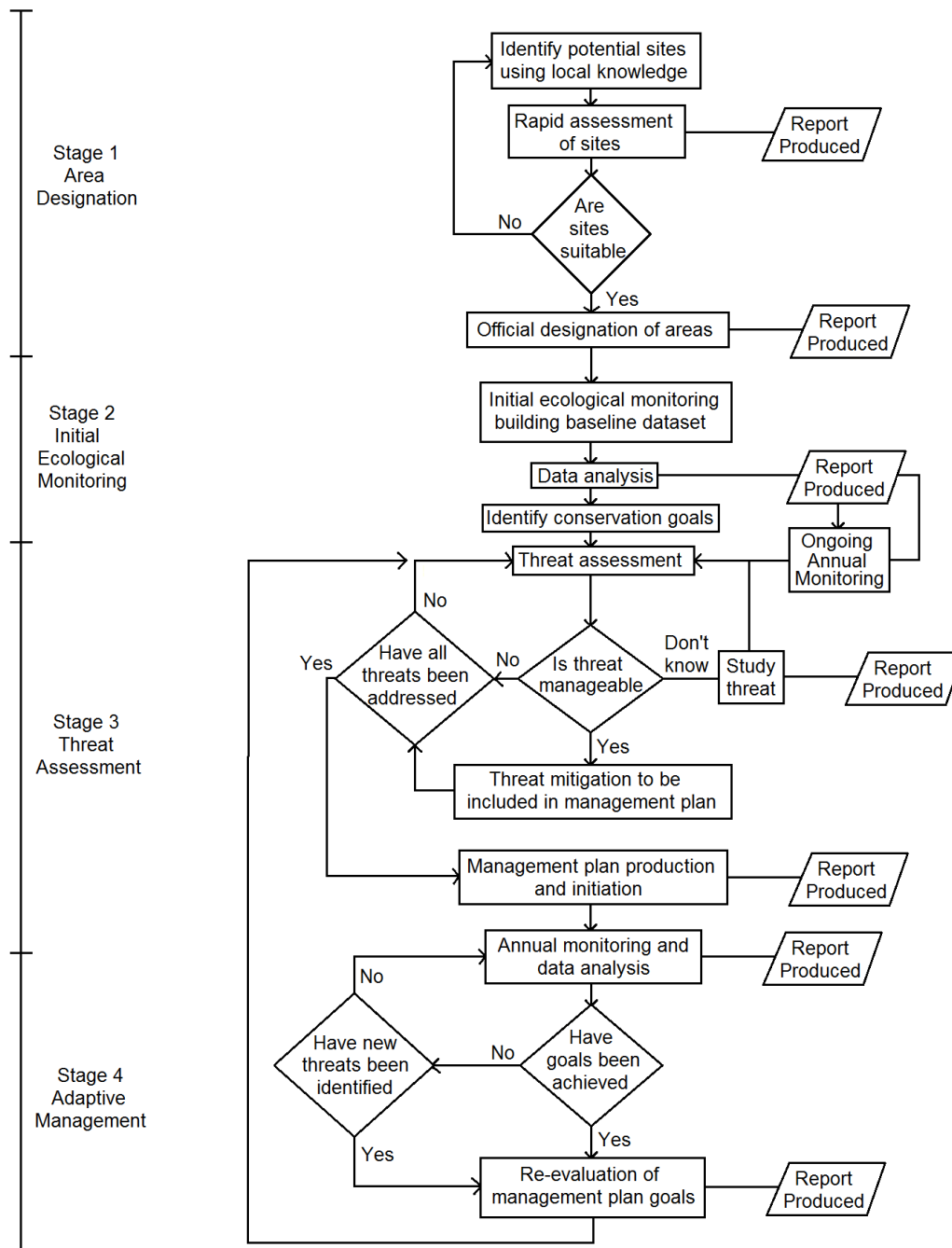


Figure 4.1 - Flow diagram depicting the basic decision making and management processes necessary for effective marine park designation and development based on lessons learnt in Anguilla. Note that the decision boxes (diamonds) will involve consultations with managers, stakeholders and experts as necessary and follow recognised procedure. Also to be noted is that area goal assessment is embedded in this process rather than driving it (as happens with, for example the 10% marine park target, as detailed in Spalding *et al*, 2012). This is to allow full adaptive management to occur, with smaller achievable goals identified first, which can later be updated to larger more challenging goals as the arena becomes more established.

For the purpose of this chapter, case studies conducted in Anguilla are used for selected perceived threats identified by ecological monitoring. These studies will attempt to identify stressors, and suggest selected management strategies to be tested for efficacy. Finally management recommendations will be made based on the results of this threat assessment that will either be fed into the final management plan (as discussed above) or concluded to be in need of further study before management actions can be taken.

The four stages of effective marine park management procedure

Stage 1: Area Designation. In the late 1980's, potential areas for designation were discussed and assessments of these areas conducted (Oxenford & Hunte, 1990). Site designation followed similar principles to that used today for special areas of conservation in the UK (Aish & Johnston, 2009), where there is a clearly identifiable area that represents the physical and biological factors essential for ecosystem function and species reproduction. Following this, five marine parks, forming the Anguilla Marine Park System, were officially designated in the early 1990's and legislated for under the Cruising Permits Act. Ecological monitoring of these areas did not occur following their designation, and because not all marine parks had been studied by Oxenford & Hunte (1990) a significant knowledge gap resulted. It is reported that monitoring of the Oxenford & Hunte (1990) sites was not continued due to resource limitations (J.Gumbs, pers. comm.), which ultimately led to over twenty years of limited managerial action of the areas. The only known active management during this time was the establishment of mooring fields in designated areas within the Anguilla Marine Park System. In 2006 baseline surveys were conducted for the five marine parks using a rapid assessment methodology (Wynne, 2007a), which retrospectively filled the stage 1 data gap.

Stage 2: Initial Ecological Monitoring. During 2007-2010 initial ecological monitoring took place, representing the beginning of the Anguilla Marine Monitoring Program. This program annually surveyed sites both inside and outside of many of the marine parks and was crucial in identifying areas of concern within these areas while building a substantial baseline dataset (chapter 2). Monitoring of these sites has continued to this day (Gumbs, 2012), allowing temporal analysis of data prior the completion of a management plan.

Stage 3: Threat Assessment. This process was conducted during the initial ecological monitoring process (stage 2) as areas of concern were identified. As far as resources would allow, practical threat assessments were conducted on as many areas of concern as possible. Literature reviews of the remaining threats were conducted prior to management plan design. This threat assessment process and the results it obtained from the main structure of this chapter.

Stage 4: Adaptive Management. This stage will begin when the management plan is initiated by the Government of Anguilla following its finalisation. The management plan has been designed with a ten year initial time frame spanning 2015-2025 (chapter 5). During this time ecological monitoring will continue to be conducted by The Department of Fisheries and Marine Resources, or other relevant managerial entity once officially legislated for. The collection of these data and subsequent analysis and report production will allow assessment of the management plan's efficacy, and produce feedback for future adaptations as goals are or are not reached.

Concerns and/or threats identified in Anguilla and suggested actions

- *Low coral cover and high levels of macroalgae on the south coast with heavily eroded almost entirely dead coastal reef systems. Lower coral cover and higher macroalgae levels on coastal and heavily fished offshore regions than expected.*

Suspected stressors and/or reasons include (but are not limited to): Overfishing via traps and/or spear-guns; low *D. antillarum* grazing pressure due to densities on most reef systems studied; and nutrient enrichment and/or suspended sediments from regional eutrophication and/or local sources. It is suspected that these stressors have led to low levels of coral recruitment, particularly on the south coast and a shift in the coral-macroalgae ecological balance. The suggested course of action is to: conduct a coral recruitment study to compare north and south coast sites; initiate a water quality monitoring programme to assess nutrient levels, turbidity, and other parameters; research the efficacy of aiding the recovery of *D. antillarum* populations; and undertake a rapid assessment of the Oxenford & Hunte (1990) study sites in an attempt to make temporal change analysis. This latter recommendation is the only historical comparative study possible in Anguilla, although the limited raw data presented in the report means only restricted historical comparisons are possible, and therefore possible causative variables may be difficult to discern. Finally a legislative review will be needed to highlight how and where changes can be

suggested to afford protection to key species and habitats. Monitoring of other stressors is also recommended as part of future work programmes (coral diseases, physical damage from hurricanes and/or boat collisions), but are not featured in this chapter.¹⁰

- *Smaller than expected size class distribution of commercially and ecologically important reef fish species; Overall lower abundance of reef fish on the south coast, coastal north coast sites and heavily fished offshore regions; Lower than expected densities of conch (*Lobatus gigas*); and high lobster (*Panulirus argus* and *Panulirus guttatus*) fishing pressure in certain areas.*

Suspected stressors and/or reasons include (but are not limited to): Overfishing via traps and/or spear-guns; overall habitat degradation; insufficient fisheries legislation; and low compliance, surveillance and enforcement of existing legislation. Of particular concern are all reef fish fisheries, the two lobster fisheries, and the conch fishery. The suggested course of action is to review all legislation and introduce/amend minimum landing sizes for species of concern, together with limitations on fish trap use limitations and spear-fishing restrictions. Consideration should be given to closed areas, associated socioeconomic impacts of such, and local acceptance levels. There should also be an increase in surveillance and enforcement activities as local resources allow.

Bridging the gap between ecological monitoring and management plan design

The identified concerns and suggested courses of action to be taken highlight a gap that exists between completion of ecological monitoring data analysis and management plan design. It is observed that if ecological monitoring (stage 2) is completed there is a tendency to move directly to the design phase (stage 4). This can lead to incorrect management measures being implemented for the stressors that are actually influencing the ecological situation. For example, in Anguilla there has been talk of a coral restoration programme for the south coast region. If however coral settlement and subsequent recruitment is not occurring along this coast such a programme would likely fail and revert back to the current situation. A better understanding of the processes at work is clearly needed before substantial funding is poured into the unavoidably costly process of direct reef restoration action: artificial reefs, coral nurseries and

¹⁰ Other factors may also be identified during the adaptive management and re-monitoring

transplantation. It is quite possible that corals are not recruiting along this coastline for other core reasons, such as eutrophication or sedimentation levels. For this reason stage 3 of the managerial process, that of threat assessment, is crucial to either: directly study the potential stressors; conduct pilot studies of potential managerial actions; or fully review the scientific literature. Only once this process has been fully completed, albeit to a level inherently governed by financial and logistical limitations, should the proposed actions be finalised in the initial managerial model.

Within this chapter five threat assessment case studies will be presented that set out to investigate stressors and the overall suitability of potential management measures suggested following initial ecological monitoring.

Methods

Coral recruitment study

A coral recruitment study was conducted to investigate recruitment levels at the ecological monitoring sites around the island (described in Wynne 2007b) and to ascertain whether the low number of observed coral recruits is due to the lack of planula settlement and initial corallite formation. The study also provides indirect data relating to macroalgal stress as this group competes with corals on new bare substrate surfaces.

Terracotta tiles (Burt *et al.*, 2009) measuring 10cm x 10cm x 1cm were placed at ten reef sites between 13th and 27th August 2008. These sites were in identical locations to the reef used for ecological monitoring (chapter 2), although two replacements were made: The site at Anguillita was replaced by Blowing Rock as tile attachment sites were more plentiful in order to increase the south coast sample size; the site at Scrub Island was replaced by Savannah Bay due to adverse weather conditions and to increase the south coast sample size. Figure 4.2 illustrates these locations, with figure 2.1 illustrating those used for ecological monitoring. Tiles were placed coinciding with initial reports of coral spawning in the Caribbean region (Brady *et al.*, 2009), primarily *Acropora spp.* and *Orbicella spp.*, with other species reported to spawn during subsequent weeks. The tiles were left in place for a period of approximately six months, with collection beginning early in 2009 as weather permitted.

Thirty tiles were placed at each site at a depth of 5m, and thirty at a depth of 10m. Sites with no 10m areas only had the 5m sets placed - the nature of the south coast sites meant deeper tile replicates were not always possible. Care was taken to ensure orientation on the reef was random following the methodology used by McWilliams (2005). The tiles were attached via a cable tie through a hole drilled into their centre. After collection the tiles were soaked over-night in a diluted bleach solution and left to dry for later examination. Tile examination consisted of using a magnifying glass to identify/count recruits (table 4.2) and record calcareous tube worms, coralline algae, filamentous algae, sponges and other biota. Recruit species identification could not be reliably conducted due to lack of microscope availability for use by the research team.

Water quality monitoring programme pilot study

With the government water lab out of commission for a number of years very little water quality data exists for Anguilla. In light of concerns over water quality around the island, especially as it relates to nutrient levels, a pilot study was undertaken to address this knowledge gap. By using staff and equipment at a water laboratory based at a local hotel development, eighty sites were assessed between September and December 2008. Sampling took place on two to three occasions at each site to produce a mean baseline value for each location (Wynne, 2009). A small hand held digital unit was also used to measure certain parameters that had to be tested directly in the field.

Of the sites studied, 43 were located on the north side of Anguilla, and 36 on the south side. One site, located in the Road Bay pond channel served as a salt pond comparative site as the channel was not connected to the sea during the monitoring period. This channel, as with other connective channels to Anguilla's salt ponds, can breach during storm surges or in other times of increased wave action. Three of the sites studied were located by outflow pipes: Crocus Bay desalination outflow; and Tenemos/Cove Bay pipe subterranean outflow pipes that connect salt ponds located within the new golf course development to the sea. Readings at these sites were taken c.0.5 m from the outflow pipe and so represent values after initial mixing has occurred.

Variable monitored were: temperature (°C); dissolved oxygen (mg/l); pH; conductivity/salinity (µs); ammonia (as N mg/l); nitrate (as N mg/l); phosphorous (mg/l); chemical oxygen demand (mg/l); and turbidity (NTU - Nephelometric Turbidity Unit). Temperature, dissolved oxygen, pH and salinity (conductivity) were measured in the field using the hand held meter, although

they were recorded again back in the lab. Samples were collected in plastic jars from c.50 cm below the surface and stored in a cooler until reaching the testing lab. Three samples sites were in deeper water and collected using SCUBA gear – two in the St Martin channel and one in Seal Island channel. Transit time between collection and testing varied, but was kept to a minimum and did not exceed three hours. Testing was conducted by a professional lab technician who worked at the islands largest reverse osmosis plant.

Diadema antillarum translocation study

Rapid assessments were conducted to identify potential donor sites that had high densities of Long-Spined Sea Urchin (*Diadema antillarum*) but were low in topographic complexity, thus facilitating urchin collection and transport. Individuals were gently scooped up using a small trowel and guided into submerged buckets using thick leather gloves before being carefully transferred to 50 gallon water filled storage bins for transport. Once all bins were full, the cargo was transported to the receiving site as rapidly as possible, and the storage bins lowered gradually into the water before slowly inverting them a few centimetres above the reef area. This methodology was developed to take into consideration resource limitations and minimising the amount of survey equipment that would need to be obtained. Due to the importance of these populations for regional and/or local larval recruitment this study was not conducted until a known population became threatened by a proposed coastal development. This donor site, located at the east end of Shoal Bay West where a marina development was proposed to take place¹¹, had high densities of *D. antillarum* in a shallow low relief shallow rocky region. It was determined that approximately 80% of individuals were exposed enough to facilitate translocation using the proposed methodology. The receiving site was chosen after rapidly assessing a number of sites within Shoal-Bay Island Harbour Marine Park. This area was chosen as a receiving site due to its marine park status, high number of potentially suitable sites, and its overall coastal nature (i.e. ease of survey work). The receiving site had to primarily have no visually sighted *D. antillarum*, while having high topographic complexity and high levels of macroalgae. The site chosen fitted these criteria well, being an interconnected series of patch reefs close to the coast near the eastern end of Shoal Bay East. A benthic survey of this site, consisting of 30 randomly distributed 50x50 cm quadrats, was conducted prior to translocation. Percentage covers of main benthic community descriptors within these quadrats were recorded.

¹¹ The development would have destroyed this resident urchin population

D. antillarum population counts were also conducted during each site visit, using 15 m strip transects (1 m wide) at metre depth intervals (table 4.3). A control site was established c.100 m away on the same patch reef area and identical surveys carried out.

Translocations, as described above, took place in November 2007, with two field visits that relocated a total of 348 individuals. Once at the receiving site urchins were observed to ascertain if any initial mortality had occurred during the translocation process. None was noted, with all *D. antillarum* moving away from the placement area in c.5m of water into the surrounding reef. Follow-up benthic surveys were conducted during March, July and October 2008 to assess *D. antillarum* population levels, look for signs of mortality, and monitor macroalgae levels.

Comparative rapid assessment of available historical data

The only available historical ecological data known to exist for Anguilla was collected by the Bellairs institute of Barbados prior to the establishment of Anguilla's Marine Park System in 1992 (Oxenford & Hunte, 1990). The sites studied were assessed for inclusion with the Anguillian Marine Monitoring Programme (AMMP) established in 2007, which formed the basis for initial ecological monitoring to develop a comprehensive management plan for the marine parks and associated shallow water habitats and fisheries. Aside from some of the seagrass areas, the majority of the sites however were concluded to be in locations not suitable for the goals of AMMP monitoring (chapter 2), and so were not included. This did leave open the possibility of locating these sites and rapidly assessing them to quantify the change that had occurred during the interim period of over 25 years. This change could be used to tentatively make conclusions about changes that may have occurred in other areas over the same time period, including those sites studied during current ecological monitoring. This would aid in assessing stressors in play around the island including, but not limited to, overfishing and nutrient enrichment. As many sites surveyed in the original study were established using terrestrial reference points still present, hand drawn overhead maps of their estimated locations, and identification of the now heavily encrusted sediments traps that had been cemented in placed during the 1989 study period. In total ten of the original twenty sites could be located reliably enough for inclusion in this assessment (figure 4.2), two seagrass sites and eight coral reef sites. It should be noted that a large portion of the Oxenford & Hunte (1990) study was to conduct unquantified visual transect surveys of eight study areas that served to select the twenty study sites and produce the first known habitat maps of the areas.

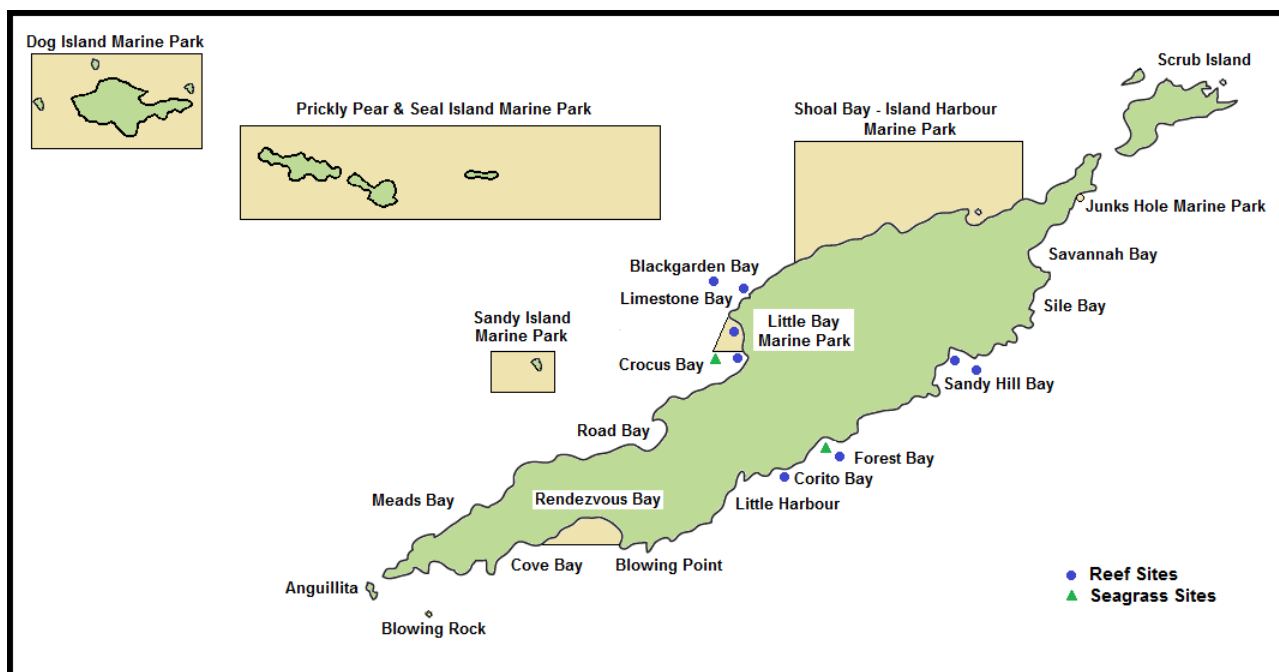


Figure 4.2: Map illustrating the location of Oxenford and Hunte (1990) study sites identified and used for this historical comparison study. Other areas mentioned throughout this chapter have also been labelled for reference.

A methodology was developed that followed as closely as possible that used in the 1990 study, while taking into account current financial and logistical limitations. Fish surveys covered equal areas at each site (100 m^2) with the present study achieving this through five $10 \times 2 \text{ m}$ belt transects while the original study used ten $10/1 \text{ m}$ belt transects¹². Twenty randomly placed $50 \times 50 \text{ cm}$ quadrats were used to assess benthic cover rather than line-intercept transects as used in the original study. This methodological amendment was made as it is felt that quadrats produce more robust results, with the line-intercept method better to assess underlying substrate rather than percentage cover of sessile organisms with a limited fixed area to the substrate (Wynne 2007b). In the original study, seagrass surveys used a somewhat complex methodology where 25 m line intercept transects that radiated out from a central point were used to assess seagrass and $25 \times 25 \text{ cm}$ quadrats to assess macroalgae. The $50 \times 50 \text{ cm}$ quadrats used during present monitoring can be directly compared to these results as percentage cover and seagrass blade length were the only variables recorded. Interestingly sand percentage cover was not measured in the original study, suggesting that the seagrass areas surveyed had 100% biotic

¹² This change was made to reduce work load while still obtaining comparable results

cover. Conversely, reported results do not always add up to 100%, suggesting the presence of an unmeasured parameter. Reference could not be found in the published report as to whether this unmeasured parameter was in fact sand. This irregularity means overall conclusions relating to these areas are tentative at best. Fish surveys were standardised by reducing AMMP results by a factor of 2.5 to account for the smaller survey area in the original study. Logistical restrictions meant offshore sites were not able to be surveyed and so conclusions relating to these areas are not possible, although tentative comparisons can be made based on the results from the coastal sites where anthropogenic pressure is greater. Temporal variations were minimised by conducting survey work at a similar time of year. Fish sizes were not assessed during the original study so any changes to this parameter similarly cannot be made. Key results from both studies are presented in table 4.4 and figures 4.5 to 4.7.

Literature/legislative review and amendments to fisheries regulations

A review of fisheries legislation was identified as a priority by initial ecological monitoring before development of a comprehensive management plan for Anguilla's Marine Park System and associated shallow water habitats and fisheries. This review assessed current legislation in Anguilla, compared it to that in existence elsewhere in the Caribbean region (including, but not limited to: The United States Caribbean territories and continental coast; Organisation of Eastern Caribbean States nations; Central and South America tropical Atlantic coast; the French West Indies and the Netherlands Antilles), and identified where new measures may be introduced to help achieve conservation goals or mitigate against stressor impact. This information was compared with all available scientific literature, reviews and recommendations by organisations such as The Florida Fish and Wildlife Conservation Commission and the Food and Agriculture Organisation of the United Nations.

Results

Coral recruitment study

Table 4.2: Results of terracotta tile examination. Low tile collection numbers at Blowing Rock were likely due to their loss following rough seas. Three hundred and seventy four tiles were collected back after approximately six months soak time.

| Site | Location | Tiles Placed | Tiles Collected | Mean Recruits per tile | Max/Min Recruits | Standard Deviation |
|----------------|-------------|--------------|-----------------|------------------------|------------------|--------------------|
| Island Harbour | North Coast | 60 | 47 | 2.3 | 25/0 | 4.1 |
| Shoal Bay East | North Coast | 60 | 53 | 4.3 | 31/0 | 5.5 |
| Long Reef | North Coast | 60 | 51 | 2.1 | 13/0 | 3.3 |
| Limestone Bay | North Coast | 60 | 44 | 7.9 | 30/0 | 7.9 |
| Sandy Island | North Coast | 60 | 49 | 2.3 | 17/0 | 3.5 |
| Blowing Rock | South Coast | 30 | 9 | 0 | n/a | n/a |
| Little Harbour | South Coast | 30 | 27 | 0.3 | 4/0 | 0.9 |
| Forest Bay | South Coast | 60 | 42 | 0 | n/a | n/a |
| Sile Bay | South Coast | 30 | 26 | 0 | n/a | n/a |
| Savannah Bay | South Coast | 30 | 26 | 0 | n/a | n/a |

Water quality monitoring programme pilot study¹³

Temperatures ranged between 28-30°C across all sites, except for expected elevations at Road Bay salt pond channel and Crocus Bay desalination plant outflow. In terms of dissolved oxygen, all sites appear well oxygenated (EIMP, 2004), exhibiting values ranging from 6.63 mg/l⁻¹ to 9.81 mg/l⁻¹, with exceptions to this again being at sites expected to differ; the desalination outflow at Crocus Bay having elevated readings (10.54 mg/l⁻¹), the two outflows from the golf course salt ponds slightly lower than other in-water sites at c.6.50 mg/l⁻¹, and the Road Bay salt

¹³ Full datasets from this work can be found in Wynne (2009)

pond channel recorded to be very low at 1.36 mg/l^{-1} . These results may be converted to a % saturation value to factor out variable temperature and salinity influences (Grasshoff *et al.*, 1999).

Values obtained for pH were all within the accepted range for reef systems between 7.5 and 8.4 (Rogers *et al.*, 1994), as were those for salinity (converted to conductivity in μs) that were all in the region of $50 \mu\text{s}$, with the exception of Road Bay salt pond channel ($107.8\mu\text{s}$) and Crocus Bay desalination outflow ($77.6\mu\text{s}$). Scatter plots of temperature vs salinity can be found in figure 4.3.

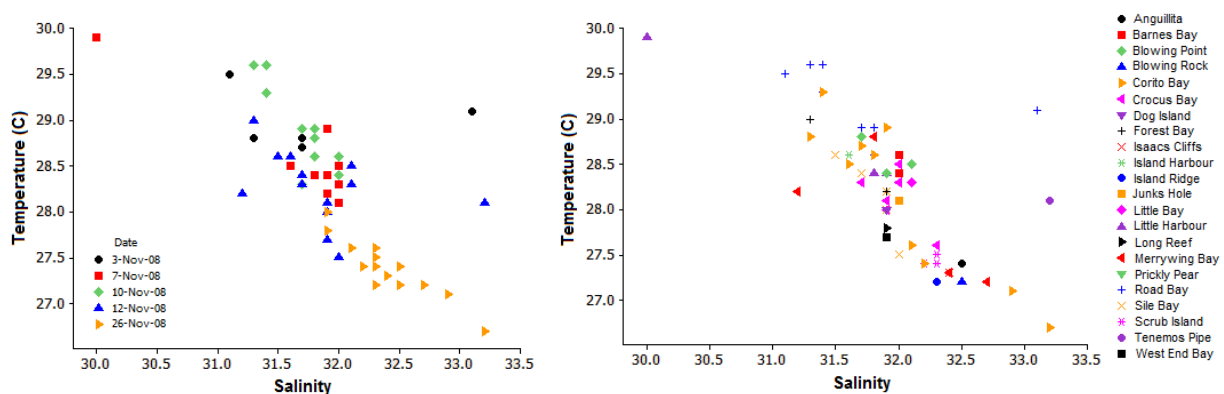


Figure 4.3: Scatter plots of temperature ($^{\circ}\text{C}$) versus Salinity (ppt) for water samples collected in November 2008. Note (left plot) November 26th points are clustered together in the lower right-hand corner of the graph signifying lower temperature saltier water, whereas in the right-hand plot these points are scattered around both north and south coast sites. This suggests temporal variation of influential water bodies rather than geographic variation.

Of the three nutrient variables recorded 85% of sites exhibited elevated levels of both nitrogen based parameters (ammonia & nitrate), and 26% exhibited elevated levels of phosphorous. Due to equipment sensitivity levels an elevated reading was anything that registered above 0.00 mg/l (Abdel-Hamid & Hamed, 2006). Chemical oxygen demand was recorded at acceptable levels around the island with 91% of sites having a value less than 1000 mg/l , and the high value recorded again at Road Bay salt pond channel (1490 mg/l). Turbidity levels across the study sites were highly variable, but the three highest values recorded were all from salt pond outlets: Cove Bay pond pipe (4.10 NTU); Road Bay salt pond (4.05 NTU); and Tenemos pond pipe (3.36 NTU).

Diadema antillarum translocation study

Table 4.3: *D. antillarum* densities (m^{-2}) prior to translocation (October 2007) and at approximately four months intervals after translocation in November 2007. No individuals were recorded deeper than 6m and it was not possible to survey depths less than 3m due to wave action and exposed coral heads.

| Depth/Survey Date | October 2007 | March 2008 | July 2008 | October 2008 |
|-------------------|--------------|------------|-----------|--------------|
| 3m | 0 | 1.5 | 1.8 | 1.3 |
| 4m | 0 | 1.7 | 1.2 | 0.8 |
| 5m | 0 | 0.7 | 0.6 | 0.1 |
| 6m | 0 | 0.3 | 0.3 | 0 |
| 7m | 0 | 0 | 0 | 0 |

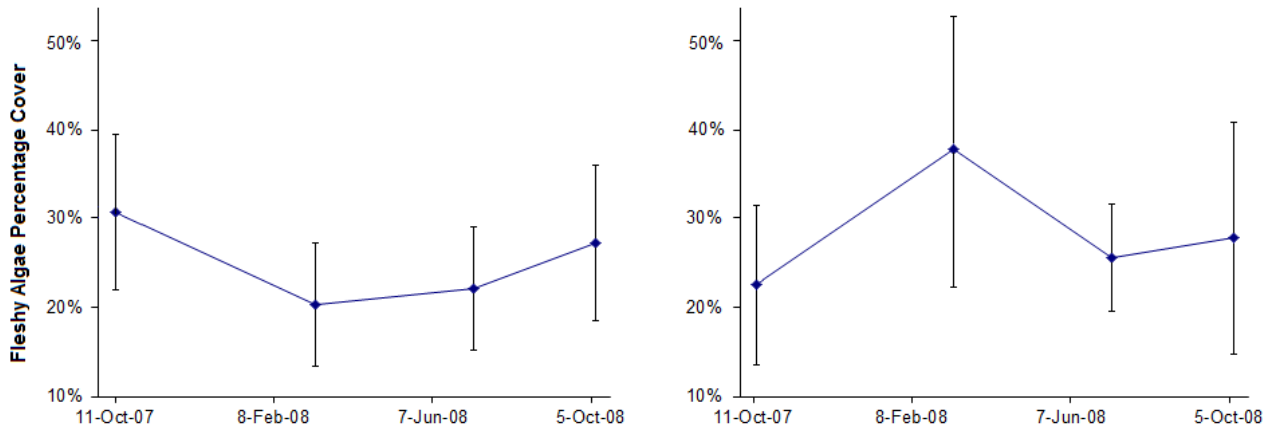


Figure 4.4: Fleshy macroalgae percentage cover at the receiving site (left) and control site (right) for the benthic surveys over the study period. No significant statistical relationships were found. Error bars have been inserted representing standard deviations for each survey date.

Comparative rapid assessment of available historical data

Seagrass site results are presented in table 4.4, showing overall declines between the two study periods, with Crocus Bay losing c.25% of its overall seagrass percentage cover, and Forest Bay losing c.10%. Blade length has either remained relatively constant or decreased slightly. A large decline in fish abundance has taken place at Crocus Bay, together with a reduced number of observed species. Forest Bay has similarly undergone decline, although both studies reveal a limited population present in the area. These results highlight the need for continued vigilance at seagrass areas around Anguilla. However, due to questions raised regarding the original 1990 study methodology, this suspected decline cannot be confirmed reliably until present day monitoring continues some years into the future.

At the reef/rocky sites similar declines can be seen with severe hard coral cover losses (figure 4.5) at all bar one site (Crocus Bay), with Forest Bay suffering an almost 99% loss. Other sites with large decreases include Sandy Hill (shore) with a 74% loss; Sandy Hill (deep) with a 65% loss; and Black Garden (shore) with an 88% loss. In total, an overall mean loss¹⁴ of 67.9% was recorded. Overall diversity losses were further noted (not illustrated) by declines in soft corals and sponges, and an increase in bare rock at all bar one site (Crocus Bay). Percentage cover of algae has increased at some sites but decreased at others (figure 4.6), suggesting levels have remained relatively stable overall with a mean loss of only 1.6%. These differences were not statistically significant. This would be consistent with the role *D. antillarum* plays as a key herbivore, as it was recorded at low densities in 1990 following the 1980's mass mortality event, and has still yet to fully recover today.

In terms of numbers of fish present (figure 4.7), many of the sites have suffered a relatively large decline between study periods, with many of those on the south side of Anguilla being the most severe: Forest Bay has undergone a 52% and Sandy Hill Bay (deep) a 72% decline. Other sites on the south side have only undergone slight decreases or relatively small increases. On the north coast some sites have again undergone decline, with both Black Garden sites exhibiting c.25% reductions. Both Crocus and Little Bay reef/rocky sites on the other hand have shown positive increases. Overall, a mean reduction of 28.1% between study periods was recorded.

¹⁴ Percentage difference between percentages (in this example, the percentage change between 9.1% and 2.9%) as described in the legend for figure 4.5

Table 4.4: Seagrass community descriptors for Oxenford and Hunte (1990) and AMMP (2009) expressed as mean percentage cover of algae (generic) and mean percentage cover/blade length of *Thalassia testudinum* and *Syringodium filiforme*. Results from the 1990 study are unclear, stating 100% cover for both species of seagrass and also 22.2% algae cover¹⁵. Thus, to get potentially comparable results the calculation $(100-22.2)/2$ was used to obtain values for both species (38.9%).

| | | | Algae | <i>T.testudinum</i> | <i>S.filiforme</i> |
|-------------------|-------------|--------------|-------|---------------------|--------------------|
| Crocus Bay | 1990 | Blade Length | n/a | 17.40 | n/a |
| | | % Cover | 11.60 | 82.28 | 0 |
| | 2009 | Blade Length | n/a | 14.61 | n/a |
| | | % Cover | 25.65 | 57.45 | 0 |
| Forest Bay | 1990 | Blade Length | n/a | 13.10 | 16.60 |
| | | % Cover | 22.20 | 38.9 | 38.9 |
| | 2009 | Blade Length | n/a | 13.95 | 12.62 |
| | | % Cover | 6.45 | 53.80 | 23.60 |

¹⁵ This method is sometimes applied to the 3D benthic landscape, but as method description did not clarify this the assumption was made that it was describing a half/half split of seagrass species and 22.2% algae cover. This assumption was based on the fact that coral site benthic assessments all added up to 100%

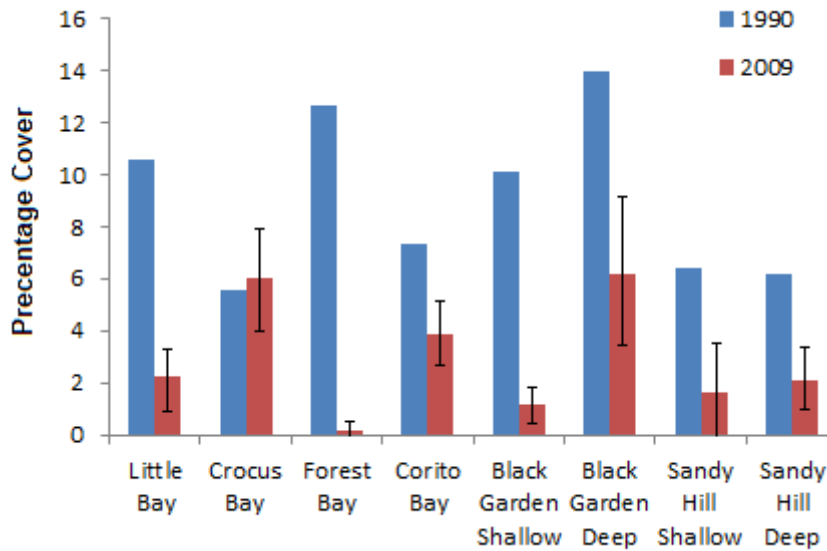


Figure 4.5: Hard coral percentage cover at the eight reef and/or rocky sites studied for both survey periods. Error bars on 2009 data represent 95% confidence intervals. Raw data for the 1990 surveys is no longer available. Total mean percentage cover across all sites was 9.1% in 1990 (SD 3.2) and 2.9% in 2009 (SD 2.2), a difference of 6.2% (SD 4.0). The change recorded between survey years was significant ($t=4.49_{17}$, $p<0.001$).

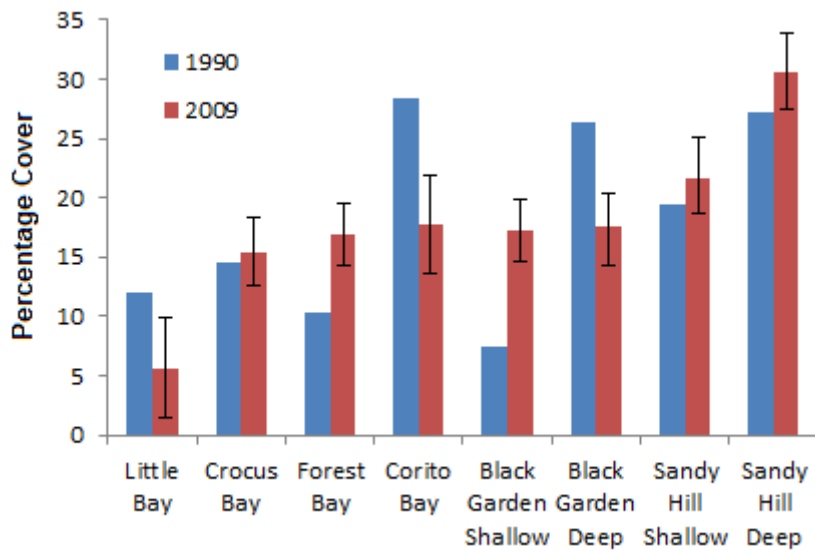


Figure 4.6: Macroalgae percentage cover at the eight reef and/or rocky sites studied for both survey periods. Error bars on 2009 data represent 95% confidence intervals. Raw data for the 1990 surveys is no longer available. Total mean percentage cover across all sites was 18.2% in 1990 (SD 8.3) and 17.9% in 2009 (SD 6.8), a difference of 2.9% (SD 7.7). These differences were not statistically significant.

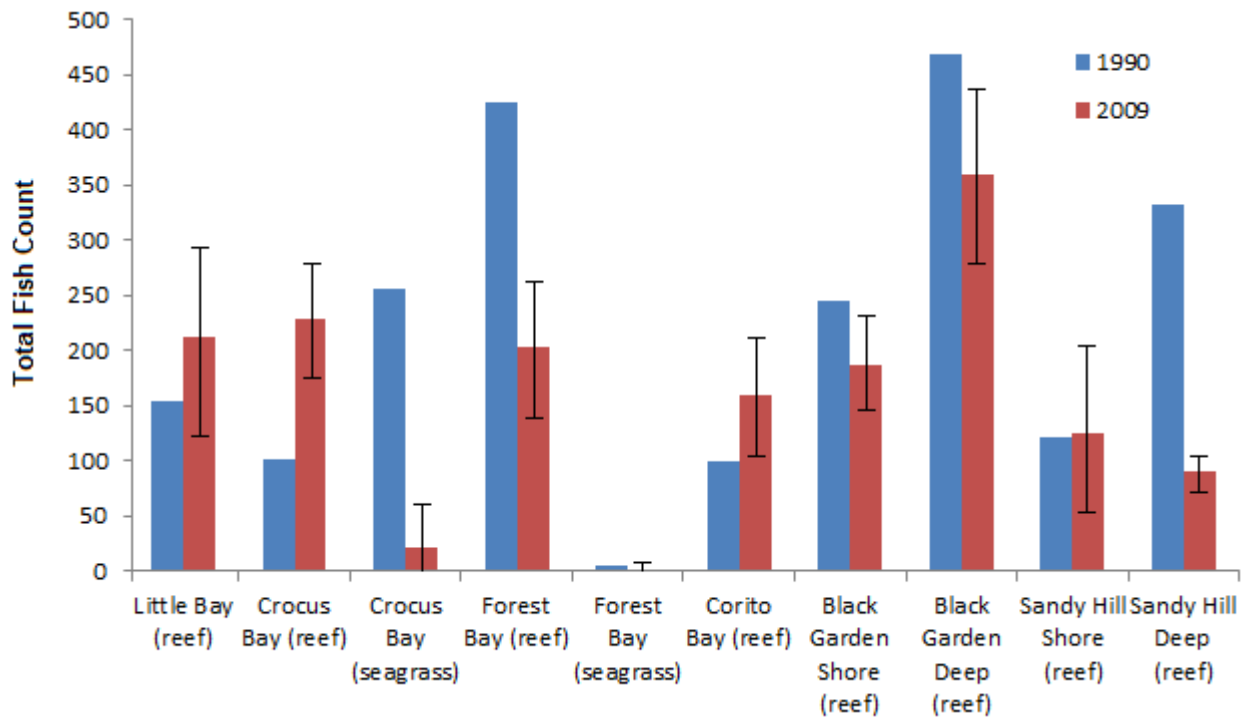


Figure 4.7: Overall fish abundances at all ten sites (seagrass and reef/rock combined) for both survey periods, per 100m². Error bars on 2009 data represent 95% confidence intervals. Raw data for the 1990 surveys is no longer available. Total mean counts across all sites were 222.4 in 1990 (SD 152.8.3) and 159.9 in 2009 (SD 106.3), a difference of 62.5 (SD 135.1).

Literature/legislative review and amendments to fisheries regulations

Following a full review of the Anguilla Marine Park Act and Fisheries Protection Act a number of legislative gaps were identified. A lack of minimum size restrictions for all targeted species aside from the Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Lobatus gigas*) fisheries, is of prime concern. Results from the minimum size review, combined with regional management suggestions in the literature, are presented in table 4.5. Other results from the legislative review are presented following this table.

Table 4.5: A legislative review for prioritised fisheries species, as identified by ecological monitoring. Also presented are minimum sizes for species considered a priority due to the importance of their fishery or those that may necessitate management if the sports fishing industry grows in the future. This list is not exhaustive. Consideration may also need to be given for other species, including (but not limited to), deeper dwelling snapper (e.g. *Etelis oculatus*, *Lutjanus vivanus* and *Lutjanus buccanella*), and large grunts (e.g. *Haemulon parra*).

| Species | Current Legislation: Fisheries Protection Act 2000 | Proposed Additions or Amendments | Purpose/Outcome of Additions or Amendments |
|---|---|---|--|
| <i>Lobatus gigas</i> | Minimum Landing Size 18cm SL and Flesh Weight 225g minus digestive gland | Increase shell length to 23cm with flared lip thickness of 9.5mm. Closed areas in marine parks. | Prevent recruitment overfishing to encourage stock recovery and promote local and regional recruitment. |
| <i>Panulirus argus</i> | Generic ¹ and Minimum Landing Size 95mm CL or tail weight of 200g. | Introduction of closed season February through May and closed areas in marine parks | Protect breeding population and build seeding population to promote local and regional recruitment. Trapping restriction protect coral reef areas. |
| <i>Panulirus guttatus</i> | Generic ¹ | Minimum landing size of 52mm CL, closed season January through March and closed areas in marine parks | Protect breeding population and build seeding population to promote local and regional recruitment. Trapping restriction protect coral reef areas. |
| <i>Cephalopholis cruentatus</i> and <i>Cephalopholis fulvis</i> | None | Minimum landing size of 25cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Epinephelus adscensionis</i> and <i>Epinephelus guttatus</i> | None | Minimum landing size of 30cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Mycteroperca tigris</i> | None | Minimum landing size of 50cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Epinephelus striatus</i> | None | Prohibited or minimum landing size of 50cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Mycteroperca venenosa</i> | None | Minimum landing size of 55cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Mycteroperca bonaci</i> | None | Minimum landing size of 80cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Epinephelus itajara</i> | None | Prohibited | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. Rare to absent in Anguilla. |
| <i>Sparisoma aurofrenatum</i> , <i>Scarus Taeniopterus</i> and <i>Scarus iserti</i> | None | Minimum landing size of 20cm | Stock recovery and to promote local and regional recruitment. Beach sand production and algal grazing. |

| | | | |
|--|------|---|--|
| <i>Sparisoma viridae</i> , <i>Sparisoma chrysopterygum</i> , <i>Sparisoma rubripinne</i> and <i>Scarus vetula</i> | None | Minimum landing size of 30cm | Stock recovery and to promote local and regional recruitment. Beach sand production and algal grazing. |
| <i>Scarus coeruleus</i> , <i>Scarus coelestinus</i> and <i>Scarus guacamaia</i> | None | Prohibited | Stock recovery and to promote local and regional recruitment. Beach sand production and algal grazing. Rare to absent in Anguilla. |
| <i>Lutjanus synagris</i> , <i>Lutjanus mahogonia</i> , <i>Lutjanus apodus</i> and <i>Ocyurus chrysurus</i> | None | Minimum landing size of 30cm | Stock recovery and to promote local and regional recruitment. |
| <i>Lutjanus griseus</i> and <i>Lutjanus campechanus</i> | None | Minimum landing size of 40cm | Stock recovery and to promote local and regional recruitment. |
| <i>Lutjanus analis</i> | None | Minimum landing size of 50cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Lutjanus jocu</i> | None | Minimum landing size of 60cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Lutjanus cyanopterus</i> | None | Minimum landing size of 80cm | Stock recovery and to promote local and regional recruitment. Potential <i>Pterois volitans</i> predator. |
| <i>Acanthocybium solandri</i> | None | Minimum landing size of 100cm | Preserve pelagic sports fishing stock |
| <i>Coryphaena hippurus</i> | None | Minimum landing size of 70cm | Preserve pelagic sports fishing stock |
| <i>Euthynnus alletteratus</i> and <i>Scomberomorus regalis</i> | None | Minimum landing size of 50cm | Preserve pelagic sports fishing stock |
| Sports Fish (other fin fish) - Generic | None | One per paying person per sports vessel | Preserve pelagic sports fishing stock |

¹ Legislation relating to *P. argus* and *P. guttatus*. Prohibited to harvest via spear-gun; be in possession of egg-bearing female; remove eggs from egg-bearing female; be in possession of freshly moulted or soft shelled individual. Furthermore any prohibited catch must be returned to the water unharmed and all individuals harvested must be landed in Anguilla whole unless in possession of a Process or Export Licence.

Fish trap mesh size - 'No person shall use any fish pot or trap for the purpose of taking any marine product unless the fish pot or trap is constructed with a mesh size of not less than 1.5" (38mm) across the minimum mesh dimension.' This applies to all fish pots and traps operated in Anguillian waters irrespective of the fishery. Although small this limit is equal to or greater than other legislation throughout the Caribbean. In fact, mesh sizes are closer to 42mm due to the restrictive nature of importing raw materials for trap construction, and as such this is often quoted as the legal limit. No viable amendments are deemed necessary/practical.

Nets and net mesh size: 'Any person who, for the purpose of taking any marine product, uses a net with a mesh size smaller than the minimum mesh size prescribed for that type of net in Schedule 7 is guilty of an offence.' Schedule 7 states [none]. However as few nets are regularly used in Anguillian water it is not deemed necessary at this stage to introduce any restrictions. Those seen in use to catch schooling Carangidae or small bait fish were of standard accepted design.

Prohibited nets: 'No person shall use any gillnet for the purpose of taking any marine product.' Gillnets were observed in the possession of certain fishers but their use for taking marine products was not observed. Although not necessary at the present time, if their use is found to exist for this purpose, it may be necessary to amend the legislation to prohibit their possession entirely or restrict their use to specially licensed individuals only.

Spear-fishing: 'No person shall, unless he is a resident, use any spear gun for the taking of marine products, or have a spear-gun in his possession while swimming or boating'. Due to the well documented negative impacts unregulated spear-fishing can have (Frisch *et al.*, 2012) it is suggested that restrictions be placed on its use urgently. Proposals include prohibition of this practice in marine parks, within 50m of land and/or in waters <5m depth, apart from in specially designated areas.

Fish trap marking: 'Any person who is the holder of a Foreign Fisherman's Licence or a Commercial Fisherman's Licence and who uses pots or traps for the purpose of taking marine products shall identify his pots or traps and any buoy or marker used in connection therewith by marking them conspicuously with the number of the Foreign Fisherman's Licence or the Commercial Fisherman's Licence which he holds.' This is in line with many other parts of the Caribbean although in Anguilla it is not enforced. To enable the enforcement of other newly proposed legislation (following) this situation will be necessary to reverse.

Discussion

Coral recruitment study

The coral recruitment results presented reinforce the difference between north and coast sites recorded during ecological monitoring. There is very little coral recruitment on the south coast,

but rates on the north coast appear relatively stable. This raises concerns relating to the ability of the south coast to regenerate its heavily degraded reef system even if afforded full protection. More research is needed to discern if this lack of recruitment is due to lack of planula settlement, or planula death shortly after settlement but prior to initial corallite formation. Alternatively the result may suggest that planula settlement occurred, followed by corallite deposition, but later mortality and subsequent erosion of the corallite left no observable evidence. The precise cause of virtually no observable recruitment on the south coast is important to ascertain prior to considering restoration efforts as, for example, a coral transplantation project may simply result in the death of introduced colonies. A suggested future experimental design to investigate this further is to repeat the terracotta tile methodology, but translocate north coast tiles between locations after the six month soak period and monitor survival of living recruits. If live recruits suffer mortality after translocation to the south coast, whereas recruits translocated within north coast areas do not, stressor management may be more effective to address rather than direct restorations measures like coral transplantation. If no changes in mortality are recorded, low recruitment levels are more likely due to issues surrounding planula settlement (for example sedimentation or nutrient enrichment; Ward & Harrison, 1997) and so coral transplantation efforts have the potential for greater success. Direct stressor management would still be important to consider, but restoration efforts could begin in unison with this rather than once stress management had been completed. Whatever the case, no restoration efforts are recommended until further studies have been conducted.

The sites in northern areas had relatively high levels of recruitment in comparison to the south coast. It is especially interesting that recruitment levels do not closely correspond with relative health percentage rankings established by initial ecological monitoring (chapter 2) as statistically the relationship was not significant. Interestingly no relationship was observed between macroalgae growth on the tiles and recruit numbers: where only 2.7% of tiles were devoid of algae growth, and those with the highest numbers of recruits counted often had $\geq 50\%$ algae cover. Specific data is not available, but percentage cover of algae varied depending on site and reflected the percentage cover recorded at these sites through ecological monitoring (chapter 2). This suggests that high macroalgae growth rates do not effect planula settlement and initial growth when competing for freshly exposed hard substrate. There was however a tendency for recruits to settle on the underside and edges of tiles where potential space competition may be more limited: once macroalgae are established this restricts subsequent settlement, and can out-compete established recruits, eventually resulting in an increased probability of smothering, overgrowth, and microbial attack (Vermeij *et al.*, 2009). Coral larval settlement is complex and

dynamic, and the subject of much current research that has found associations between many factors including (but not limited to): the overall topography of settlement surfaces (Whalan *et al.*, 2015); the presence of certain crustose coralline algae species (Ritson-Williams *et al.*, 2010); the colour of settlement surfaces (Mason, 2011); and the degree of sunlight intensity and/or colour (Strader *et al.*, 2015).

The coral settlement data illustrates the potential ability for the sites on the north coast, even those exhibiting the highest levels of degradation at present, to recover if stress levels imposed on these areas are reduced through management. This raises the suggestion of the Island Harbour area being suitable for a coral restoration pilot programme in Anguilla should funding become available. Prior to this, further study is needed to establish the reasons for low ecological health in this region and whether it is possible to reverse this through management. An initial suggestion is to establish recruitment test beds in the area. By actively monitoring new recruits and semi controlling their environment it would be possible to view the progress of recruits developing into small colonies and record survivorship levels; by, for example, removal of macroalgae and other invasive flora/fauna surrounding the new recruit on the upper surface of a tile. If mortality of recruits is the reason for the low level of coral cover observed in the Island Harbour area, which is the primary conclusion of this present study, reasons behind this mortality need to be studied before any restoration programme were to fully commence.

Water quality monitoring programme pilot study

pH: Lowering values are of increasing concern throughout coral reef systems. Ocean acidification, reportedly due to the oceans absorbing one third of anthropogenic CO₂ produced over the last 200 years (Maier *et al.*, 2013), is expected to cause a 0.4 unit drop in ocean pH by 2100, affecting calcification rates of stony corals. Values obtained by the current study were all within the accepted range for reef systems of between 7.5 and 8.4 (Rogers *et al.*, 1994).

Conductivity/salinity: Data collected were all close to the accepted seawater mean of 54µs aside from Road Bay pond channel (107.8µs) and Crocus Bay desalination outflow (77.6µs). These sites were expected to be elevated due to their nature and do not represent cause for concern. Some interesting temporal variations were noticed within salinity results (figure 4.3). The two graphs demonstrate how on November 26th Anguilla was being influenced by cooler, saltier water (presumably due to the influence of the Atlantic Ocean) than on the other four November

sampling days where warmer, less salty water dominated. The November 26th data points are spread around both north coast and south coast sites. This suggests that the island might be being influenced by two different water bodies, depending on weather forcing and/or seasonality, which may be of importance in terms of the Green Water Events (GWE) discussed in chapter 1 and their potential occurrence. For example, if a North Brazilian current ring laden with nutrient rich waters were travelling in the direction of Anguilla, the occurrence of a GWE would depend on if weather forcings are pushing the water body away from the island or towards it.

Nutrients: Coral reefs are typified by waters that contain low levels of inorganic nutrients. Of the nutrient parameters studied, threshold values, above which coral reef decline from eutrophication begins to occur, are: 0.5-1.0 μ M (0.007 – 0.014 mg/l⁻¹) for nitrate; 0.2-0.5 μ M (0.004 – 0.01 mg/l⁻¹) for ammonia; and \geq 0.3 μ M (0.03 mg/l⁻¹) for phosphate (Abdel-Hamid & Hamed, 2006). The equipment used in this study could only record values \geq 0.01mg/l⁻¹, which is in fact higher than these threshold ranges for inorganic nitrogen, although not so for phosphorous. This means a result for nitrate or ammonia of 0.01 or greater signifies eutrophic conditions in terms of N. Bearing this in mind, even those with a value of 0.00mg/l⁻¹ could still be considered eutrophic as actual results may still be above the stated thresholds, only below detectable limits of the equipment and tests used. Indeed, due to the high dispersal potential within highly connected marine systems it is highly likely that this is the case. In terms of eutrophication through phosphorous a more specific picture emerges, as it isn't across the board eutrophic conditions. In fact this variable may be more useful, due to the low sensitivity of the equipment used, to highlight sites of concern. Some of the sites with elevated levels included (but were not limited to) areas within Road Bay, Island Harbour and Little Harbour – localities that were suspected to be eutrophic due to more turbid water often being present. Other sites with elevated levels however were more of a surprise and may need re-evaluating as elevated results may be of greater concern – for example Prickly Pear had the second highest Phosphorous levels recorded, and is a heavily used tourist area with a number of large catamarans visiting daily in the high season and two beach bars with hand dug septic systems.

Alternatively however Goreau & Thacker (2006) concluded that levels of 0.003 mg/l⁻¹ total Phosphorous (orthophosphate plus dissolved organic phosphorus) and 0.014 mg/l⁻¹ total Nitrogen (nitrate plus ammonium plus nitrite) could be considered eutrophic in a coral reef ecosystem. This places the threshold values much lower and would mean that any positive phosphorous score in this study represented eutrophic conditions. Using the Abdel-Hamid & Hamed (2006) threshold values 98.8% sites exhibited some kind of eutrophic conditions whether

from Ammonia, nitrate, phosphorous or a combination of the three. The most commonly occurring eutrophic variable was nitrate, which was recorded above threshold levels at 93.8% of sites.

In line with observations made during ecological monitoring (chapter 2), planula from coral species such as *Porites astreoides*, *Porites porites* and *Agaricia spp.* are able to settle on surfaces in nutrient rich waters whereas *Orbicella spp.*, *Diploria spp.*, and *Siderastrea spp.* were not (Tomascik, 1991). This may explain, in virtually all areas surveyed during ecological monitoring, why *Porites astreoides* is now the most common hard coral species.

Chemical oxygen demand: This variable is often considered an indicator of sewage or other pollution in aquatic systems (Adams, 1990), with the Swiss Government setting a range of 200-1000 mg/l⁻¹ to be reached before waste-water can be returned to the environment. Cited values for COD in the literature may be expressed in mg/l⁻¹ or as a percentage, with NOAA reporting levels as high as 25,000 mg/l⁻¹ in industrial waste and unpolluted surface waters around 2 mg/l⁻¹. Results from the present work suggest that COD levels are not above levels that signify pollution concerns, with the highest value recorded to be, as expected, at the Road Bay pond channel with a value of 1490 mg/l⁻¹. Notwithstanding this, the mean value recorded at Rendezvous Bay Great House, 1310 mg/l⁻¹ is elevated enough to warrant prioritisation during future monitoring work as it may represent a failing sewage system at this particular tourist development, one of the first to be built on the island.

Turbidity: Increasing levels of turbidity are often considered a sign of reducing water quality, a key variable in terms of tropical ecosystems (Johansen & Jones, 2013). Turbidity levels in coral reef systems usually arise from sediment re-suspension and/or sources of terrestrial run-off. Loya (1976) reported drops in coral cover over 1.5 NTU and Coles & Ruddy (1995) found a positive relationship between coral species such as *Orbicella sp.* and turbidities less than 1 NTU. Other species may be less effected by turbidity such as *P.astreoides* (Lirman *et al.*, 2008) and begin to seemingly flourish compared to other species in more turbid conditions, especially if suspended sediment is nutrient enriched. Loya (1976), for example, went on to report coral covers still at 30% of their original levels at 5.5 NTU. The impacts of turbidity on overall coral cover are therefore complex, and made more so by light restrictions caused by suspended particles rather than the effect of settling suspended matter. Levels recorded in this study were highly variable, ranging from 3.36 NTU in Merrywing Bay, to 0.26 NTU at Savannah Bay. The highest overall results were from Tenemos pond pipe outlet (4.10 NTU); and Road Bay pond

channel (4.05 NTU). This result highlights the role salt ponds can play introducing suspended matter into the marine system if they are connected enough to act as a source.

North coast – south coast comparisons: Comparisons were made between values obtained at north coast sites, compared with those obtained at south coast site (with the exclusion of Road Bay pond channel). The only variable that exhibited a significant difference between the two treatments was turbidity, that had an increased likelihood of being higher along the south coast than along the north coast ($t=1.99_{77}$, $p=0.05$). Although this test may have confounded sources of error or structures within the data (dates, locations, replicates etc), it does suggest that nutrient enrichment is an island wide phenomenon and so more likely due to regional or background eutrophic waters combined with uniform nutrient input and mixing from local sources. If an influential local point source of pollution were present one would expect for the respective sampling site to reflect this in the results. Despite the lack of such evidence, based on the results and subjective observation some sites have been identified as potential outliers to be prioritised for further more focused study: Road Bay, Rendezvous Bay, Island Harbour, Maundays Bay and Little Harbour.

Future study: As this study only represents a mean three month snap-shot, conclusions drawn need to be substantiating with continued monitoring. It is suggested that the recommendations here be incorporated into the marine water monitoring programme of the Government Water Lab once it is again running to capacity. Originally ten sites were studied by the Lab (Barnes Bay, Meads Bay (West), Meads Bay (East), Maundays Bay, Rendezvous Bay (Central), Little Harbour, Shoal Bay East, Road Bay, Cul De Sac and Crocus Bay). These sites encompass all of the initial sites of concern identified here aside from Island Harbour, so it is suggested to include it in the Labs monitoring schedule, together with one offshore site to act as a relative control, to bring its complement up to twelve sites. Ideally however, if capacity exists, this number would be at least double, thus allowing the inclusion of the offshore keys and a more complete spread around the mainland coast.

Future tests: Recommendations to be made to the Government Water Lab when it picks up the monitoring schedule are to continue measuring all the parameters recorded here, but also include Chlorophyll-*a* testing as it can provides insights into phytoplankton levels and therefore another potential reference to nutrient enrichment (Otero & Carbery, 2005). This is especially important in reference to the ‘green water events’ discussed in chapter 1. It is also suggested that Faecal Coliform, Faecal Streptococci, and Enterococci tests are conducted, as they were during the labs

last reported round of monitoring (between February 2005 and May 2006), where ten sites were sampled an average 1.5 times (Anguilla Government Water Lab, unpublished data). Many of these bacteriological readings were positive, with the highest recorded at Road Bay. However these results do not necessarily represent an anthropogenic sewage source. Both Faecal Coliform and Faecal Streptococci can come from other sources including certain industrial processes (FC) and other warm blooded animals (FS). It is more widely accepted (USEPA, 2012) to use Enterococci when testing sea water as they are typically more human-specific than the larger Faecal Streptococcus group. Again, Road Bay had the highest Enterococci count of all sites sampled by a mean factor of ten (March 2006). This source, which again is not 100% of anthropogenic origin, may be from failing sewage systems inadvertently leeching from ageing developments, polluted salt pond breaches, or dumping of waste by ocean going vessels. As such the source needs to be urgently identified, and thus parameter testing, especially for Enterococci, should continue at the earliest possible time.

Recommendations: It seems clear then, that although many basic parameters in the waters around Anguilla are within acceptable levels, nutrient levels are not and overall eutrophic conditions prevail. At a small number of sites with levels higher than surrounding areas this would appear to arise due to proximity to salt ponds (e.g. Little Harbour, Road Bay) or in areas where boat activity is high and/or waste waste/leeching from septic tanks may be an issue (e.g. Island Harbour, Road Bay, Prickly Pear). However, these local point sources cannot be attributed to the nutrient levels recorded at all other sites, and as Anguilla has no large population centres and very limited agriculture these results must be due to background nutrient levels brought in from regional sources. This has substantial implications for management, as controlling these local point sources, although not a bad thing (and in fact the only direct mitigation measure possible), will not alleviate this background level. Instead it will be necessary to attempt mitigation measures against the effects of eutrophication rather than eutrophication itself. Thus the herbivorous species that live on the reefs and help to keep macroalgae levels down will need protection prioritisation, along with filter feeders that may help to reduce phytoplankton and/or particulate matter. Such mitigation measures may include (but not limited to): Protection of areas with recovering *D. antillarum* populations; minimum landing sizes for, or prohibition against, harvesting Parrotfish (*Scarus spp.* and *Sparisoma spp.*) or Surgeonfish (*Acanthurus spp.*); and restrictions against damaging fishing practices, for example trap fishing in reef areas. If these measures are followed, together with strict control over any identifiable local nutrient sources, it is possible that habitat degradation may be reversed somewhat, or at least slowed down. Unfortunately however it seems that unless coordinated multinational intervention occurs

against regional nutrient sources (chapter 1), the habitat degradation that has been seen occurring across the Caribbean over recent decades is set to continue.

Diadema antillarum translocation study

D. antillarum were recorded to be in low densities (0.15 m^{-2} , $\text{SD} = 9.68$) at all reef sites ($n = 10$) surveyed during initial ecological monitoring in Anguilla (chapter 2), and macroalgae levels predominantly high. *D. antillarum* are known to be important for macroalgae control on the reef (Tuya, 2004), and attempting to rebuild their populations back to levels prior to their die-off in the 1980's is favourable for overall coral reef health. The aim of the present study was to assess the potential for active management that could do this by translocating *D. antillarum* from other areas. If successful this may ultimately mitigate against some of the effects of eutrophication and overfishing by increasing the number of key herbivores on the reefs.

In an attempt to rebuild populations in areas yet to recover a number of *D. antillarum* translocation studies have been conducted over the years with mixed successes (Moe, 2003). Methods used have been to release hatchery reared juveniles or to translocate adults from other reef areas. The release of juveniles has had few successes when released into areas lacking an adult population, as adults may provide important predation refuges for new recruits (Nishuzaki & Ackerman, 2007). Furthermore juvenile survival is thought to be greatly enhanced by the cultivation effect (Rogers & Lorenzen, 2008), where larvae prefer surfaces clear of macroalgae (Bak, 1985). Adult *D. antillarum* populations are associated with low macroalgae cover and high reef complexity (Lee, 2006), and are documented to determine the macroalgae structure on reef areas (Tuya, 2004), accounting for 40% of the overall herbivorous grazing (Mumby *et al.*, 2006). Thus, it seems ineffective to release hatchery reared juveniles unless an adult population is already established, yet if an adult population is established there is less of a reason to release hatchery reared juveniles in the first place. This may mean the translocation of adults is the preferred course of action when making population restoration efforts. The translocation of adults has similarly suffered setbacks over recent years due to low levels of retention and high levels of mortality (Miller *et al.*, 2007). However, the release of adult urchins at high enough densities has been problematic due to logistical difficulties and the paucity of naturally occurring populations available for translocation (Rogers & Lorenzen, 2008).

In Anguilla, dense populations of *D. antillarum* exist in rocky areas almost entirely bare of macroalgae, with reef areas yet to recover having high levels of macroalgae. It is postulated here that the low macroalgae levels in recovered areas are not necessarily a direct result of *D. antillarum* presence, but rather the low macroalgae nature of the rocky area facilitated larvae settlement. Even though these areas are of low topographic complexity there are many small crevices for settlement to occur and provide predation refuge prior to adult population establishment. These areas are also in relatively exposed areas meaning currents have the potential to bring in a steady larval supply. The more complex reef areas with high macroalgae in which high *D. antillarum* densities would be expected may not yet have recovered due to the cultivation effect inhibiting settlement (Rogers & Lorenzen, 2008). Higher macroalgae cover also often occur in areas that are less exposed in nature which may reduce larval supply via regional or local currents. Although it has been suggested that *D. antillarum* themselves determine macroalgae structure on reef areas, the reversal of large fleshy algae dominance may not be straight forward (Rogers & Lorenzen, 2008). It is likely these areas will take more time to be repopulated by urchins, but that once numbers reach a certain level more rapid recruitment of new juveniles will be possible. The large fleshy algae will gradually erode away and the urchins restrict new growths, eventually returning it back to its previous state. Furthermore, restricting algal growth on reefs will reduce algae-derived dissolved organic matter, which has been suggested to increase mortality in reef building corals through hypoxia created by rapidly growing microbes (Gregg *et al.*, 2013). This further highlights the role recovering *D. antillarum* populations may play in reversing the phase-shift seen between corals and macroalgae on Caribbean reefs since the 1980's.

Contrary to the paucity of *D. antillarum* at the surveyed reef sites, high densities were observed during rapid assessments in other areas. This patchy recovery observed in Anguilla has been well documented throughout the region over recent years (Miller *et al.*, 2003) with some areas exhibiting recovery since the mortality event of the 1980's (Carpenter & Edmunds, 2006) and others not (Lessios, 2005). Precise reasons for this patchy recovery remain unclear but are likely a combination of limited larval supply (Miller, 2009) and Allee effects¹⁶, where low population densities can negatively influence fertilization success, larval settlement and post-settlement survival (Rogers & Lorenzen, 2008). This is especially prevalent through populations of broadcast spawners such as *D. antillarum*. (Lundquist & Botsworth, 2004). After fertilisation the egg develops through the blastula and gastrula stages before developing into the true planktonic

¹⁶ This suggests the need to translocate the highest number of individuals possible to reduce density dependence risks

larval form, the echinopluteus. Although this stage is considered free swimming (via cilli) and later able to feed on particles suspended in the surrounding water, its movement and distribution is primarily influenced by the velocity and direction of water currents from spawning sites (Williams *et al.*, 2009). Estimates of larval duration from laboratory studies range from 4-5 weeks (Eckert, 1998) to 52 days (Carpenter, 1990). It has been suggested that this variation may be due to larvae having the ability to delay settlement and thus increase the window of opportunity to contact suitable habitat; although this delay may cause decreased growth rates and higher mortality (Highsmith & Emllet, 1986). Larvae are made aware of suitable juvenile microhabitats through environmental cues as they relate to food, predators and conspecific abundance (Strathmann, 1978). It was also reported by Burke (1980) that larvae can evaluate the substratum initially settled upon with their podia and retain the option of swimming away to sample another area if deemed unsuitable. Once settled, the larvae undergo metamorphosis into a juvenile and locate a protective crevice in which to begin development. As the juvenile grows the dependence on such crevices diminish as at least two adult behavioural patterns develop (Ogden, 1973): Urchins that have a crevice in which they hide remain within its vicinity while foraging at night; whereas those who lack suitable crevices do not exhibit this homing tendency and rely instead on proximity of conspecifics for protection.

The results from this study suggest *D. antillarum* has a preference for shallow areas as after their initial placement in c.5 m of water, populations appear to gradually migrate into the 3-4 m zone (table 4.3). Over time their numbers get progressively less even at these depths until October 2008 (one year after translocation) when more than half of the remaining population is in 3 m of water. Due to the fact that surveys were not possible in regions <3m it is not possible to conclude whether the decreasing overall numbers are due to migration into these shallower areas or mortality. It is likely however that both factors play a role. For example, some mortality was observed to occur in the form of scattered test remains, although these were not found in substantial enough amounts to account for overall gradual population reductions in the deeper zones. Whereas in combination with the observed migration of the population into shallower regions over time (especially the March & July 2008 counts), combined with visual but unquantified observations of urchins in the shallow regions of the reef, would better explain this reduction. A year into the study it is unlikely that any further mortality would be due to translocation stress meaning it more probable that these latter reductions were in fact due to migration into shallower areas as suggested. Any mortality at this point would be due to natural predation only. It is suggested that the shallow areas favoured by *D. antillarum* are more secure from predators such as the Queen Triggerfish (*Balistes vetula*).

Benthic changes were recorded at the receiving site, which reflected that expected based on urchin population counts: with the introduction of *D. antillarum* a drop in levels of fleshy macroalgae was recorded compared to increases at the control site (figure 4.4). However, no significant statistical relationships were found. As the population drops the levels begin to return to those observed previously. This illustrates results expected from the literature, but highlights the need to minimise either mortality or migration; if individuals can migrate they can potentially reduce their density, a key factor in urchin ecology. Thus, if future translocations are to be attempted it is suggested that a small isolated patch reef be chosen for the receiving site to keep their densities as high as possible. It is also suggested that potential predators be removed from the patch reef, and in-line with the findings of Rogers & Lorenzen (2008), macroalgae be removed from the site to increase the potential for successful juvenile settlement. This patch reef, if properly placed and managed, could serve as an important refuge for recruiting *D. antillarum* and seeding ground for the surrounding region.

The translocation methodology, given the resource limitations present in Anguilla, has been given the go ahead for similar future work. However, due to potential but unquantified stress and damage induced mortality, it is only recommended to do so if a known densely populated area is threatened with destruction. Due to the global economic situation that developed during 2008, the marina development in Shoal Bay West was shelved for the foreseeable future, and as such the remaining urchins scheduled for translocations were left undisturbed. Even though the desired densities were not reached on the receiving site, and no significant benthic changes recorded, this study does illustrate the potential for such work to succeed, and as such should be re-continued if/when the marina development takes place. It is also recommended that the receiving site should continue to be surveyed to assess long term survival of translocated individuals and record any recruitment that their presence facilitates.

Comparative rapid assessment of available historical data

Despite these overall declines that have occurred since 1990, results from the original study still reflect results from present ecological monitoring, where the south coast is concluded to have been more degraded over recent decades than the north coast (chapter 2). Indeed, Oxenford & Hunte (1990) state that the coastal marine habitats around Anguilla were in a healthy condition and made the assertion that there has been limited deterioration of these habitats since the previous qualitative descriptions given by Salm (1980). The only changes noted were reduced *D.*

antillarum numbers in Crocus Bay and mangrove/juvenile lobster reductions in Little Harbour. Although it is not possible to dispute this, the noted declines in *D. antillarum* combined with high levels of macroalgae at certain sites might be concluded as illustrate that declines in habitat health had in fact already begun. From reviews of the literature on this it is also largely concluded that the declines in coral cover started prior to 1990, and have initially been attributed to white band disease causing large scale *Acropora palmata* mortality, a species that once dominated the region (Bythell & Buchan, 1996). White band disease is no longer commonly recorded in Anguilla, probably due to low numbers of target species, but yellow blotch disease is still today degrading much of the remaining *Orbicella spp.* colonies that also formed extensive reef systems in Anguilla. Based on all available information (most notably Bythell, 1995), the north and south coast reefs historically varied due to differences in their exposure level. This environmental variation lead to many areas along the south coast being *Acropora palmata* dominant, and this lower coral species diversity lead to a lower resilience along the south coast.

These south coast reefs were impressive structurally however, with Salm (1980) noting that the area formed a 17km reef area which was considered to be one of the most important largely unbroken reef areas in the Eastern Caribbean. This lower resilience was highlighted when white band disease (and later yellow blotch disease) spread throughout the region. These diseases affected the significant reef builders along the south coast, and hurricane induced storm surges destroyed their weakened structures: Bythell & Buchan (1996) recorded a 61% decline in hard corals and a 45% decline in seagrass cover immediately after hurricane Luis in 1995. No signs of recovery have since been recorded, with *Acropora palmata* still in relatively low abundance, and large tracts of its skeletal remains present in both south and north coast areas. Along the south coast many of these remains have been piled up into coastal berms that are not documented to have existed prior to the 1980's. Among other factors, this lack of recovery due to lower resilience has been attributed to: Increased algae growth through eutrophication and reduced herbivore numbers; and increased turbidity and sedimentation through eutrophication and loss of structural protection. The north coast, which underwent similar losses of the significant reef builders *Acropora sp.* and *Orbicella sp.* is less exposed and so many of these dead structures still remain intact, not having been destroyed and piled up into berms as is the case along the south coast. As these structures still remain, wave action is still much reduced along the north coast and so turbidity is usually lower and overall conditions still favourable for other coral species to survive. Over time however, if the offshore barrier reef that protects the north coast erodes away due to lack of reef building coral recovery, it is probable that the energy regime will change in this area also, likely leading to increased coastal erosion and reduced overall diversity. This is

already being observed to happen in the area of Shoal Bay East Point, where once flourishing reefs are now smothered in sediment with few fish present. Erosion in the area has increased to such an extent that some coastal properties have been relocated and palm tree trunks and other material are scattered along the sea floor (S.Wynne, pers. obs.).

Without fish size estimations for the 1990 study it is not possible to make inferences on changes in fish size class distribution. It is however interesting to note that *Scarus croicensis* (Midnight Parrotfish) was recorded at selected sites in 1990, whereas today it is thought to be locally extinct. Fish species counts were conducted but the usefulness of these results came into question when for example it was noted that Oxenford and Hunte did not record the presence of *Scarus iserti* (formally *Scarus croicensis*) which is today one of the most common fish sighted on reefs. Reasons for this remain unclear, although it may be due to confusions relating to identification similarities with *Scarus taeniopterus*.

Literature/legislative review and amendments to fisheries regulations

The information compiled has been used to produce up-to-date legislative additions and/or amendments (table 4.5) that are recommended to be enacted prior to the full implementation of the completed management plan. Without these additions/amendments the proposed management plan (chapter 5) will be insubstantial in terms of meeting its goals. For example: Fish size classes were observed to be small and abundances for some species low, suggesting minimum sizes need to be introduced; Queen Conch (*Lobatus gigas*) numbers were low and scientific literature suggests legislation in Anguilla is insufficient; and Lionfish (*Pterois volitans*) introduction (chapter 2) mean potential *P. volitans* predator populations should be encouraged. Of particular concern are parrotfish species (*Scarus spp.* and *Sparisoma spp.*) who are important herbivores that are regularly targeted by spear-fishers, and especially favoured by lobster fishers as bait; and grouper (*Cephalopholis spp.*, *Epinephelus spp.* and *Mycteroperca spp.*) who, as well as being important potential *P. volitans* predators are also highly prized fishery species. Today many of these species are seen in very low numbers compared to those reported historically by older local fishers (E.Carty, pers.comm.). For example, *Epinephelus striatus* and *Epinephelus itajara* are now locally rare or extinct (respectively), compared to a few decades ago when *E. striatus* was one of the most commonly targeted species.

Most of the measures listed are relatively common throughout the region, although this largely depends on the rigorousness of local management regime. This means the majority are found in places such as Florida and/or the Netherlands Antilles, but not in the more independent and locally Governed island nations. Through organisations like the OECS and the Caribbean Community (CARICOM) however such management initiatives are becoming more common and accepted practice within these areas. Such unified management efforts are essential if, for example, regional stressors to reef health like eutrophication are to be addressed in the most effective way possible.

Prohibition of placing fish pots or traps directly on the reef: During rapid assessments of reef areas many fish traps were observed to be placed intrusively onto reef structures, often causing damage to corals, sponges and other flora/fauna underneath. Trap damage is well documented to have negative effects on the reefs physical structure (Sheridan *et al.*, 2003), but few territories have yet to limit their use. One recent example of such a measure occurred around the Florida Keys in 2012 when NOAA established sixty relatively small no-trap zones surrounding the known stands of Elkhorn and Staghorn coral in federal waters (Diersing, 2013). It is therefore that consideration be given to restricting their use directly on the reef, and their use prohibited within certain marine parks or areas within marine parks. Fisheries Officers will also need to be given the power to confiscate gear for collection by the owner later. For such legislation to succeed it will be necessary to enforce the current legislation of owners marking fish traps with their licence number.

Escape vents in traps: In line with other territories throughout the Caribbean it is recommended to include provision in the Fisheries Regulations that stipulates the presence of a biodegradable escape panel in the wall of fish traps. This is necessary to stop 'ghost fishing' where lost or discarded traps continue to keep catching and ultimately killing fish and lobster for many months or years into the future, or until the trap mesh finally degrades by its own means. Observations in the waters around Anguilla confirmed the presence of such lost or discarded traps, which always contained dead, dying or freshly caught fish and lobster (S.Wynne, pers.obs.).

Closed areas: The marine parks, or regions within the marine parks will be used as closed areas to certain fishing practices within the proposed management plan (chapter 5). Such practices to be prohibited within certain areas/parts of areas will include spear-fishing and trap fishing for reef fish and lobster/crayfish. Provision for closed areas exists within the Fisheries Regulations,

and each area will be decided upon based on its current threat status, and the financial return it provides through either fishing or tourism/recreation.

Closed seasons: Proposed for *P. argus* (February through May) and *P. guttatus* (January through March) to occur each year. These dates have been chosen as they will impact minimally on local fishers due to the adverse sea conditions that often persist during these times and the limited demand from restaurants that occurs due to the end of the tourist season. Provision for closed seasons exists within the Fisheries Regulations, and any imposed will be species specific and based on reviewed scientific literature and/or local research. Closed seasons will likely have a potential impact on local fishers, especially if conducted during peak breeding season when this fishery resource is in its highest demand. Thus closed areas will protect the breeding population during these times, and closed seasons introduced, at least initially, during lower demand periods. This will afford the species in question protection from recreational fishing practices which still continue during these periods. Costs towards this measure are limited as surveillance will be conducted concurrently with other work, and the concept already has the support of key community fishers who have been advocating both closed areas and closed seasons for a number of years now (W.Harrigan, pers.comm; E.Carty, pers.comm.).

Compliance: A 95% compliance understanding should be adopted as it is recognised that, for example, it is not possible for fishers to measure all their catch while at sea, or indeed be accurate in their measurements/by eye estimations. In this example this rule allows for 5% of their catch to be sub-legal. In addition, when catch is measured, a 5% leeway should be given, and measurements rounded up to the nearest agreed unit. Such a compliance rule is problematic to legislate for as it is wide reaching and inherently allows flexibility and thus should be more of an understanding between officials and fishers rather than legally binding.

Conclusions

Overall, the threat assessment has led to the following recommendations that should be taken into consideration during the development of the proposed management plan for Anguilla's Marine Park System and associated shallow water habitats and fisheries. These considerations will allow informed management decisions to be made and facilitate the successful management as dictated by the management plan's overall goals.

- Waters around Anguilla are eutrophic in nature. This appears to be largely due to regional nutrient rich water and local background sources rather than any significant local point sources. It is however recommended to review sewage treatment protocols and legislative background as concerns exist in some areas that relate to potentially old and/or faulty systems. It is also recommended to restrict/enforce legislation as it relates to the removal of coastal flora and sand mining activities.
- Turbidity is higher along the south coast than the north coast. This may be due to reef degradation leading to higher wave action along the south coast picking up sediment from the sea floor. These two factors combined, together with eutrophication and overall low reef resilience in this area, are likely responsible for the low levels of coral recruitment now confirmed along the south coast. Further investigations are needed to confirm if this is due to lack of planula settlement or post settlement mortality before any restorative efforts are continued for this area.
- *Diadema antillarum* translocations may be a viable method of rebuilding populations present prior to the mortality event that occurred in the early 1980's, although questions still remain regarding mortality and migration into shallow regions. It is therefore not recommended to do so unless a healthy population is identified as under threat from coastal developments: Healthy unthreatened populations should remain in place as their density dependant life history traits mean these populations are more valuable from a local/regional seeding perspective rather than colonists whose survival after translocation remains in question.
- Degradation has occurred to Anguilla's reef systems and associated fish populations since it was first considered a concern in the mid 1990's. This degradation has been concluded to have begun prior to 1990, contrary to the findings of the Oxenford & Hunte (1990). This degradation was accentuated by hurricane Luis in 1995, but has continued at a steady rate ever since. Degradation to seagrass areas has yet to be confirmed; in fact they appear to have recovered since reported damage to them occurred during the 1995 hurricane event. It is recommended vigilance continue with regards to anchoring and other activities in seagrass areas, whereas reef areas need more substantial guidance.

- Fisheries Legislation in Anguilla needs updating. Based on the findings here it is recommended to introduce minimum landing sizes for many targeted species of reef fish; amend minimum shell length for *Lobatus gigas*; introduce a minimum landing size for *Panulirus guttatus*; prohibit spear-fishing in marine parks, coastal areas and shallow water habitats unless otherwise designated; restrict trap fishing in marine parks or areas within marine parks; restrict trap placement directly onto any reef structures throughout Anguillian waters; oblige fishers to include a biodegradable escape vent into their trap design; and enforce all current legislation, including marking of traps with licence numbers and giving Fisheries Officers the legal power to issue fines as well as confiscating fishing gear contravening any of these provisions.

As stated above and detailed in figure 4.1, the completion of the threat assessment means Anguilla is poised to move beyond stage 3. To enter the adaptive management stage a management plan is needed that identifies an initial conservation goal and puts forward a means of realistically achieving it. Conservation goals also need to be distinguished from overall policy goals; for example a country may decide to try and protect 20% of its waters by a certain date (policy goal), with the reasons behind this to protect the flora and fauna within this area (conservation goal). Within the overarching conservation goal, specific management goals need to be identified, and embedded within the adaptive management regime (as seen embedded in figure 4.1). These goals can be more specific and realistic (i.e. to protect herbivorous fish species) and have a measurable outcome (i.e. to increase numbers of herbivorous fish by specific percentage). This is the process that will be focussed upon in chapter 5.

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Chapter 5

Technical report: Developing an adaptive management plan for Anguilla's Marine Park System and associated shallow water habitats and fisheries

Summary

Anguilla's Marine Park System was officially established in the early 1990's, but to date no management plan has been implemented to facilitate the reaching of the marine parks' intended goals. Despite the production of a draft management plan in 2001, unaddressed legislative gaps ultimately led to it not being officially adopted and led to a continuation of managerial stagnation. These legislative inadequacies have been identified as:

- No officially designated managerial agency.
- Incorrect and/or ambiguous designation of which areas are true marine parks.
- Insufficient regulations within the Marine Parks Act.

Since its establishment, the Department of Fisheries and Marine Resources (DFMR) has assumed an *ad-hoc* role in the management of these areas, working within the limited legislation as it currently stands. Despite limited financial and logistical resources, DFMR has spent over a decade filling the knowledge gaps necessary to produce a comprehensive management plan. It has also developed a strategy to overcome the legislative road block that has prevented the success of past initiatives, in the hope that it will kick-start the long overdue managerial process essential for the success of the Anguilla Marine Park System.

The strategy put forward is for DFMR to continue its assumed management role for the marine parks until they are named legally as such, but to do so in a more assertive manner by taking the lead role in the design and implementation of this management plan. Headed by DFMR, other members from key government agencies, non-governmental organisations, and stakeholder group representatives will be involved to ensure the cross-disciplinary nature of this initiative is addressed effectively. Through this means DFMR aims to accomplish the administrative success of this plan while strongly advocating all the legislative changes needed to facilitate this.

The management plan has been designed to allow Anguilla's Marine Park System to reach its originally intended goal, that being 'To protect fish, flora and fauna found in the park areas while preserving and enhancing the natural beauty of such areas' (statement first published in Policy Statement on Marine Parks for Anguilla, Government of Anguilla, c.1978). The overall goal is to reduce anthropogenic pressure on the degraded nearshore ecosystems through effective management of visiting tourists, coastal developments and extractive fishing activities. In terms of this latter pressure, a long term strategic plan is to encourage the development of offshore

fisheries resources, a goal that this plan aims to achieve in combination with a sister document, the Anguilla Fisheries Development Plan (Gumbs *et al.*, 2015). For this reason, and due to the inherent intricacies and interactions between marine areas, the management of marine parks also needs to consider surrounding marine environments, and (at least in part) their associated fisheries. Key management actions identified within this plan include:

- Unification of all current marine protected areas around Anguilla into the Anguilla Marine Park System.
- Fishing restrictions to be imposed within park boundaries and introduction of special licences for certain fishing methods.
- Protection of dive sites and other important tourist attractions both within park boundaries and in surrounding areas.
- Tourism enhancement within the marine parks to attract more paying visitors, combined with a review of marine park user permit fee structure.
- Production of outreach materials aimed at education and awareness of the marine parks and their role in livelihood sustainability.
- Additions made to fisheries legislation outside of the Marine Parks Act, including (but not limited to) the introduction of minimum size limits for certain species and/or amendments to existing size limits. These changes will apply to all marine areas, not just those within the marine park system.
- Creation of a Coastal Zone Fisheries Management Area (CZFMA) that will act as a buffer zone and link the marine parks with surrounding coastal regions and support them through strict surveillance and enforcement efforts under the Fishery Protection Act.
- Based around current resource constraints, the area that can realistically be regularly patrolled by the marine police and/or DFMR to become known as the Anguilla Marine Management Area (AMMA), which includes within it the zonation plan based on CZFMA and the Marine Park System.
- A ten year initial structured plan of action should be adopted with regular interim reports that mark adaptive management phases. These reports will introduce management revisions as deemed necessary through ecological monitoring, stakeholder feedback, and other information sources.

Section 1: Introduction

Anguilla (18°12.80N and 63°03.00W), is the most northerly of the Lesser Antilles leeward island chain and forms part of the British West Indies (figure 1.1). It has a land area of 91 km² and is comprised of flat, low-lying uplifted limestone surrounded by a variable shelf with several uninhabited offshore cays. The largest of these cays include Sandy Island, Dog Island, Prickly Pear Cays, Seal Island, Anguillita Island, Scrub Island, Scilly Cay and the distant Sombrero Island. These islets support a variety of reef habitats, the majority of which are fringing, the largest of which runs from Prickly Pear Cays almost parallel to the mainland north coast for a distance of approximately 10 km. The crest of this reef breaks the surface in a number of places and runs down to a depth of 15 m or deeper. The northern, leeward, coast of Anguilla is characterised by extensive patch reefs interspersed with sand flats and seagrass beds. The south coast historically houses extensive fringing *Acropora spp.* reefs, the vast majority of which are now severely degraded. There are also extensive seagrass beds in the area. There are over forty beaches around the island and offshore cays, most of which consist of white sand derived from fine ground coral remains and *Halimeda spp.* fragments. Seven marine parks are currently recognised in Anguillian waters, five of which form the Anguilla Marine Park System: Three of these surround the offshore cays of Dog Island, Prickly Pear Cays and Sandy Island, one encompassing the patch reef system of Shoal Bay & Island harbour, and one in the seagrass regions close to Little Bay. Areas around Sombrero Island and Junks Hole are also legally marine parks, but are more important as heritage sites rather than of ecological significance. An eighth protected area not legislated officially as a marine park is at Rendezvous Bay. This important seagrass area has recently been adopted by DFMR as a marine park but has yet to be fully encompassed in the Marine Park System. The legislative situation is clarified further in the following paragraphs. Currently no formally adopted management plan exists for these areas, although it has long been recognised that this is a management gap that much needs filling. It is the objective of this report to do just this, not just for a fully unified Marine Park System, but also for the associated fisheries and other shallow water habitats.

A Brief History of Anguilla's Marine Park System

Although the original Marine Parks Ordinance was produced in 1974, with draft regulations produced c.1978 (Gov Axa, c.1978), it is usually documented that Anguilla's marine parks (figure 5.1) were originally designated under the later Marine Parks Ordinance of 1982 (Lum

Kong, 2008). This Ordinance was again superseded by the Marine Parks Act (2000) which was revised again in 2008 & 2010. However, the parks actual designation is more officially cited as occurring in 1993 (CaMPAM, 2010) when the Marine Parks Regulations came into force. Under the regulations one marine park was listed for demarcation, the Junks Hole Marine Park - the waters surrounding the site where the wreck of the Spanish Galleon El Buen Consejo is situated. Notwithstanding this, the Junks Hole Marine Park is not usually cited as part of Anguilla's Marine Park System as it is more recognised as a heritage site rather than being of ecological importance.

The five areas usually cited as being part of Anguilla's Marine Park System were not designated under the Marine Parks Act until its regulations were revised in 2010. Instead, four of them (Dog Island, Sandy Island, Little Bay and Prickly Pear) were listed within the Cruising Permit Act (1980, later superseded in 2000) as areas with anchoring restrictions. Also listed in this Act is Rendezvous Bay, which until recently was not considered a marine park and thus not part of the Anguilla Marine Park System. These five areas would therefore have been better described as marine protected areas until 2010, rather than marine parks as they were technically only under anchoring restriction. Shoal Bay-Island Harbour has never been listed under the Cruising Permits Act and so only became a true protected area when it was listed under the revised Marine Parks Regulations in 2010. Despite this it has always been considered part of the Anguilla Marine Park system. It remains unclear how this area was originally designated as no mention of it has been found in the legislation prior to the Marine Park Regulation revision. It is thought this area was instead listed in the Government of Anguilla's official gazette, although confirmation and publication date of this has not been found.

This legislative confusion lead to it sometimes being cited that (prior to 2010) Anguilla did not have any Marine Protected Areas (Lum Kong, 2008), even though the areas listed under the Cruising Permits Act were afforded some protection and Junks Hole Marine Park was designated under the Marine Parks Act. Furthermore, these areas, as with all of Anguilla's marine systems, were also subject to the generic protection afforded by the Fisheries Protection Act (2000). Such restrictions under this legislation include (but are not limited to) fish pot mesh size, size limits for the *Panulirus argus* and *Lobatus gigas* fisheries, and controls on all turtle fisheries. For the purpose of this report, Anguilla is considered to have eight marine parks, six designated for ecological purposes, one (Junks Hole) designated for heritage purposes, and one (Sombrero Island) for heritage and potential ecological purposes, pending marine survey work. As a final clarification, until only a few years ago, Rendezvous Bay was not considered a marine park,

rather an area under special management, and so not included in Anguilla's Marine Park System. This is no longer the case as it has been adopted as an unofficial marine park. To avoid future confusion, one of the main recommendations under this management plan will be to unify the legislation governing marine systems and to ensure all these areas are correctly listed under the Marine Parks Act.

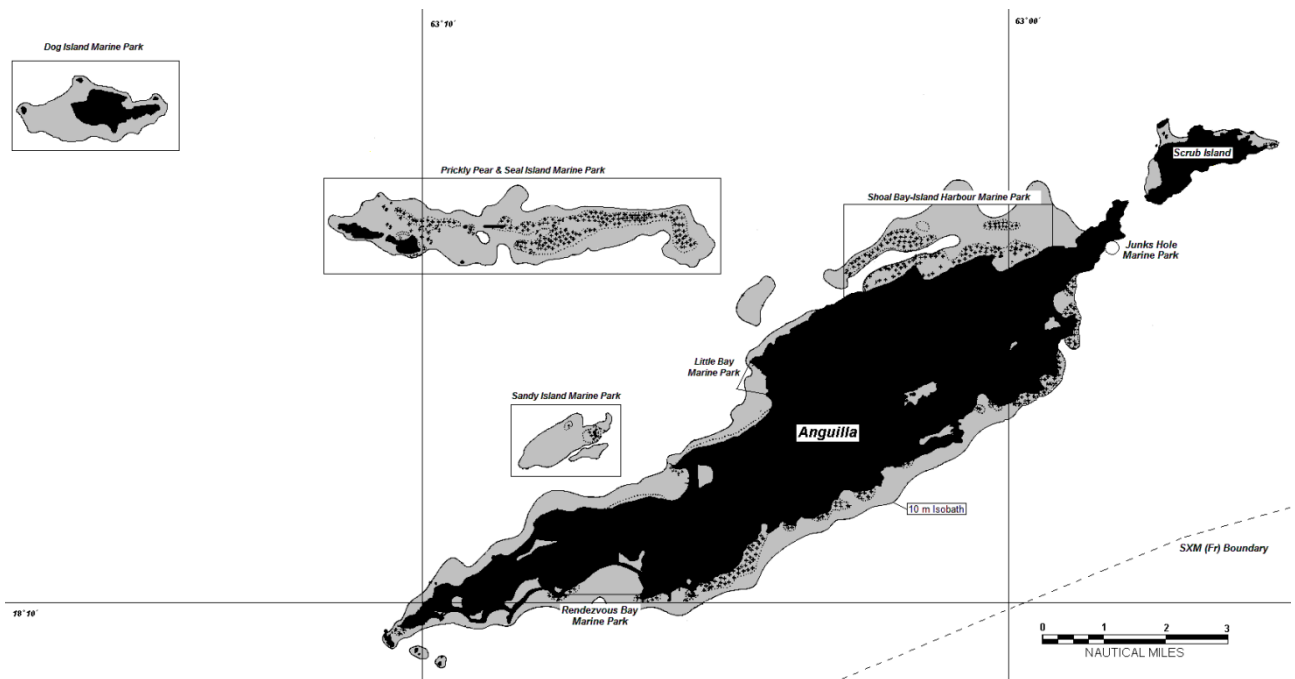


Figure 5.1: Map of Anguilla illustrating locations of marine parks, including Rendezvous Bay. Shallow water areas (<10 m) are illustrated in grey with 10 m isobath. The distant Sombrero Island is not illustrated. The shallow areas are proposed to become the Coastal Zone Fishery Management Area (CZFMA), a buffer zone and link between the marine parks and surrounding coastal regions where surveillance efforts will be concentrated. The whole area depicted on the map, excluding that part which belongs to French St Martin, will become the Anguilla Marine Management Area (AMMA). AMMA will be the focus of future enhanced surveillance as resources allow: that which is practical to patrol using one vessel on a daily basis.

Note on future legislation: The Biodiversity and Heritage Conservation Act (2010) is reportedly set to supersede the Marine Parks Act. The regulations for the BHCA have yet to be finalised and so the potential for this remains unclear. The BHCA does however state that ‘the marine parks existing on the coming into force of those [BHCA] regulations are deemed to have been established as protected areas under [the BHCA]’ ; and that the Governor in Council may repeal the Marine Parks Act and the Marine Parks Regulations. This means that the BHCA is posed to supersede the Marine Parks Act at some unspecified date in the future.

Management of the Marine Park System

Current management of the Marine Park System, including Junks Hole Marine Park and Rendezvous Bay, is the responsibility of the Department of Fisheries and Marine Resources (DFMR), not because they are the official managing agency (none has yet been designated), but rather due to the Department's general mandate of promoting sustainable use of the marine environment. Furthermore, their quasi-managerial role has necessitated an *ad hoc* approach as no official management plans exist for these areas (OTEP ANG402, 2007). As part of site management DFMR installs and maintains mooring fields in three of the marine parks (Prickly Pear, Sandy Island and Little Bay), with plans to extend this to Shoal Bay-Island Harbour. DFMR, on top of its regular mandated work, also conducts regular beach monitoring surveys, which although technically (or at least partially) outside of their jurisdiction, they conduct for similar reasons as they do the management of marine parks.

This lack of an officially designated management agency is largely due to the inevitably complex political nature of small island developing states such as Anguilla, especially when considering the management of areas with jurisdictional cross-overs and their multi-disciplinary nature. For example DFMR are mandated only up until the high water mark, with other agencies responsible for terrestrial areas (for example the Department of Environment, Anguilla Air and Sea Ports Authority, etc.). For this reason it is likely that for the successful management of these areas, new legislation, or amendments to existing legislation, will be needed. This appears to be one of the functions behind the Biodiversity and Heritage Conservation Act, which deals with the multi-sector nature by jointly assigning the administration of this act between the Minister of Fisheries and Marine Resources and the Minister of Environment. This is the first jointly administered Act in Anguilla and does potentially pave the way for more unified and successful

management of protected areas: Where the Minister of Fisheries and Marine Resources is the competent Minister with respect to aquatic species, their habitats, and protected areas that are established and maintained to protect of primarily protect aquatic species and their habitats; and the Minister of Environment is the competent Minister with respect to terrestrial species, their habitats, and protected areas that are established and maintained to protect of primarily protect terrestrial species and their habitats. The full implications of this will not be clear however until the production and enactment of the BHCA regulations.

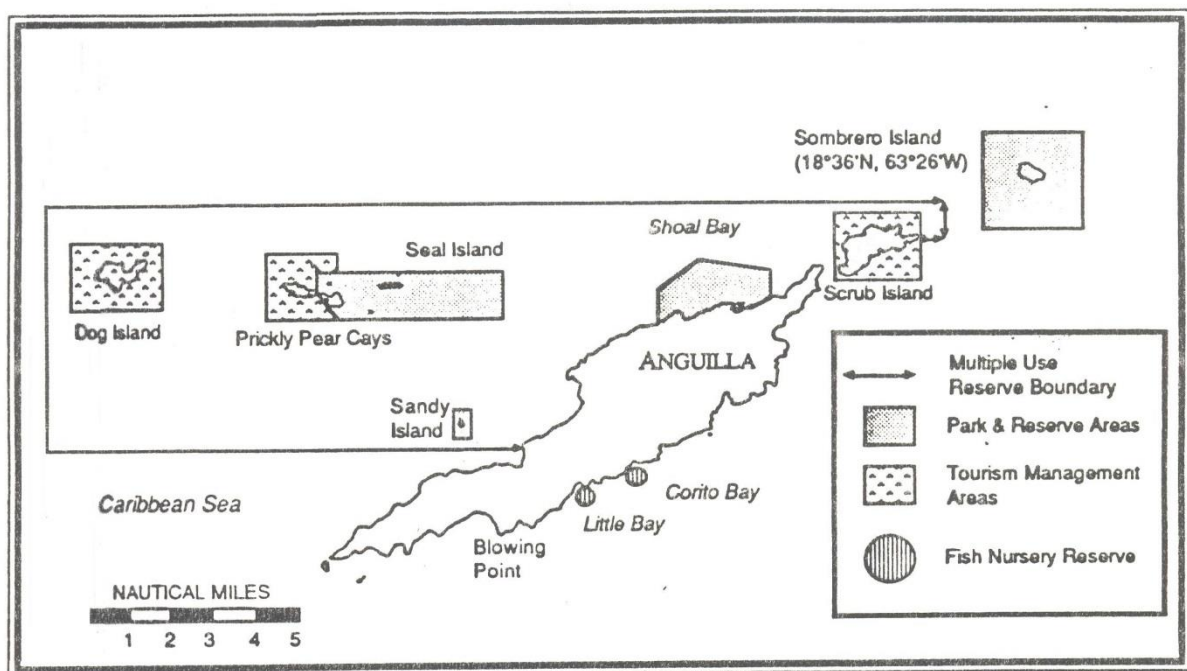
Historical Record of Marine Management Plans

Although management plans have been produced in the past, none have officially been adopted for Anguilla's Marine Park System, or indeed any of Anguilla's Marine habitats and/or fisheries. According to Oxenford & Hunte (1990), the Anguilla Resources Development Project (ARDP) conducted in 1980 was one of the first steps towards the management of coastal resources and habitats in Anguilla. This work, initiated by the Government of Anguilla and the Eastern Caribbean Natural Area Management Programme (ENCAMP) resulted in three reports: Salm (1980); Olsen & Ogden (1980); and Jackson (1981). This latter report proposed a preliminary management strategy for Anguilla's critical marine resources and essentially became Anguilla's first marine management plan. This plan also contained the first recorded management zonation map for Anguilla's immediate marine areas and cays, and proposed national marine parks at Sandy Island and Shoal Bay East together with a number of other multiple use zones with varying degrees of protection and/or management. As a side note, a policy statement on marine parks for Anguilla (Gov Axa, 1978), which was probably still being discussed while Jackson collected his field data, although not a management plan, did suggest four areas around Anguilla be established as marine parks: the reefs around Sandy Island; the waters around Prickly Pear Cays; the reefs and waters at Little Bay in the Flat Cap Point region; and the reefs around Shoal Bay East.

The work by Jackson, combined with reports of habitat degradation in other parts of the Caribbean, led to an increasing recognition of the urgent need to manage Anguilla's coastal resources (Oxenford & Hunte, 1990). Indeed, the importance of protecting coastal marine resources was stressed further in the 1987-1997 Fisheries Development Plan for Anguilla (Stephenson, 1987). Thus a program was initiated to establish a number of marine protected areas around the island, and an action plan produced by Jackson (1987) laid out a road map for

the development of marine parks. This action plan used the same zonation plan as his earlier 1981 paper, which was again used in a simplified form by Goodwin (1989) in what appears to be a sister project conducted by the Caribbean Conservation Association, the same body who requested the action plan produced by Jackson (1987). Goodwin cites a number of unavailable reports that appear to have been assessing the various areas around Anguilla being proposed as protected areas (namely Dog Island, Sombrero Island, Seal Island, Prickly Pear Cays, Scrub Island, Shoal Bay, Sandy Island, Corito Bay and Little Harbour). This simplified zonation plan is presented in figure 5.2.

Proposed Marine Resource Management Zones, Anguilla



Taken from Goodwin M. (1989)

Figure 5.2: Management zonation for Anguilla’s nearshore marine resources taken from Goodwin (1989). It represents a simplified plan from that originally proposed by Jackson (1981).

The marine park areas that were eventually established in 1993 were only partially complimentary to those proposed by Jackson (1981) & Goodwin (1989), and as such the zonation plan became somewhat outdated. At the same time though, Jackson’s rationale was still being used as a general guideline for the development of management approaches for the coastal resources of Anguilla up until Oxenford & Hunte (1990), and on into the mid-late 1990’s. The work conducted by Oxenford & Hunte does give detailed descriptions of Jacksons (1981)

recommendations, and contributes a number of suggestions as to how to update the work based on the ecological monitoring they conducted. Despite this, and their recommendations for management of marine resources at their study sites, they did not lay down a detailed management strategy for the island and thus no up-to-date management plan was in effect during the establishment of the marine parks in 1993. Regardless, it is generally agreed that the marine parks are located in optimum locations, although it may have been beneficial to have included additional areas in the Anguilla Marine Park System also (Scrub Island and Anguilla Island-Blowing Rock for example).

A decade later in 2001 a new management plan was produced for Anguilla's marine parks (Hoggarth, 2001). It was prepared for the Organisation of Eastern Caribbean States Natural Resources Management Unit in St Lucia, under a project funded by the Department for International Development in the Caribbean. No known record exists of the Government of Anguilla directly requesting the production of this plan although acknowledgements of help are given to members of DFMR and other stakeholders. The plan, based on seven days of research in Anguilla and those data available at the time, is a thorough attempt at organising action towards the management of Anguilla's marine parks, although the plan itself was never formally adopted. The plan is cited as being a draft interim management plan only, and states that 'this management plan should be regarded only as a first attempt at describing the status and management of Anguilla's marine parks'. It goes on to say that 'As guided by the terms of reference, the main focus was placed on assessing needs for monitoring the status of marine habitats. In this and other areas, much further analysis, consultation and design remains to be done', and 'This interim plan should be upgraded to a first full management plan upon completion of a further participatory planning process as described in the following sections. Anguilla's marine resource stakeholders need to agree the future goals and institutional arrangements for the marine parks system, and the objectives, zonation, and regulations specific to existing parks and any new parks'.

At the time of its writing, the 2001 management plan was based on the ecological data collected by Oxenford & Hunte (1990)¹⁷, and recognised the fact that these data were in need of updating, and as such that the initiation of a long-term monitoring scheme be of immediate and utmost importance. Thus, although this interim plan was not upgraded directly as recommended, it may have contributed to the priority that DFMR placed on collecting such data five years later (see

¹⁷ Despite the fact that this work did not survey all the marine parks designated, and as such represents a significant knowledge gap at the time of designation

section following). Furthermore, the relative completeness of the plan means it is an ideal foundation for the current management plan being developed, and as such this plan may be viewed by some as the upgraded version that Hoggarth recommended.

Historical Record of Ecological Data Collection

The earliest known report specifically aimed towards fisheries management in Anguilla was authored by Camacho R.V. (1974). However, as no known copies of this report were located it is unclear whether any data were collected as part of its production. It is, in fact, unlikely that they were as a later report by Olsen & Ogden (1980), the earliest known surviving report orientated towards fisheries management in Anguilla, states that 'there has been little previous work in Anguilla' and that 'These fisheries are poorly known since they have been largely overlooked by the United Nations Development Project of the 1960's and have not been visited by the Western Central Atlantic Fisheries Common which has recently produced many useful analyses of the fishery potential of many of the Caribbean Islands'. As fisheries were themselves of prime concern back then, and little attention given to the habitats that they existed in, it is unlikely any ecological data had at that time been collected. Indeed, as Olsen & Ogden were part of the Anguilla Resources Development Project (ARDP) that also yielded the preliminary management strategy put forth by Jackson (1981), it is also highly probable, albeit not possible to confirm, that the zonation map proposed was not based on any ecological data either, although it did 'describe the near shore marine resources and recommend a system of marine parks' (Oxenford & Hunte, 1990). Also falling under the umbrella of the ARDP, the surveys conducted by Salm (1980) and outlined in his associated report, although representing the first known work on Anguilla's reefs, contained predominantly qualitative descriptions with only limited quantitative data. Salm writes 'Both the north and south coasts have fringing and patch reefs, together with coral assemblages on limestone terraces. The terrace assemblages are more extensive in the south, forming a 17 km reef area which is considered to be one of the most important largely unbroken reef areas in the Eastern Caribbean. These southern reefs are however more exposed to hurricane generated damage as is evidenced by the higher percentage of dead and broken coral recorded by Salm (1980). From the limited published information available, the northern reefs seemed to support a higher percentage cover of living coral with fields of intact *Acropora palmata* and *Acropora cervicornis*'.

Based on the recommendations from the ARDP, the Government of Anguilla selected a number of candidate sites for consideration in the management scheme. These sites included Prickly Pear/Seal Island, Sandy Island/Dowling Shoal, Shoal Bay Island Harbour, Black Garden Bay, Crocus/Little Bay, Little Harbour, Corito Bay, Forest Bay, Sandy Hill Bay, Dog Island, Scrub Island and Sombrero Island (Oxenford & Hunte, 1990). This led in 1989 to a Cambridge-Anguilla Expedition that was mounted to examine marine habitats, initiate permanent monitoring sites and make management recommendations for the first three of these areas. This expedition collected data at these sites (Shoal Bay, Sandy Island & Prickly Pear/Seal Island), although surveys were relatively generic in nature (Reef Quality Index; Environmental Impact Index; substrate type by depth and by site; grouper species abundance; surgeonfish abundance; angelfish abundance; and butterflyfish abundance). Furthermore without at least semi-raw data, potential for temporal comparisons are limited.

The Government subsequently requested assistance from the British Development Division to carry out a 'Coastal Inventory and Analysis Project' to examine the remaining candidate sites and to develop a management strategy. The project administered by the then Department of Agriculture and Fisheries, and conducted by the Bellairs Research Institute of McGill University in Barbados (Oxenford & Hunte, 1990), is the result of this request and represents the most rigorous known surviving marine and coastal ecological data for Anguilla during this period. Surveys were conducted at eight of the candidate sites (Black Garden Bay; Crocus/Little Bay; Little Harbour; Corito Bay; Forest Bay; Sandy Hill Bay; Dog Island, and Scrub Island), which diverged somewhat from what appeared to be the general site consensus of the time. Unfortunately this work didn't cover Shoal Bay, Sandy Island or Prickly Pear, a fact that may be due to the Cambridge Expedition having surveyed them the year earlier. As it appears that this expedition was less rigorous in data collection than Oxenford & Hunte, information at these sites from the time is more limited. It is unknown if more detailed data were presented in a final report of this 1989 expedition as only an informal draft is currently known to exist. For these reasons it is only the Oxenford and Hunte data that were used by Hoggarth (2001) to develop the first detailed management plan for Anguilla, which means significant knowledge gaps were present as only two of the five marine parks (Little Bay and Dog Island) had any detailed available data. These Oxenford and Hunte data are still used today for temporal analysis of those sites surveyed in 1990 (chapter 4), although as this work was conducted pre-GPS, only ten study sites were able to be reliably located.

Following Oxenford and Hunte, in 1995 the coastal and sub-littoral habitats of the islands and reefs were surveyed and mapped under the Anguilla Marine Resources Inventory Project by rapid ground truth data collection using aerial photography from 1991 (Blair-Myers *et al.*, 1995). The output of this project provided the most accurate map of Anguilla's benthic environments at that time and was used extensively during the following two decades as the definitive reference material for planning decisions. In 1995 Hurricane Luis hit Anguilla and according to an impact assessment study (Bythell & Buchan, 1996) significant damage to the coral reefs and seagrass beds occurred. This study used a methodology identical to that of Blair-Myers *et al.* (1995) so to allow realistic continued use of the benthic habitat map. The scale of these two projects, combined with the necessary rapid approach to surveying does however mean that no detailed quantitative data were produced.

Early the following decade limited survey work that formed part of the Reef Check initiative was conducted on a reef 100 m north of Blackgarden (Hoetjes *et al.*, 2002) and yielded a small amount of data. Additional surveys elsewhere around Anguilla do appear to have been conducted. Following this, the Anguilla Coastal Resource Assessment Mapping and Monitoring Project (ACRAMAM) was conducted during 2004-2005, which aimed to use a similar methodology as Blair-Myers *et al.* (1995). Once completed the collected habitat data were rendered into a Geographical Information System (GIS), which became known as the Anguilla Coastal Resource Information System (Axa CRIS). The rapid assessment methodology yielded only generic ecological data but produced an important resource for future planning purposes. For a number of years this intranet resource was available to Anguilla Government employees for work related purposes. Unfortunately, glitches with the coordinate system used meant data were not always reliable, which ultimately lead to the systems discontinuation. During this time other ecologically based studies were conducted by visiting overseas students indirectly yielding data for various areas around Anguilla. The most notable of these were conducted on the Spotted Spiny Lobster (*Panulirus guttatus*) in 2004 (Wynne, 2004; Wynne & Côté, 2007) and reef fish surveys conducted during 2003-2004 as part of a wider ranging Ph.D. thesis (Molloy, 2006).

The first detailed ecological data collected for the Anguilla Marine Park System were obtained as part of a project entitled 'Enhancing marine protected areas management in Anguilla – Phase 1', funded by the Overseas Territories Environment Programme (OTEP), where stationary point counts, roving diver surveys and benthic habitat quadrats were used to survey thirty sites within

five of the marine parks¹⁸. Rendezvous Bay was not surveyed at that time as it was not considered a marine park, rather an area under special management. This survey work was undertaken jointly by the Anguilla National Trust (ANT) and DFMR and produced a dataset that serves as a baseline from which future temporal comparisons can be made (Wynne, 2007). Following this project, DFMR initiated a Government funded permanent monitoring scheme known as the Anguilla Marine Monitoring Programme (AMMP). This project, which started in 2007, ultimately established fifteen monitoring sites around the island: ten at coral reef sites and five at seagrass sites. Sites were located in certain areas within the marine park system as well as within at non-marine park sites, thus expanding Anguilla's ecological dataset to include representative sites within other shallow water habitats. These data, combined with that collected at the thirty OTEP sites, will form the basis of the current management plan.

In 2010 DFMR began its first detailed fish catch data collection and analysis, although these data are currently used to provide fish landing statistics to requesting agencies, with no dedicated official report yet produced. Ultimately, these data will fill an important gap in marine ecological data for Anguilla, and be used as reference materials for fisheries related management decisions and report writing.

A second important gap in ecological information that needs filling is that for benthic habitats and fish populations around Sombrero Island. Based on its inclusion within the Marine Parks Regulations (2010), this area needs to be encompassed by this management plan, but until ecological data are collected no informed management recommendations can be made. To date, the only evidence of survey work conducted around Sombrero Island is an unavailable and undated report produced by Christoph Grueneberg, an overseas student working in collaboration with the Anguilla National Trust entitled 'Survey of the Fish & Coral Fauna on Sombrero Island' (Wynne, 2010). It is probable that Sombrero Island will in fact be more relevant to the Anguilla Fisheries Development Plan (AFDP) currently in production by DFMR (Gumbs *et al.*, 2015). The AFDP will serve as a sister document to this management plan. Overlap intentionally occurs between these two plans to link them together, but the AFDP is more relevant to deeper offshore areas where pelagic fish stock are potential targets (see following Section). It is the aim of both plans combined to steer fishing in Anguilla more towards these offshore resources to protect shallow coastal areas. This common goal, but difference in ultimate focus, is the reason the AFDP has not been included as part of this plan, yet will be developed in unison with it.

¹⁸ Project reference OTEP ANG402 (2007)

Scope and Successful Implementation of this Management Plan

This current plan sets out to be a comprehensive management breakdown not just for Anguilla's marine parks, but also for nearshore shallow water habitats and associated fisheries. These latter facets will serve to link the marine parks together into a true network with an all-encompassing nature that will hopefully aid the management plans official adoption. As mentioned earlier areas that are not included within this plan are more distant deeper offshore regions and the pelagic fisheries that they may contain. These areas will be covered by the AFDP although additional studies may be required to clarify pelagic stocks, and include fishing grounds not yet surveyed (for example: Old England, that lays 20 km northeast of mainland Anguilla; and Tuna Bank, that lays a similar distance to the West). Pelagic fisheries that cross-over into the Marine Park System (or the proposed Anguilla Marine Management Area – AMMA) will be mentioned in this plan, but again be more relevant to the AFDP. Examples of such include sport fishing and trolling for pelagic species in nearshore areas. As mentioned above, one of the over-arching purposes of this management plan to compliment the AFDP and help steer the Anguillian fishing industry towards offshore fisheries resources in order to help mitigate known degradation of nearshore reefs and other fishery resources (chapter 2). Due to the wide ranging nature of this report, legislation governing its success falls under the Fisheries Protection Act as well as the Marine Parks Act. Efforts have been made throughout this report to clearly identify which legislative amendments fall under which Act in order to clearly steer its developmental progress.

This plan uses baseline data for the marine parks collected and reported in Wynne (2007), and current up-to-date monitoring data that were collected as part of the AMMP (2007-2010). AMMP has continued beyond 2010, but these data will only be used for subsequent revisions to this plan as they have yet to be fully organised and analysed. These revisions will allow adaptive management to be undertaken, which is characterised by a flexible approach to management, where both environmental and socio-economic conditions change over time. As stated by Hoggarth (2001) 'What is appropriate today may not be appropriate tomorrow or in ten years time. An adaptive approach is thus recommended, that recognises the complexity of natural resource management and develops management strategies based on learning and feedback'. This feedback system is illustrated in chapter 4, and this plan will follow the structure laid out therein.

Finally, to ensure the successful adoption of this plan it is essential that it is based on an integrated and multi-disciplinary approach, and one that is fully participatory in terms of those involved with the development, implementation, and future revision. Although to better guarantee success it is prudent to have a single government department spearheading the production of this management plan, continued interagency meetings together with regular stakeholder meetings, public consultations, and general outreach are essential. The results of these meetings and consultations will be continuously fed into future versions of this plan and noted within the text.

Section 2: Habitat Descriptions

General Areas and Data Sources Used

The current plan seeks to unite the Marine Park System with other identified management areas and objectives around the island. The overall aim is to establish the Anguilla Marine Management Area (AMMA) that will encompass the Marine Park System and other important marine areas around the island, including the Coastal Zone Fisheries Management Area (CZFM). As mentioned above, data collected by Wynne (2007) will serve as baseline information for the five established ecologically based marine parks. These data will be used in combination with those collected as part of the ongoing AMMP initiative. This initiative serves to fill the long-term monitoring gap identified in past studies (Hoggarth, 2001), and data spans not just the marine parks but also other areas of interest (see following subsections). These data will form the critical quantitative backbone of this management plan, as well as being used extensively within other DFMR objectives. This plan also encompasses data outputs from chapters 1 – 4, and will be cited as such within the text. Further data used as reference materials for this plan will relate to fisheries management aspects and be derived primarily from fish catch data collected by DFMR over the last five years. A map of generalised marine habitats around Anguilla (based on the ACRAMAM project) is presented in figure 5.3, with boundary coordinates and general habitat types for Anguilla in table 1.

Dog Island: The second most distant park from mainland Anguilla, lying approximately 15 km north-west of mainland Anguilla, Dog Island Marine Park, which includes three smaller cays and other scattered rocky outcrops has an overall area of c.10 km² (c.4.5 km x 2 km). The island itself comprises 207 ha of limestone and is recognised as an Important Bird Area (IBA) by

Birdlife International (since 1999). Much of the marine habitat consists of sand patches and flat pavement, low complexity, hard bottom communities. The most ecologically diverse area exists between Dog Island and West Cay, where topologically complex subsurface rocks are encrusted with a large variety of sponges, soft corals and hard corals. There is a wide diversity of fish species in the area, with pelagic and reef species coexisting throughout the area. This leads to favourable fishing in the area, although again, its distance from mainland Anguilla serves to restrict this activity somewhat. Sharks are relatively common and turtles are often sighted making this an attractive area for recreational diving. Great Bay is also an important sea turtle nesting site. Sea conditions and strong currents mean survey work can be problematic to conduct here, thus only three baseline 2007 sites could be surveyed and despite a number of efforts it is not included within current AMMP monitoring. Lobster, snapper and conch fishing occur in the area as well as trap-fishing for reef fish species, spear-fishing, and seasonal ‘rounding of the jacks’.

Junks Hole Marine Park: Surrounding the area within a radius of 500 yards (457 m) from GPS coordinates marking the location of the wreck of the Spanish Galleon El Buen Consejo. This area (c. 0.65 km²) is not of ecological significance, being protected instead as an important heritage site. For this reason it is not considered part of Anguilla’s Marine Park System.

Prickly Pear Cays and Seal Island Reefs Marine Park: This park, the largest within the Marine Park System, lies approximately 9 km north-west of mainland Anguilla and consists of three main cays with an overall park area of c.33 km² (c.12.5 km x 2.5 km). Prickly Pear East, with an area of 31 ha of dense scrub, with Hoggarth (2001) recognising it as an Important Bird Area (IBA) due to 180 pairs of nesting Bridled Terns (*Onychoprion anaethetus*). Up-to-date bird counts are presented in Lloyd & Mukhida (2014). Extensive sand and rubble patches are present around the cays, with a number of small rocky outcrops and a chain of barrier reefs stretching c.10 km eastwards. This barrier reef has extensive hard and soft coral communities together with a wide variety of reef fish species. Juvenile turtles frequent the area, both Green (*Chelonia mydas*) and Hawksbill (*Eretmochelys imbricata*) Turtles, with a small amount of nesting known to occur on certain beaches. Although little data exists to corroborate as such, it is believed that this reef system has degraded markedly over recent decades due to fishing impacts, coral diseases, and hurricane damage. One sign of this is that the area, although still important for fishing, is not visited by fishers in the numbers once reported (S.Wynne, pers. obs.). No recreational diving regularly occurs in the vicinity although the cays are a very popular snorkelling spot with dozens of tourists descending on the reefs closest to shore on a daily basis.

Eight sites were surveyed for baseline data collection in 2007, and one AMMP site is located towards the more pristine eastern end of the barrier reef system. Trap-fishing for local ‘crayfish’ (*P. guttatus*) occurs extensively along the barrier reef system as well as spear-fishing and trap-fishing for reef fish species.

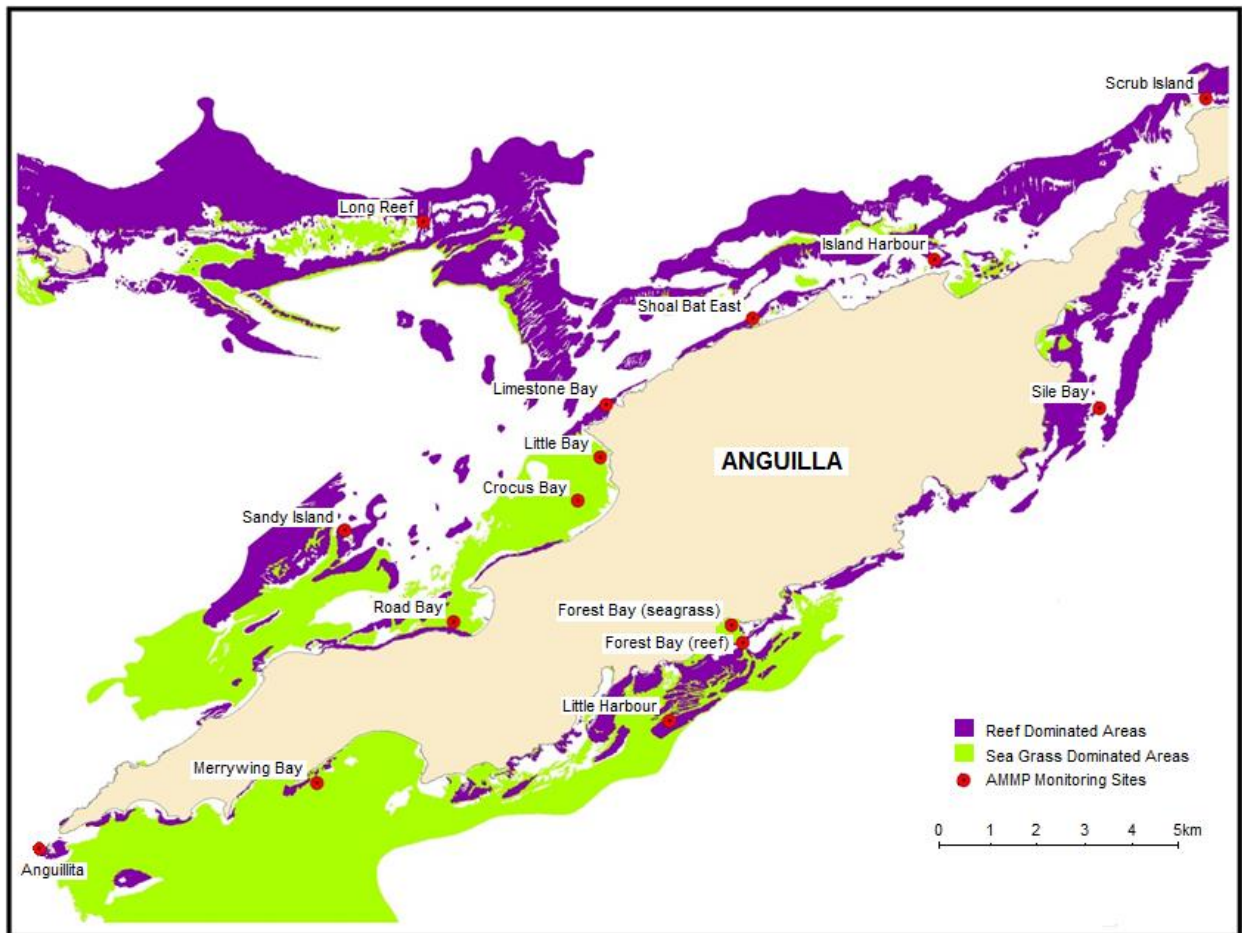


Figure 5.3: Generalised marine habitats around Anguilla in regions of less than 30m depth. Green areas represent those dominated by plants and algae (seagrass beds, algal flats etc) and purple areas those dominated by corals and sponges (hard coral reefs, soft coral pavement reefs etc). Locations of AMMP monitoring sites are also marked. Dog Island and other further offshore areas are not included. (*Map modified from version prepared by the Department of Physical Planning, Government of Anguilla*).

Sandy Island Marine Park: One of the smallest offshore cays within the marine park system, situated only a few km north-west from mainland Anguilla. The cay is made entirely of sand and coral fragments/rubble, with the park itself having an overall area of c.5 km² (c.3 km x 1.5 km). The habitats around Sandy Island are varied, with sand/rubble areas, seagrass beds, patch reefs and fairly extensive deep reefs. Dowling Shoal is one such example which has variable hard and soft coral communities and a wide variety of reef fish species. It is an important juvenile turtle habitat for both Green (*Chelonia mydas*) and Hawksbill (*Eretmochelys imbricata*) Turtles, with a small amount of nesting known to occur on the cay. Relatively high levels of fishing occur in the area (mainly trap-fishing with some spear-fishing also) and it is popular with snorkelers visiting by boat. Two or more recreational dive sites exist within park boundaries. Four study sites were surveyed for baseline data collection in 2007. The eastern most of these sites became a long term monitoring site as part of AMMP.

Little Bay Marine Park: This triangular shaped coastal protected area is the smallest within the marine park system (<1 km², c.1 km x 1 km x 1 km triangle), extending from Pelican Point (southern tip) to Flat Cap Point (northern tip). The bay has extensive seagrass and is considered to be an important nursery area for reef fish species and spawning ground for Yellowtail Snapper (Hoggarth, 2001). The small size of this park, combined with the fact that it attracts a lot of visitors, mean user conflicts are reportedly high. It is a very important juvenile turtle habitat for both Green (*Chelonia mydas*) and Hawksbill (*Eretmochelys imbricata*) Turtles, with occasional nesting activity on the beach. Some hard and soft corals are present in the submerged rocky coastal regions together with a variety of reef fish. Snorkelling is very popular here but no diving occurs aside from the occasional training course. A small number of fish-traps can occasionally be found within the park area, but fishing is mainly hook and line from the sea rocks, spear-fishing, or seasonal seine netting for species of Jacks (Carangidae).

Shoal Bay and Island Harbour Reefs Marine Park: The largest of the marine parks bordering Anguilla's mainland coastline at c.19 km², this area flanks one of the longest stretches of white sand beaches in Anguilla. The northern limit of the park runs for c.7 km at approximately the same latitude as the southern end of Scrub Bay. This northern boundary lies 3.5 km offshore at the western end of the park past Lower Shoal Bay East and 1.75 km offshore at the eastern end of the park beyond the important fishing community of Island Harbour (that includes Scilly Cay). Habitats, and therefore resources in the area, are varied ranging from extensive patch reefs to fringing *Acropora palmata* reefs and mixed seagrass beds. The area is important for virtually all marine species including juvenile sea turtles that forage in the area, and adults that regularly

nest on the beaches from March through November. It is a popular snorkelling spot although diving, which was once popular in the area, no longer regularly occurs due to reported degradation and travel distances for dive operators. Fishing is common and ranges from spear-fishing to lobster fishing for *Panulirus spp.* Twelve sites were surveyed for baseline data collection in 2007. One of the most westerly of these became a long term monitoring site as part of AMMP, with a second site eastwards close to Island Harbour. An important socio-economic study was conducted for this park in preparation for the development of a management plan which highlighted the challenges that this area will face (Mukhida & Gumbs, 2007).

Sombrero Island Nature Reserve Marine Park: This park encompasses the land and sea areas within a 2000 yard (1.83 km) radius of GPS coordinates marking its central point, giving it a total size of 10.5 km². Historically, this island played an important role in Anguilla as it was the site of relatively extensive phosphate mining derived from bird guano that was exported as fertiliser. This mining was conducted first by the Americans in the mid 1850's and later by the English who took over operations in the mid 1860's. By 1870 the mining operation was yielding 3000 tonnes of phosphate each year, but by 1890 reserves were exhausted and operations ceased. There are still ruins on the Island that remain from this time and as such Sombrero Island is considered an important heritage site. The first lighthouse on the island was erected in 1868 which was replaced in 1962 after hurricane damage. The Lighthouse was manned until 2001 when an automated system was put in place. The Ministry of Infrastructure, which DFMR falls under, is still responsible for the maintenance of this navigational aid, and visits the island with the Marine Police sporadically. Today the island is visited only occasionally by fishers, biologists, divers and Government staff. The island has been identified as an IBA by Birdlife International due to a number of breeding seabird species, and is being nominated by the Government of Anguilla for protection under the Ramsar Convention. One short report (Grueneberg, undated) is the only evidence of any past survey work being conducted there. One dive was undertaken by DFMR staff in the southern coastal area in 2009 that classified it as a rocky pavement reef habitat in some ways similar to that found at Dog Island, with an abundance of pelagic fish species. Quantitative data of the marine habitats around Sombrero were collected during four underwater video array transects in 2015 by DFMR (report in preparation). Further survey work is recommended before management measures can be proposed.

Rendezvous Bay: Although not yet officially a marine park, the area has extensive seagrass beds and as such listed as a no anchoring zone. Its boundary transects the bay from Shaddick Point to

Cove Bay Point, and includes the smaller Merrywing Bay. As a seagrass habitat it is considered to be an important nursery area for reef fish species and Hoggarth (2001) notes that it is a spawning ground for Yellowtail Snapper (*Ocyurus chrysurus*). It is also important for juvenile foraging Green Turtles (*Chelonia mydas*) and as a nesting site for adult sea turtles. No diving occurs here and snorkelling is relatively uncommon due to the overall sand/seagrass benthic nature of the area. The beach is relatively busy in the tourist season due to surrounding coastal developments. A small number of fish-traps can occasionally be found within the bay, but on the whole fishing does not regularly take place here. The area includes one AMMP monitoring site at Merrywing Bay.

Table 1: Boundary coordinates and general habitat types for Anguilla’s marine parks as listed in the Marine Parks Regulations (2010). The coordinates listed for Sombrero appear to be erroneous as they relate to a central point out as sea, the 2000 yard radius of which only partially encompasses the Island – as it is listed as a ‘Nature Reserve Marine Park’ this suggests that the entirety of the island was intended to be included.

| Marine Park Name | General Habitat Type | North Western Corner | North Eastern Corner | South Eastern Corner | South Western Corner |
|------------------------------|-------------------------|----------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Junks Hole Marine Park | Coast and Shallow Rocks | 18° 15'74"N 62° 58'29"W | 500 yard radius from central point | 500 yard radius from central point | 500 yard radius from central point |
| Dog Island | Offshore Islands | 18° 17'17"N 63° 16'32"W | 18° 17'17"N 63° 14'00"W | 18° 16'07"N 63° 14'00"W | 18° 16'07"N 63° 16'32"W |
| Prickly Pear and Seal Island | Offshore Islands & Reef | 18° 16'46"N 63° 12'07"W | 18° 16'46"N 63° 05'05"W | 18° 15'24"N 63° 05'05"W | 18° 15'24"N 63° 12'07"W |
| Sandy Island | Seagrass and Reefs | 18° 13'00"N 63° 08'25"W | 18° 13'00"N 63° 06'49"W | 18° 12'06"N 63° 06'49"W | 18° 12'06"N 63° 08'25"W |
| Little Bay | Seagrass | 18° 13'54"N 63° 04'26"W | Triangular Area | 18° 13'21"N 63° 04'09"W | 18° 13'20"N 63° 04'38"W |
| Shoal Bay and Island Harbour | Coast & Reef | 18° 16'45"N 63° 03'12"W | 18° 16'45"N 62° 59'20"W | Sea Rocks at 63° 03'12"W | Sea Rocks at 62° 59'20"W |
| Sombrero Island | Offshore Islands | 18° 36'00"N 63° 26'30"W | 2000 yard radius from central point | 2000 yard radius from central point | 2000 yard radius from central point |
| Rendezvous Bay | Coast & Seagrass | Coast Line Curvature | Coast Line Curvature | 18° 10'06"N 63° 07'40"W | 18° 10'04"N 63° 06'16"W |

Other Shallow Water Areas (<30m)

North Coast Regions: The north coast comprises a diverse range of habitats from extensive patch, fringing and barrier reef systems, seagrass beds and sand/rubble areas. The reefs are largely incorporated as part of the Marine Park System, although a number of these habitats do occur outside these areas. Beginning in the eastern-most area, Scrub Island has relatively extensive reef areas and is popular among fishers from Island Harbour fishing port. These reef areas continue along the coast to Shoal Bay-Island Harbour Marine Park with scattered sand patches and pavement areas. Further westwards, and of particular significance, is the coastal region between Shoal Bay East and Flat Cap Point, especially the area offshore from Limestone and Blackgarden Bay. These areas, including a reef dubbed 'Anchor Reef' (no previous name recorded) that lies offshore from Flat Cap Point beyond a deep sand channel, house a wide variety of hard and soft corals and a diversity of reef fish. Fishing is common in the area, with extraction method being predominately via traps. Juvenile Hawksbill Turtles (*Eretmochelys imbricata*) forage in the area and nesting adult turtles of various species are known to nest on the beaches. There are a number of dive sites along this stretch of coast were previously visited by dive operators on an almost daily basis. Today, most of these sites are not used, reportedly due to habitat degradation combined with travel distance for dive operators. Westwards from Flat Cap Point to Road Bay the habitat becomes more dominated by seagrass with charter yachts and private boats being regular visitors not just to Little Bay Marine Park, but also to Crocus Bay where there are no anchoring restrictions. Mega yachts also anchor in this area from time to time. Road Bay is an important commercial and recreational area with numerous private moorings, many beach bars and other tourist developments, and a relatively large container port. The bay is predominantly seagrass. Further westwards beyond Road Bay the habitat becomes less dominated by seagrass and becomes more sandy in nature with algae flats and/or pavement/rocky areas prevailing towards the western end of the island and Anguillita. Anguillita is surrounded by pavement/rocky reefs and drop-offs with a good variety of both reef fish and pelagic species. It is a popular fishing area and includes a regularly visited dive site. Other northern shallow offshore areas, aside from a few scattered rocky outcroppings, are comprised mainly of sand/algal flats and pavement areas with a scattering of low density seagrass beds. AMMP sites exist at Limestone Bay (reef), Crocus Bay (seagrass), Road Bay (sea grass), and Anguillita Island (reef).

South Coast Regions: The south coast is far less diverse than the north coast with few extensive reef systems aside from heavily degraded fringing *Acropora palmata* areas. An exception to this

is Blowing Rock which lies to the south-east of Anguillita. This small exposed rocky outcrop is surrounded by relatively diverse reef areas. Eastwards from Blowing Rock sand and seagrass areas dominate until Blowing Point where hard bottom communities and fringing reef systems begin. These areas, with scattered seagrass regions in sheltered bays (i.e. Little Harbour, Forest Bay, Sandy Hill Bay) are often characterised by coral rubble berms and rocky shores. The ferry terminal at Blowing Point is located here, with petroleum shipment mooring buoys located a little further east at Corito Bay. Corito Bay is also where Anguilla's landfill site is located. The sites proximity to the coast is the reason for a number of anecdotal reports relating to leeching into the sea, although no research has yet confirmed this¹⁹. Pavement/rocky reef areas become more dominant eastwards towards Scrub Island, although rough sea conditions in the area mean survey work is often problematic. Sile Bay and Savannah Bay house some extensive *Acropora palmata* reefs although degradation levels are high and overall coral cover low. Away from the coast into the St Martin Channel, the habitat becomes dominated by sand/rubble algal flats and sometime diverse soft coral communities. Many areas in the channel are important Queen Conch (*Lobatus gigas*) grounds, and are visited frequently by conch fishers based out of Cove Bay. AMMP sites exist at Merrywing Bay (seagrass), Little Harbour (reef), Forest Bay (reef and seagrass), and Sile Bay (reef).

Section 3: Anguilla's Marine Resources

Uses

Beaches and sand: Over forty beaches surround Anguilla and its offshore cays, which are mainly comprised of picturesque white sand and very important for Anguilla's tourism sector as well as nesting sea turtles. Some of these beaches are considered the most beautiful examples of such in the Caribbean. Particularly in the Western end of the island, many of these beaches have large hotel and villa development which support Anguilla's economy. Beaches are an important buffer zone for wave action and their protection is essential. Sand extraction used to occur extensively with early development relying on it as a raw material. Sile Bay, for example, has been entirely depleted, and Windward Point Bay heavily degraded. In 1994 sand extraction was prohibited from most beaches although it was still 'unofficially' permitted at Windward Point Bay. In the past consideration has been given to sand extraction from offshore areas, although most

¹⁹ Water sampling described in chapter 4 did not highlight any concerns here, but a more detailed suite of tests is recommended

proposals were not accepted. Currently the only area where this takes place is a short distance offshore from Barnes Bay, where sand dredging is permitted under special licence by Viceroy (large hotel development) for beach nourishment purposes.

Reefs: Shallower reefs serve as an important natural defence against storm surges and associated wave action and thus protect against coastal erosion. The reefs are also an important source of local protein and a livelihood for approximately 500 fishing operations. Boats are generally outboard powered vessels ranging in size between 5-10 m with two or three crew members. The fishing industry can be broadly split into two main sectors: finfish fisheries and lobster fisheries. Both of these fisheries sectors primarily use fish-traps that can be broadly described as using an Antillean Arrowhead design. Finfish fisheries also use lines and seine nets, and although an extensive feasibility study was conducted into developing a long-line industry to reduce reliance on fish-traps (R.Hodge pers.comm.), to date little further development has occurred. The two lobster fisheries (*P. argus* and *P. guttatus*) operate mainly from the north-eastern harbours and target individuals in and around north coast reef areas. A growing *P. guttatus* hand capture fishery has also been identified that targets individuals all around the island in close to shore regions, often by opportunistic residents on a sporadic basis (Wynne, 2004). Diving is also an important service provided by reef areas with three operators currently in business on the island.

Seagrass: These habitats serve as important nursery areas for certain species of reef fish, feeding grounds for sea turtles, and important for the Queen Conch (*Lobatus gigas*) fishery. Although the conch fishery is small, it provides a much sought after protein source, also being conducted on a more recreational basis by snorkelling residents. Another important use of seagrass is in terms of sand fixation, where the plants root system restricts sand movement during storm surges or times of increased wave action.

Mangroves: Limited mangrove stands exist around Anguilla, with most fringing salt ponds rather than coastal zones. Those present however do contribute to coastal stability and trap sediments and nutrients that may otherwise enter the marine system. They also provide important nursery areas and feeding grounds for many marine species.

Mud and bat/bird guano: Although not technically a marine resource this material has been included as it occurs in the cliffs and small caves of Little Bay. The mud especially is collected and used as face-packs, and as the area in question is quite small, even limited extraction can lead to increased erosional processes and thus affect the park. Bat Guano, the source of the

phosphate mined on Sombrero Island is no longer mined and believed to be exhausted. Terrestrial survey work would be needed to confirm this.

Open water: Often overlooked as a marine resource, open water areas are important recreational sites and house pelagic species that can be an important source of protein and livelihoods for local residents.

Threats & Impacts (local)

The local threats detailed below have impacts that, at times, cross-over into different habitats, or have multiple impacts affecting multiple habitats. These cross-overs have been highlighted below but are grouped together for ease of reference. Figure 2.3 illustrates areas where some of these threats have been identified as a cause of concern.

Sand mining: The removal of beach material was once a common practice in Anguilla, but has been heavily restricted for a number of years. It still occurs throughout the island, but most notably at Windward Point, Junks Hole and Forest Bay (F.Mukhida, pers.comm.). The impacts of this practice ultimately lead to the complete loss of any recognisable beach, as can be illustrated by Sile Bay. Windward Point Bay is also heavily depleted of beach material. Erosional processes are evident and appear to be leading to land loss. Areas affected also become less aesthetically pleasing and less attractive to tourists and residents. For example, Sile Bay was once one of the more popular beaches for local residents to visit during weekends. It is now virtually always deserted. This historical context can be corroborated with tourist maps of the area that depict it as a sunbathing beach. Sand mining also passes on a message of irresponsibility: Anguilla's economy depends on tourism which, in turn, depends on its beaches. Tourists cannot understand why a local population that directly thrives on this industry would allow the practice to continue.

Removal of beach flora and coastal development: Vegetation on beaches helps maintain their stability and restricts erosional processes. In the past mangroves were harvested for fire wood and construction purposes (principally fish-traps). More recently however coastal vegetation is removed for tourism purposes - to make way for building or to 'enhance' the area for sunbathing/recreational activities. Erosional processes and the role beach vegetation plays in its mitigation can be currently observed at the east end of Shoal Bay East. After a period of

accretion, erosion began again (c.2008) on the Upper Shoal Bay side of Shoal Bay Point. The beach itself disappeared rapidly, but erosion was slowed by palms, sea grapes and other vegetation. Many of these palms eventually washed away, and can now be seen underwater a short distance offshore. Erosion has continued to this day, but the vegetation line has slowed it dramatically. Without this vegetation, it is probable that Shoal Bay Point would have eroded away almost entirely. Sand accretion devices have been attempted in the past but overall were unsuccessful. Beach vegetation is also essential for nesting sea turtles that rely on it to provide a range of internal sand temperatures. Sand temperatures affect sea turtle hatchling sex ratios where males develop at cooler temperatures than females. The removal of flora, and thus cool nesting spots, can therefore lead to an over-production of females and an overall drop in turtle population fecundity (Broderick *et al.*, 2000). Coastal developments are often the drivers that lead to the removal of beach flora. In addition, if conducted in an inappropriate way and/or location these developments can also lead to cliff instability which may increase land based sediment input due to collapse or rainwater runoff. This will lead to increased water turbidity and impact benthic marine communities through decreased light penetration or smothering. Coastal developments can also pose a pollution risk if undertaken in close proximity to the shore. Pollution as a threat is, however, discussed under a separate heading.

Anchor damage: Inappropriate and careless anchor placement can cause extensive damage to all habitat types, especially during times of increased swells/currents. This can especially be the case in seagrass areas where an anchor may have to be set multiple times before it catches. Dragging anchors can rip long gouges into seagrasses and, if unnoticed, can also pose a danger to the vessel using the anchor. In reef areas anchors can similarly drag across the bottom while seeking a hold thereby damaging small hard/soft corals, sponges and other benthic life. Once secured, if under excessive pressure during swells, entire coral heads can be snapped off. Even large coral heads can be ripped up by large enough vessels. This situation is especially problematic in areas of 'reef' that are in fact rocky areas encrusted by corals, and the rocks, not being directly fixed to underlying solid substrate, can move if sufficient force is placed on them. Anchor lines can also tangle around coral heads and snap, causing damage over time to coral polyps through rubbing (Harriott, 2002; Godfrey, 2009).

Overfishing and removal of herbivorous species: The harvesting of fish species is essential for local livelihoods and the tourist trade but, if carried out unsustainably, can have long-term negative effects on these industries and overall ecology. Creating the correct balance of this resource use versus negative impacts can be one of the biggest challenges faced by managerial

agencies. Reduced fish numbers can lead to fishing practices becoming less economically viable and an overall reduction in fish availability as a food source. Depleted reef areas are less attractive for divers and snorkellers and lead to a negative image of the managing agencies. Spear-fishing on reef areas can actively target fish species in such an efficient manner that areas of patch reef can be rapidly depleted if this practice takes place in an unregulated fashion. Often in Anguilla, many of the fish targeted by spear-fishers do not end up being used as a direct protein source, and are instead utilised to bait lobster pots. Lobsters, the most economically valuable fishery resource by weight, are much sought after in the tourism industry. In addition, the removal of herbivorous fish species can lead to under-grazing of macroalgae, affecting the coral-algae balance (Williams & Polunin, 2001; Jompa & McCook, 2002). It is especially important to promote the sustainable use of herbivorous species as regional/locally sourced eutrophication can increase algal growth rates.

Fish-trap damage: If placed directly onto the reef, fish-traps can cause damage to the benthic life underneath or adjacent to them (Marshak, 2007). When retrieving the trap it can drag along the bottom snapping off small coral heads and other encrusting species, especially in times of rough sea conditions. Fish-trap lines easily become entangled around coral heads and can either lead to damage of the head or loss of the trap entirely. Lost traps continue catching fish (ghost fishing) until they finally degrade sufficiently to allow free movement of fish. This process can take a number of years especially when zinc anodes are used by fishers on their traps to reduce mesh corrosion.

Boat groundings & engine damage: During times of adverse weather conditions navigating the shallow reef areas can be problematic, especially for fishers who often need to place their fishing gear close to the reef to target their desired species. This can be an increased problem for fishers targeting the lobster species *P. guttatus* via traps as they need to be placed very close to the reef in often very shallow areas. Larger boat groundings do not happen regularly, but when they do occur can cause extensive damage to the local area, especially when attempting to retrieve the vessel. Outboard motors may also strike the reef, but vessel owners, wanting to avoid expensive damage, do their utmost to avoid this. In shallow seagrass regions however, when throttling away at speed, outboard engine propellers can gouge out strips of vegetation without causing engine damage and as such it is likely less care is taken by vessel owners in these areas.

Recreational damage & disturbance: It is possible for virtually all recreational activities to be conducted in a non-destructive manner, but unfortunately this is rarely likely to be the case. Even

the most responsible divers, swimmers and snorkellers can inadvertently kick corals or disturb sediment. Water sports such as kite surfing may cause collision damage in a similar way to boats and pose a danger to swimmers. Currently jet-skiing is banned in Anguillan waters, but due to pressure from various agencies this ban may be lifted in the future and a zoning scheme introduced. If this happens it will also be wise to include other water sports/activities within this zoning plan to avoid conflicts.

Boat pollution – oil and grey water: There is a heightened potential threat level of oil pollution originating from boats in the commercial areas of Sandy Ground, Blowing Point and Corito Bay (see figure 2.3), with reported incidents occurring at these sites over recent years. This type of pollution can be damaging to marine life (including sea birds), beaches and recreational users. Grey water pollution originates mainly from charter and/or private yachts, and may also include the dumping of raw sewage at sea. It is of most concern in areas of high usage by such vessels, primarily that of the marine parks. Raw sewage is a serious public health concern. Dumping of grey water increases the potential nutrient load of local waters and so adds to the regional eutrophication concern.

Land based nutrient input and point source pollution: This threat is complex in nature as it may arise from a number of sources, and be indirectly linked to other threats already cited. For example, salt pond leaching and terrestrial run-off can cause an increased nutrient load in coastal waters and thus add to regional eutrophication concerns. In many cases, however, it can be worse in areas where beach flora has already been removed (see previous threat). Storm surges may also cause salt pond breaches, which may be of increased concern in the future should reef areas begin to offer less storm surge protection. Linking salt ponds directly to the ocean can also increase nutrient input, as has occurred in Cove Bay where underwater pipes from a salt pond within the golf course development area exit near the fishing jetty. Other sources of pollution, some of which may include leaching from old septic tanks, are thought to be of concern, especially in older developed areas such as Sandy Ground and Rendezvous Bay. This poses a serious health concern and also again increases the potential nutrient load in local waters. Leaching may also occur from the Corito Bay landfill site. Land based nutrient input may also be heightened by the use of fertilizers or other horticultural products. It is not believed that this is of significant concern in Anguilla though as agriculture is limited and usually takes place inland.

Disease and mortality events: Both of these threats are for the most part caused by other factors detailed in this section or by regional stresses. A number of coral diseases threatening certain coral species are due to cyanobacteria growths which can be partly attributed to increased nutrient levels either from local or regional sources. Coral bleaching, which can cause significant coral mortality during periods of high sea surface temperature also poses a threat, although to date in Anguilla severe events have not been reported/documentated. Hurricane damage can also inflict severe damage to reef areas, although it is documented to aid dispersal of certain species through fragmentation. This however may not be the case with potentially increasing hurricane frequency and reducing reef resilience through algal dominance and coral diseases. Other mortality events may come from unknown sources or recognised pathogens acting in unknown ways. Examples of this being other reported coral diseases and the mass mortality event that almost entirely wiped out populations of the important grazing species of sea urchin, *Diadema antillarum* in the early 1980's (Lessios, 1988). Populations of the urchin are still undergoing a patchy recovery in Anguilla even after thirty years (chapter 4), in a similar way to other parts of the Caribbean (Lessios, 2015). The exact mechanism behind this remains unclear, but has been widely attributed to a low supply of recruits or high post-settlement mortality (Rodríguez-Barreras, 2015). It is widely recognised that reduced populations of urchins have allowed algal growth to dominate certain reef areas in a similar way to the removal of herbivorous fish species. This, in combination with the regional/local eutrophication discussed within this Section suggests an over-riding reason for continued reductions in reef resilience and an associated increase in degradation.

Invasive species: The Red Lionfish (*Pterois volitans*) is currently the only known invasive marine species in Anguilla. First introduced into the Caribbean from the Indo-Pacific in the early 1990s, *P. volitans* was initially reported in Anguilla in 2010, and has since spread to virtually all reef areas around the island (S.Wynne, pers.obs). This species is a voracious hunter and can consume large numbers of juvenile reef fish, detrimentally effecting adult population numbers. With limited amounts of known and/or common predators in the Caribbean, its own population can proliferate and potentially lead to dramatic decreases in numbers of native fish. This will ultimately have negative impacts on certain livelihoods. Overall however, *P. volitans* are still found in lower numbers than expected (Wynne, 2016), based on densities recorded in other parts of the Caribbean (Morris & Whitfield, 2009).

Litter/marine debris: Although not considered a significant problem along beach fronts in Anguilla, this is, at least in part, due to clean up efforts by resorts and community activities

facilitated by the Anguilla National Trust (ANT). If unmanaged, underwater impacts of such debris can be significant. Marine debris can wrap around coral heads causing polyp damage and clog the digestive tract of certain marine species, especially sea turtles. Of the marine debris in Anguilla, the largest threat is posed by discarded fishing gear, most notably old nets and line. These can continue to entangle species long after having been discarded, and thus pose a 'ghost fishing' threat. This discarded gear also poses a threat to boats and swimmers who may become similarly entangled.

Removal of cliff mud/bat guano: Reportedly having therapeutic properties, cliff mud is, from time to time, removed by visitors to Little Bay. Such activity has led to a small amount of cliff instability and erosion (which may be accentuated by grazing goats). Eroded materials can increase sediment loading and raise water turbidity, in turn affecting light penetration.

Threats & Impacts (regional)

As detailed in chapter 1 regional sources of ecological stress can have potentially catastrophic environmental impacts and are inherently difficult to manage against on a local level. Threats include (but are not limited to): increased hurricane frequency; coral bleaching; ocean acidification; and eutrophication. The first three of these are essentially climate related, and aside from attempting to increase overall habitat resilience little can be done on a local level. For this reason these threats, despite their high levels of impacts (particularly to coral reefs) have been left largely unmentioned in the mitigation section later in this plan. The latter stress however, that of regional eutrophication, can be somewhat mitigated against on a local level as local threats can add to its effect even beyond the level of habitat resilience. The impacts of eutrophication include (but are not limited to): increased macroalgal growth that can out-compete hard coral species; increased cyanobacterial growth that can increase incidences of coral diseases; increased macrophyte growth on seagrasses limiting their photosynthetic potential; and increased water turbidity leading to lower light penetration and affecting photosynthetic potential of both seagrasses and coral zooxanthellae.

Increased hurricane frequency: Despite a potential cyclical nature that is linked, at least in part, multidecadal Atlantic oscillation patterns (Woolings *et al.*, 2014; Steinman *et al.*, 2015), hurricanes are reported to be increasing in number and severity in the Caribbean (Goldenberg, 2001; McAdie *et al.*, 2009). Hurricanes, which causes coral fragmentation and therefore asexual

dispersal of certain coral species (Lirman, 2000), can also inflict severe damage to reef areas and the coastal zone. Damage to beaches can be extensive and, if occurring above a certain frequency, may not allow natural recovery of the effected systems. One such example of this potentially occurring in Anguilla was revealed through DFMR's beach monitoring programme established in 1992. Certain beaches that were showing recovery after Hurricane Luis in 1995 were once again affected by Hurricane Lenny in 1999. Following this second hurricane, recovery occurred more slowly. By the next severe hurricane event, Omar in 2008, some beaches still had not built themselves back to pre-Luis levels. This trend continued post Hurricane Earl in 2010, and then again Gonzalo in 2014. As mentioned elsewhere, this erosion can be accentuated by reef degradation and lead to increased and unprecedented loss of beach material. This may potentially be the cause of, or a contributor to, the unusually high levels of erosion at the eastern end of Shoal Bay East over the last seven years. Hurricanes may also interact with other stressors in this Section, where, for example, decreased reef resilience (caused by, for example, eutrophication) combined with increased hurricane frequency, leads to reefs being unable to recover after such disturbance events.

Coral bleaching events: Primarily caused by increased sea surface temperatures during hurricane season, coral bleaching tends to be intrinsically linked to increased hurricane activity. It should be noted however that bleaching can also occur or be accentuated when corals are placed under alternative sources of stress, such as nutrient enrichment (Wiedenmann *et al.*, 2012) and ocean acidification (Anthony *et al.*, 2008). Regardless of its cause, coral bleaching has become a serious threat to Caribbean corals over the last decade, although different species may be more susceptible (Guest *et al.*, 2016) and less resilient to repetitive bleaching episodes (Schoepf *et al.*, 2015). A major bleaching event in 2005 led to between 20-50% coral loss at many locations around the region and up to 90% at the worst hit areas (Wilkinson & Souter, 2008). Although not on the same scale as the 1998 bleaching event that occurred in the Indo-pacific region, it did bring to the forefront the threat that coral bleaching poses in the Caribbean. No region-wide events have taken place since 2005, although sporadic localised bleaching has occurred.

Ocean acidification: While the effects of a decreased pH in the world's oceans through increased carbon dioxide absorption has yet to be quantified, it is still recognised as a realistic threat (Orr *et al.*, 2005). If it continues, there will be wide-ranging detrimental effects on species that rely on carbonate precipitation as part of their life cycle, for example hermatypic coral species (Freely *et al.*, 2004). It is reasonable to conclude that this acidification will lead to decreased resilience of coral species and increased reef degradation. Anthony *et al.* (2011), for example, conclude that

reefs already subjected to herbivore overfishing and eutrophication are likely to be more vulnerable to increasing carbon dioxide in the water. Effects will likely be complex, and impacts uncertain, but may include, but might not be limited to: depressing metabolic rates and immune responses; triggering coral bleaching events; and decreasing oxygen levels as algae are killed off. The overabundance of algal growth currently observed in the Caribbean however means this latter effect will unlikely be a cause for concern in the foreseeable future.

Eutrophication: Although land-based local nutrient sources can accentuate the impacts of this threat, there has been growing recognition over recent years that regional eutrophication is a significant threat to Caribbean marine ecosystems. Chapter one discusses this in detail and concludes that although nutrient sources are wide ranging, from cumulative build-up of local run-off and sewage to larger scale inputs from entire ecosystems such as the Florida Everglades, one of the most seasonally significant sources is the combined output from the Amazon and Orinoco river plumes. These plumes appear to be the contributing factor behind recent Green Water Events (GWE) in the Caribbean during 2009 and 2010. The GWE signify high levels of nutrients in the water column that increases productivity and reduces light penetration which is important for coral survival. The GWE, which can last a number of days depending on location and severity, also bring with it increased numbers of fish and top predators that feed off these fish. Thus, much of the nutrients are theoretically removed through consumption, at least to a certain extent. Remaining nutrients however are still elevated enough to promote algal growth, which is likely the reason behind the huge *Sargassum spp.* blooms (for example) recorded in the Caribbean during 2011 and 2014/2015. Once the Sargassum washes ashore, it again signifies the removal of nutrients from the marine ecosystem, especially if the plant matter is not allowed to rot on the beaches. In tourist areas this is usually the case as developments tend to remove the unsightly material from bathing beaches. More of a threat to the marine ecosystem however is the promotion of algal growth directly on to the reefs, especially if overfishing or other factors have removed herbivorous species. Where this is the case algal species can outcompete coral and smother entire reefs. This has been observed at a number of locations around Anguilla. If the situation persists Anguilla's important reef systems will gradually degrade and erode away. This will effect remaining fish populations, but more importantly for the island as a whole, will increase beach erosions as the reefs can no longer afford protection from wave action and storm surges.

Status

Beaches: Long-term beach profiling by DFMR has documented changes that have occurred over time at certain beaches in Anguilla (Wynne *et al.*, 2016). Generally results illustrate that these changes are usually cyclical in nature providing that beach material and flora are not removed by human activity, for example through sand mining. Sand mining has historically occurred (and continues to occur) at a number of sites, for example, Sile Bay and Windward Point Bay), where removal of dunes for construction materials has led to the loss of the beach. Other beaches appear to be suffering from similar losses although no notable sand mining has occurred, for example Shoal Bay West. Instead, times of high erosion levels coincided with hurricane events. Recovery of beaches post hurricane appears to now only be happening partially. This may be due to increased hurricane frequency and the inability of beaches to recover within more limited time frames. At the same time, reasons may also be more complex in nature and result from a knock-on effect of sand mining in other areas, or offshore dredging that has begun to occur in other areas around the island.

Another beach that has been exhibiting high levels of erosion over recent years is the eastern end of Shoal Bay East. This loss does not appear to tie in so succinctly with hurricane events and may be either due to the nature of the area, or possibly be the first signs of reef degradation and the associated loss of protection that occurs. Most of the other beaches around Anguilla appear relatively pristine, suffering only from cyclical losses and/or recovering from hurricane events given sufficient time. The examples in the previous paragraph, however, illustrate the need for caution when removing sand from an area, and the potential for more permanent erosion events to occur that may threaten coastal developments. Additional studies are also required to better understand potential causes for erosion so that appropriate restorative and mitigative measures may be applied.

Reefs: Studies conducted in 1990 (Oxenford & Hunte) reported that although there were signs of human impacts in certain reef areas, Anguilla reefs were generally considered to be in good condition. Recent studies comparing present day surveys with this work, as detailed in chapter 4 threat assessments, show that this is no longer the case. Reduced hard coral cover and varying reductions in fish numbers lead to the conclusion that Anguilla's reefs are now suffering from variable amounts of degradation. This is especially the case for south coast reef regions, despite the fact that this area has been noted as more susceptible to damage since early reports from the 1980's (Reefwatch, 1989). Macroalgal levels however, although currently high, were also

recorded as such in the 1990 study and were attributed to low *D.antillarum* numbers. Although *D.antillarum* numbers have partially recovered in certain areas, continued high macroalgae cover is likely being accentuated by removal of herbivorous fish species and increased availability of organic nutrients. Interestingly, both 1990 and present day surveys recorded low levels of macroalgae at Dog Island. This may be due to strong currents restricting growth and associated rapid movement of potentially nutrient-poor water, as other areas dominated by strong currents often share this characteristic (S.Wynne, pers.obs.). Thus of all areas surveyed, those at Dog Island are considered to be the most 'pristine'. Figure 2.3 presented previously in chapter 2 illustrates the perceived status levels of Anguilla's reef areas based on all available survey work. These status levels also take into consideration what the considered natural state of these areas would be. Although subjective in nature, such consideration is important when comparing a variety of habitat types in this way.

Seagrass: Although seagrass areas represent a relatively small area in relation to Anguilla's national waters, they are nonetheless an important habitat for a wide variety of marine species, especially foraging Green Turtles (*Chelonia mydas*), Queen Conch (*Lobatus gigas*) and a number of juvenile fish species. The most notable of these areas in shallow coastal regions include, but are not limited to: Forest Bay; Little Harbour; Rendezvous Bay; Road Bay; Crocus Bay; and Island Harbour. Of the seagrass sites studied by Oxenford and Hunte (1990) most were considered to be in good condition with a high plant percentage cover. Today, percentage covers remain high, although both anecdotal reports suggest that overall size of these areas may have reduced over time. Indeed, Bythell and Buchan (1996) recorded a reduction in frequency of seagrass beds following Hurricane Luis, and it is likely that similar reductions have occurred during subsequent hurricanes. Quantifications of this are not possible however, and it is probable some level of recovery took place during the interim periods. Increased hurricane frequency over recent years may have hindered this recovery somewhat and so caution is recommended in terms of seagrass bed management. Higher than expected levels of sedimentation and epiphytes were observed on seagrass fronds during monitoring (although not reliably quantified) which, if sustained, may affect future seagrass growth. This increase in sedimentation/epiphyte cover, as mentioned earlier, might in part be due to increased nutrient levels, and illustrates how eutrophication may affect these areas in ways other than light penetration reducing photosynthetic potential.

Mangroves: Considering its size and low lying nature, only limited mangrove stands exist around Anguilla. The most notable of these are around coastal salt ponds, for example at Little

Harbour. Historically it is believed mangroves were more extensive, but fell prey to the need for fuel and fish trap construction as wood resources were limited. Bythell & Buchan (1996) reported that mangroves were not abundant in Anguilla prior to Luis, and those stands which were present were virtually all eliminated with mortality rates relative to 1994 between 68 and 99%. Buttonwood (*Conocarpus sp.*), a more inland species, was lesser effected. Unfortunately, as with the other habitats listed, lacking historical records mean longer term comparisons are not possible. The mangrove stands that do remain today however appear to be in relatively good condition, and their protection is encouraged as they are an important habitat for juvenile fish species and coastal stability/sediment entrapment.

Fisheries: Of those present in Anguilla, the fisheries considered to be of greatest significance to DFMR and fisherfolk are currently: the finfish fishery (which may be subdivided into reef fish, pelagics and sharks/rays); the lobster fishery (which may be subdivided into *Panulirus argus* and *Panulirus guttatus*); and the Queen Conch (*Lobatus gigas*) fishery. Although other groups/species may be locally targeted they are considered more artisanal/recreational in nature and not a formal fishery - for example the West Indian Sea Egg (*Tripneustes ventricosus*) and the West Indian Top Shell (*Cittarium pica*). Of these main fisheries, reef fish, lobster, and conch are considered by DFMR to be currently in a status of decline and in need of enhanced management. This conclusion is based on the monitoring efforts of DFMR (Wynne, 2010), interviews with fishers, anecdotal historical reports and many unquantified in-water observations by staff (S.Wynne, pers.obs.). For example: throughout all in-water surveys, fish abundances and overall population size class structure were concluded to be much lower than would be expected historically; fishers report lower catch rates of various species in many areas, such as *P. guttatus* in Seal Island Reef (R.Webster pers.comm.); many retired fishers report that historically there appeared to be much higher densities of key species such as Nassau Grouper (*Epinephelus striatus*) and Red Hind (*Epinephelus guttatus*); and Queen Conch (*L. gigas*) and reef fish are at times difficult to purchase at local retail outlets on the island (although exports to St Martin may be partially to blame for this). Extrapolating on this latter point, five years ago reef fish were much more widely available on the island although often they were undersized or undesirable species (S.Wynne, Pers. Obs.). Although many of these reports are qualitative they do point to decreasing fishery stocks, a conclusion that is supported by field data collected by DFMR. The status of pelagic fisheries, which currently mainly consist of sport fishing vessels, remain unclear due to a lack of available data. At the same time, they are likely under exploited due to their larger spatial dispersion and fewer fishers. Status of the shark and ray fishery is also presently unknown. It is hoped that by considering aspects of these fisheries within this

management plan, combined with a more thorough analysis in the Anguilla Fisheries Development Plan (AFDP), managerial enhancement can be achieved.

The Red Lionfish (*Pterois volitans*) is now established in Anguillan waters, but due to localised removals by DFMR and promotion of it as a food source, their numbers are currently considered to be relatively low. During the past five years 'hot spots' have been noted at some of the offshore cays, Crocus Bay and Meads Bay. Populations are more problematic to control in the more offshore areas such as Dog Island and so special effort will be needed to address this. For the time being most regions close to mainland Anguilla appear to be effectively managed by current practices. At this time, a population study is being conducted by DFMR to confirm this.

Mitigation of degradation & zonation

The following management plan will put forward mitigation measures for all of the impacts and threats identified above. It is recognised that in many marine management areas, complex zoning plans are often proposed to allow effective use of multiple purpose region, as was proposed by Jackson (1981). Zoning offers an effective way of achieving the multiple objectives required of protected areas by defining discrete areas for specific uses and/or purposes as described by Kelleher (1999). Examples of these purposes include (but are not limited to): providing protection for critical species and/or representative habitats; separating out and directly managing detrimental and/or conflicting human activities; preserving and directly managing areas for particular human uses; protecting areas from as many anthropogenic stress sources as possible; and allowing for scientific research and/or education.

The implementation of any zoning plan should be fully participatory and introduced in phases to allow acclimatisation and education of all resource users. Care needs to be taken to not isolate specific stakeholder groups or regions. For example, as identified by Oxenford and Hunte (1990), the zonation plan proposed by Jackson (1981) discriminates against north coast fishers by suggesting the creation of a large 'multiple use reserve' that would encompass all of Anguilla's north coast and the offshore cays from Scrub Island to Dog Island, with most of the south coast being only under generic fisheries management legislative control. It was suggested that to avoid this, the multiple use area should either be expanded to encompass the whole island shelf, or the principle be abandoned entirely. The current management plan has been based on an evolved principle of the former, and hence is not just a management plan for Anguilla's Marine

Park System, but also for associated fisheries and shallow water habitats (that is, those on the whole island shelf). It is proposed that the Marine Park System forms the backbone of this multiple use approach, with marine parks afforded the highest levels of protection. The coastal zone, that being under the greatest threat outside of the marine parks from tourism and fishing, should be placed second to this.

The danger posed by zoning plans is over complication leading to associated user confusion. This appears to have been recognised by Goodwin (1989), who simplified Jacksons original proposal to that in figure 5.2. This is a view shared within the current management plan, where simple zonation is recommended, using the marine parks as the foundation for this. Figure 5.4 illustrates this plan, which in many respects reflects the zones proposed by Jackson, but in a simplified form. As mentioned in Sections 5 and 6 it may be necessary however to assess and introduce other small demarked areas for water sports. To help simplify zonation, boundaries have been placed in areas that loosely follow habitat boundaries and the proposed activities closely follow the usage that has already naturally evolved in different areas. It is hoped that this approach will allow acceptance of the management plan by all stakeholders and/or resource users, while offering an effective way of managing and/or keeping control of these uses.

Zone simplification is of special importance as it is very difficult to physically demarcate areas in the ocean environment. Fences are not possible as they are in terrestrial protected areas and signs can only be placed for user referral on beaches or at ports/jetties. This can lead to user confusion if plans are overly complex and the increased ability for persons contravening regulations to plead ignorance to infringements. Thus presents the dilemma for surveillance and enforcement: how to police areas without being overly heavy-handed, the breeding of resentment among users for the management of marine resources, or the failure of park management. Community support is absolutely essential. For this reason it is recommended that enforcers of regulations be lenient on first time offenders and only pursue penalties against repeat offenders.



Figure 5.4: Map (not to scale) depicting the Anguilla Marine Management Area (AMMA - blue) that contains, the Coastal Zone Fisheries Management Area (CZFMZ - yellow), and the Anguilla Marine Park System (Grey). Wreck dive sites (wreck symbol), and main swimming or snorkelling areas (numbers), are also shown. These numbered areas will need further zoning or restrictions if water sports and swimmers are to not conflict. Although AMMA and the CZFMA are governed under the same legislation (Fisheries Protection Act) they have been differentiated as zones because, being close to land, it will be possible to patrol the CZFMA regularly and thus enforce regulations effectively. It is proposed that this is the area, outside of the marine parks, that management efforts are initially focused on. AMMA on the other hand, although still possible to be under active management will only realistically be patrolled on a weekly basis, so enforcement would be less stringent.

Section 4: Legislative & Managerial Structure

In order to facilitate the adoption of this management plan, the aim is to create a framework that relies on, where possible, existing legislation or minor amendments to existing legislation. Although ultimate managerial goals may be more wide reaching, a primary aim is for other measures to be introduced, at least in the initial stages, via public awareness initiatives/education. This will encourage a community based approach and aid public acceptance and future support. Complementing this approach, much of the legislative backbone needed for this plan has either already been enacted (although in some cases not enforced), drafted but yet to be enacted, or proposed but not yet added as amendments. The main pieces of legislation as they relate to this plan have been listed below:

- **Beach Protection:** The Beach Control Act (2000). Earliest known version is the Beach Control Ordinance 1961. This Act makes provision for the control of beach usage and the need for a license to build on a beach or the sea floor. It states that the Act will not be used to affect fishing rights. The Beach Protection Act (2000) is a statute Act which makes provision for the Governor to declare a particular beach as protected. Under this, the Beach Protection Orders name eighteen beaches as protected. It also prohibits against sand mining. The Access to Beaches Act (2000) aims to ensure that all beaches remain public, but also affords protection in terms of (for example): littering; damaging plants; driving on the beach (unless it is an established custom).
- **Cruising Permits Act (2000):** Earliest known version is the Cruising Permits Ordinance 1980. This Act falls under the jurisdiction of Customs and provides provisions for cruising permit fees and no anchoring zones in Little Bay, Sandy Island, Prickly Pear Cays and Seal Island Reef, Dog Island and Rendezvous Bay.
- **Fisheries Protection Act (2000):** Earliest known version is the Fisheries Protection Ordinance 1986, with amendments in 1990 and 1995. This Act was due to be updated in 2008 together with a newly drafted set of 2010 Regulations. To date, this has not yet happened. The current 2000 Act legislates all current legal fishing practices and licensing, including (but not limited to): legal size of lobster and conch; molestation of lobsters exhibiting reproductive activity; marking of fish-trap buoys with fishing licence number; molestation of other fishers traps; minimum mesh size for fish-trap mesh; prohibition of taking or being in possession of a turtle (to remain in force until 15-12-

2020), either whole or a portion of the meat; and prohibition of using gillnets. The Act also makes provisions for: closed seasons (schedule 3); closed areas (schedule 4); minimum size of marine products (schedule 6); minimum mesh size of nets (schedule 7); and designated fish aggregating devices (schedule 8).

- **Marine Parks Act (2000):** Earliest version is the Marine Parks Ordinance 1974 (revised 1982). Amendments to the regulations under this act were made in 2008 and 2010. No controlling agency has been appointed but DFMR act in this capacity by default. In Section 15 of this Act however, Customs Officers are included as having powers to arrest persons and seize vessels. Regulations include restrictions on (but not limited to): Fishing by non-belongers; diving by unauthorised dive operators; camping; damaging flora and fauna; water skiing; discharging sewage; building fires; and installation of moorings. Provisions are also made so that the Governor in Council may designate any portions of the marine areas of Anguilla as a marine park where it is considered that special steps are necessary for: the protection of fish, the flora and fauna and wrecks found in such areas; preserving and enhancing the natural beauty of such areas; the promotion of the enjoyment by the public of such areas; the promotion of scientific study and research in respect of such areas. Currently Rendezvous Bay is not listed under this act although it is demarked as a no anchoring zone under the Cruising Permits Act.
- **Land Development (Control) Act (2010):** Earliest version is unknown. This Act is relevant in situations where marine parks include privately owned land within their boundaries, or if future beach set-back regulations may be required. For example, Dog Island is privately owned and therefore any form of development on the island must be approved by the Land Development Control Committee. Set-back recommendations are made when developments are proposed but no legally-binding set-back legislation currently exists above the vegetation line.
- **Trade in Endangered Species Act (2010):** This Act is relevant in terms of certain endangered species, for example the Hawksbill Turtle (*Eretmochelys imbricate*), although the Act does not have direct implications within this management plan. The Department of Environment are the management authority, with the Act's primary purpose to compliment the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulations and Appendices.

- **Biodiversity and Heritage Conservation Act (2010):** This new Act is poised to become one of the most relevant pieces of legislation to this management plan (in combination with the Fisheries Protection Act), although as its governing regulations have yet to be produced the full implications remain unclear. As described earlier both the Minister of Fisheries and the Minister of Environment have joint authority under this Act, as delegated by their competency. Once the regulations are produced this Act will likely replace the Marine Parks Act, and so it is fundamental that the regulations contain all that is already in the Marine Parks Act, together with the relevant amendments suggested within this plan. The BHCA also provides provision for buffer zones, and so compliments the proposed creation of the Coastal Zone Fisheries Management Area (CZFMA). As these regulations have yet to be produced, for the purpose of this management plan, the Marine Parks Act will be cited as the current governing legislation unless stated otherwise.

Management and Managerial Structure

Currently management of the Marine Park System, although limited, is conducted by the Department of Fisheries and Marine Resources by default. DFMR is ideal for the role of management agency as it has: over twenty years experience managing Anguillian waters; a sea going vessel; seven dive certified staff, five of which are competent in underwater survey work and can identify at least 95% of Anguilla's marine species; complete sets of equipment including those needed for diving, all in-water survey work, and mooring buoy installation/maintenance. Notwithstanding this, because the management of the marine parks involves an integrated approach across many sectors and also encompasses certain terrestrial habitats, DFMR will rely on input from other agencies and, at times, likely seek support from owners of land that falls within park boundaries.

DFMR will assume the lead role in implementing this management plan until it is named officially as lead agency within the Marine Parks Act. In the initial stages of management plan development DFMR will hold public consultations to gauge acceptance of proposed management. Once completed a final draft management plan will be produced and circulated within the relevant areas of Government. Aside from high level approval of the document, it will be important to get feedback from both the ANT and Department of Environment (DoE) due to their expertise in the management of the terrestrial habitats falling within the marine park

boundaries. Following this the management plan will be circulated more widely to other agencies/stakeholders for their comment. These will include:

- Department of Lands and Surveys
- Department of Physical Planning
- Department of Environmental Health
- Anguilla Hotel and Tourism Association
- Anguilla Tourism Board
- Anguilla Fisherman's Association(s)
- Anguilla Sea Turtle Conservation Group
- Owners of land within the marine parks
- Charter Boat Operators
- Dive Operators

Through public consultations and private meetings with fishers and other stakeholders, the roots of this management plan will be founded within the local community. This community based approach will continue throughout the development process and be essential when revising this document as necessitated under the adaptive management approach. An overall goal is to produce this updated document on an annual basis at the end of each year, based on progress made and information gained over the previous twelve months. Stakeholder involvement will be an essential part of this process.

Section 5: Management Plan and Legislative Amendments

The overall vision for the Anguilla Marine Park System to be achieved through this management plan is to enhance tourism and recreational use of these areas while protecting the important habitats that they house. By doing this it is hoped to increase revenue through user fees and provide sanctuary areas for marine species that, via spawning and/or migration will help populate surrounding areas and the Caribbean region as a whole. The management actions within this plan also aim to promote livelihood diversification, either through tourist related activities or by encouraging the utilisation of new and/or under exploited fisheries resources. The secondary purpose of the managerial actions proposed within the plan is to mitigate against a number of the identified threats/stressors to Anguilla's marine environment (chapters 1-4). It is

suggested to use Anguilla's Marine Park System as the core units behind this protective undertaking, but in the same way as past zonation maps have suggested (the earliest being Jackson 1981), to also use other shallow water areas and associated fisheries as integral units also. This means legislative amendments will be necessary not just within the Marine Parks Act, but also the Fisheries Protection Act. It is felt that isolating the marine parks in a management effort is not the most efficient and/or effective way to achieve overall managerial goals, and that an integrated approach to management is now recognised as a far better means of doing so (Crowder & Norse, 2008). This is especially important when dealing with a range of habitats, a range of stakeholders, and thus a range of economic activities (Elliot, 2014). Bearing in mind a number of the Marine Parks contain within their boundaries privately owners islands (for example Prickly Pear Cays) it will be essential to actively involve these owners using a grass roots type approach whenever possible. For the purpose of this current plan however only the marine portions and immediate coastal areas of the marine parks will be taken into consideration. If an integrated grass roots is possible through land owner cooperation it is suggested that separate managerial documents be produced in direct combination with the other managerial agencies.

Until land owner cooperation can be guaranteed, it was also felt that to better serve Anguilla all of the marine parks should be treated predominantly as one managerial unit, with only slight variations between overall goals of each area (table 2). Forming complex zoning regimes or overly differentiating areas can clog the legislative process and stall managerial progression. Such complex plans also lead to increased confusion among stakeholders. Currently, the situation is already orientated favourably in this way, with all parks known collectively as the Anguilla Marine Park System. To keep in line with ideology based around simplification, the shallow water regions outside of the marine parks that fall within this plan will also be considered as one unit. These will encompass those areas less than 10m in depth and form a buffer zone that will link the marine parks with surrounding coastal regions (the CZFMA). AMMA encompasses the Marine Park System (with the exception of Sombrero Island) and the CZFMA, and can be generally described as those marine areas <30m in depth (Figure 5.3).

The backbone of this plan is a list of legislative amendments to be put forward by DMFR as lead agency that fall primarily under the Marine Parks Act and the Fisheries Protection Act. The amendments that relate to this plan are listed under group headings following.

Table 2: Overall goals of the Areas within the Anguilla Marine Management Area and uses.

| Marine Park Name | Overall Goals of Area and Uses |
|--|--|
| Junks Hole Marine Park | Heritage conservation. Restriction to activities in the area to preserve site from damage and/or looting |
| Dog Island | Fisheries and habitat conservation. Land portion privately owned, but important for nesting sea birds and sea turtles. Restrictions to anchoring to preserve rocky reef habitat integrity and other benthic life. Anchoring permitted in Great Bay and is not heavily visited by tourist charters so mooring field not necessary. Pelagic fish and reef species reserve, including conch and lobster. |
| Prickly Pear and Seal Island | Fisheries and habitat conservation and recreation enhancement. Land portion privately owned, but important for nesting sea birds and sea turtles. Owners have spoken of an interest in integrated management. Restrictions to anchoring to preserve reef and seagrass areas, with two mooring buoy fields. Pelagic fish and reef species reserve, including conch and lobster. Prickly Pear East is popular destination for tourist charters and snorkelling trips. Wreck dives are within park boundaries. Crayfish fishing to be permitted. |
| Sandy Island | Fisheries and habitat conservation and recreation enhancement. Land portion privately owned. Restrictions to anchoring to preserve reef and seagrass areas, with one mooring buoy field. Pelagic fish and reef species reserve, including conch and lobster. Is a popular destination for tourist charters and snorkelling trips, with some dive sites within its boundaries. |
| Little Bay | Fisheries and habitat conservation and recreation enhancement. Restrictions to anchoring to preserve seagrass integrity, with two mooring buoy fields. Restrictions to fishing to conserve populations, particularly conch and juvenile lobsters. Potential site for artificial reef project and/or snorkelling trail, including moulded concrete lobster casitas for lobster village sanctuary. Tourism area (swimming, snorkelling, sailing). Coastal area not heavily developed. |
| Shoal Bay and Island Harbour | Fisheries and habitat conservation and recreation enhancement. Restrictions to anchoring to preserve reef and seagrass areas, with one small mooring buoy field. Pelagic fish and reef species reserve, including conch and lobster. Is a popular area for snorkelling and glass bottomed boat, with some currently unused dive sites within its boundaries. Coastal area heavily developed, with Shoal Bay very popular with beach goers. Swimming zones need consideration due to boat traffic conflicts. Crayfish fishing to be permitted. |
| Sombbrero Island | Heritage and bird population conservation on land portion (Government owned). Marine area management uncertain due to lack of habitat and/or fisheries data. Potential area for pelagic fish species reserve and other habitat related resources. |
| Rendezvous Bay | Fisheries and habitat conservation and recreation enhancement. Restrictions to anchoring to preserve seagrass integrity. Restrictions to fishing to conserve populations, particularly conch and juvenile lobsters. Potential site for artificial reef project and/or snorkelling trail, including moulded concrete lobster casitas for lobster village sanctuary. Tourism area (swimming, snorkelling, sailing) and suggested site for new mooring buoy field. Coastal area relatively heavily developed, and among the most popular beach goers locations on Anguilla. |
| Coastal Zone Fisheries Management Area (CZFMA) | Fisheries and habitat conservation through prioritised surveillance and strict enforcement of the Fisheries Protection Act. |
| Anguilla Marine Management Area (AMMA) | General surveillance and enforcement of the Fisheries Protection Act as logistic and financial restrictions allow. DFMR collaboration with the Marine Police will facilitate this process. |

Proposed Amendments to the Marine Parks Act and/or the BHCA

- Clarification of lead management agency: Under the Marine Parks Act no administrative agency has been listed. Instead it states that “The Governor may appoint any person as Controlling Officer”. This role has been assumed by DFMR since the park’s creation, but a Controlling Officer has yet to be appointed. In the new BHCA, The Department of Fisheries and Marine Resources, through the Minister for Fisheries, have been indirectly named as lead management agency for the marine areas under the Act. Until the BHCA officially supersedes the Marine Parks Act DFMR will continue to assume the lead role and begin implementing this management plan. The Marine Parks Act will continue to be viewed as the guiding legislation for the marine parks until this time. As such, the Governor needs to officially state that the Director of Fisheries and Marine Resources (or Minister of Fisheries) is the Controlling Officer under the Act, or the Act needs to be amended to state that DFMR (or the Minister of Fisheries) is responsible for administering the Act.
- Enforcement and ticketing: In order for DFMR to be able to fulfil their managerial role under the Marine Parks Act, Fisheries Officers will need official enforcement capabilities. This should include the ability to issue on-the-spot fines (ticketing system) and confiscate fishing equipment infringing on legal fishing practices. Provision for this has been made under the BHCA, but as with the lead management body, until regulations are produced under the Act, the Marine Parks Act is still the governing legislation. No enforcement capabilities are listed under the Marine Parks Act. N.B. Under the Fisheries Protection Act fisheries officers are given some limited enforcement powers, but these mainly relate to boarding and seizing vessels, and do not directly relate to enforcing legislation. It is currently prudent for Fisheries Officers to conduct patrols together with Police Officers for this purpose.
- Official designation of marine parks: All park areas within this management plan need to be correctly listed under the Marine Parks Act, together with their anchoring restrictions as detailed currently in the Cruising Permits Act. These restrictions can simply be transferred across, or remain in the Cruising Permits Act and simply be updated: one small alteration to correct a typographical error stating that Great Bay (Dog Island) is a no anchoring area; Shoal Bay and Island Harbour is not listed in the Cruising Permits Act, and it is proposed to make it a no anchoring zone to protect its extensive reef and

seagrass areas, as is already the case in Little Bay; Rendezvous Bay also needs to be listed in the Act as a marine park and its anchoring restrictions reviewed; the coordinates given for Sombrero Island in the 2010 revision of the Marine Parks Act appear incorrect as they fall quite a distance out to sea, rather than being placed centrally on the island as would be expected. DFMR owns, but has yet to install, fifty marine park boundary marker buoys that should be placed in appropriate locations along the demarcation boundaries.

- Fishing restrictions in marine parks: An overall aim for the marine parks is for them to house healthy populations of marine species that will migrate to other areas and be viable catch for fishers. To enable this, fishing restrictions within the parks will be needed. To gain community support it would not be wise to prohibit all types of fishing in the marine parks at this time. Instead it is suggested to allow all types of fishing that involves the use of a hook and line (rod and reel, trolling, vertical long-line etc) or seine nets. Hook and line methods do not remove herbivorous species, and can directly target certain species of certain sizes through gear choice. It is also arguably less damaging to the habitat, although nylon line entanglement can cause minor problems. Seine netting is also proposed as permitted in marine parks at this time as it, for the most part, targets pelagic species that migrate between areas rather than species that live ‘permanently’ in one place. However, an exception to this is trap-fishing for Crayfish which will be permitted still in Shoal Bay-Island Harbour and Prickly Pear-Seal Island Marine Parks. The remaining marine parks, where Crayfish fishing will be prohibited, will be considered closed areas to this practice, and thus will be dealt with under the Fishery Protection Act amendments in the next subsection. Under the Marine Parks Act, as it makes better sense to keep regulations under this Act generic to all marine parks, only spear-fishing and removal of conch will be prohibited. Sports fishing should also be prohibited in marine parks, although current sport fishing licences stipulate this as a regulation so in effect it is already in force.
- Marine pollution fines: A fining system should be developed where the dumping of grey water, black water and/or oil based substances be prohibited within the marine parks. These fines should be graded based on the severity of the pollution event. It may however be prudent to include such a fining system for all marine areas and, if so, would be necessary to make the legislative amendment under the Fishery Protection Act rather

than the Marine Parks Act. Notwithstanding this, the Merchants Shipping Act (2010) already makes provision for such regulations under section 66(1)(c). Thus this Act might better serve as the legislative origin for such a fining system.

- Fee for tourist enhancement features: The tourist enhancement features suggested for Little Bay, Rendezvous Bay and/or Shoal Bay will need moorings and maintenance to keep them running effectively (these features will be underwater and not affect the above water beauty of the areas they are in, being only visible via diving or snorkelling). In order to pay for this maintenance small visitor fees will be needed. Under the Marine Parks Act section 7 (1)(h), the Governor may make a regulation regarding to “the charging of fees for any of the services provided in marine parks”. All visitors to the underwater features (not the marine park as a whole) will be charged this fee (suggested as EC\$5.00 per person per day). As a method of implementing the collection of these fees it is proposed to make bracelets available for purchase at local outlets. Spot checks will be conducted by DFMR to check those snorkelling or diving around the feature are in possession of one. These spot checks will aid compliance although it is not proposed to have a fine in place for those without a bracelet: they will only be asked to leave the area.

Proposed Amendments to the Fisheries Protection Act

- Enforcement and ticketing: As mentioned under the amendments for the Marine Parks Act, Fisheries Officers need to be given greater powers when it comes to enforcing relevant legislation. Currently under the Fisheries Protection Act powers are generally limited to boarding and seizing vessels. This needs to be extended to, for example: seizing of fishing gear being used in a way that contravenes the Act; and spot fining of offenders.
- Fishing restrictions: *Trap-Fishing* should be conducted with fish-traps that are fitted with an easily erodible escape door; traps should only be placed on sand areas and not directly on the reef; netting of deep water pelagics (i.e. Coryphaenidae) and spawning aggregations of Snapper (Lutjanidae) or Grouper (Serranidae) should be prohibited; existing legislation should be enforced as it relates to marking fish-trap buoys with licence numbers. *Spear-fishing* should be permitted by licence, not by default. *Seine net*

fishing should only be permitted with minimum stretch mesh size of 3 inches. This can be provided for under schedule 7 of the existing legislation. *Hook and line fishing* should be permitted without restriction (recreationally) but with a licence (commercially). Minimum landing sizes should be imposed for certain species as detailed below (note: these regulations apply to all areas, not just the marine parks, hence their inclusion in the Fisheries Protection Act rather than only in the Marine Parks Act).

- Minimum landing sizes: To protect juveniles of certain fish species and encourage the recovery of their stocks. Under schedule 6 of the Fisheries Protection Act (thus relevant to all marine areas, not just the marine parks) key targeted fish species need to be legislated for in terms of a minimum landing size. Species to focus on primarily are those targeted by fishers that belong to the families Serranidae (seabass), Lutjanidae (snapper), Scaridae (parrotfish), Carangidae (jacks), and Acanthuridae (surgeonfish). Minimum size recommendations are presented in chapter 4 and also detailed within the AFDP. It is also recommended that while these changes are taking place public awareness posters be produced detailing the rationale behind these minimum size limits with some life size examples of key species. It would also be beneficial to produce a ruler like scale for fishers that depict recommended sizes for each species. This will facilitate compliance with the legislation once it comes into force.
- Conch legislative revision: Current Queen Conch (*L. gigas*) legislation is insufficient to protect immature individuals from harvest. Based on research over recent years it is recommended to update legislation to take into account the thickness of the flared lip, as detailed in chapter 4. This will work in combination with the marine parks being closed areas to harvest conch and thus promote the sustainability of this important fishery.
- Lobster legislative revision: Insufficient legislation relates to *P. guttatus* (local name crayfish) as no minimum landing size exists for this species as it does for *P. argus*. Chapter 3 makes recommendations for a minimum size based on extensive local research. This is especially important to protect immature individuals, which cannot be readily captured by trap, from the expanding night-time hand capture fishery. Introduction of a closed season for both species, as closing certain marine parks to harvesting these species may not be sufficient to allow stocks to remain economically sustainable. This is especially the case for *P. argus* where offshore grounds are reportedly much less productive than they were a decade or two ago (W.Harrigan, pers.comm.). It is suggested for this species to have a closed season between 1st June and 1st November

each year. For *P. guttatus* a closed season between 1st Jan and 1st June each year is suggested. This will work in combination with the marine parks being closed areas to harvest both lobster species and thus promote the sustainability of these important fisheries. Closed seasons can be legislated under schedule 3 of the Fisheries Protection Act.

- Closed areas: All marine parks except Shoal Bay-Island Harbour and Prickly Pear-Seal Island are to be closed to all types of trap-fishing. Schedule 4 of the Fishery Protection Act allows prohibited areas to be named in such a way. Dive wrecks should also be named under this schedule, but to all types of fishing entirely. These wrecks are extremely important with the diving/tourism industry. Acting as marine species aggregation structures, these wrecks house not just fish populations but also lobsters, turtles and many other marine species. These species are what many of the divers pay to observe. It is easy, especially for foreign vessels, to fish out the wrecks because a dive buoy advertises their locations and provides a mooring that can be used while fishing takes place. Reports have been made of these vessels stripping a wreck of its lobster inhabitants in a matter of minutes. Strict protection of these wrecks is therefore of utmost importance. It is suggested to prohibit fishing of any kind with 50m of the red buoy installed and maintained by DFMR to mark a wreck. As a long-term goal all dive sites marked with a red DFMR buoy should be completely protected, but until their locations are properly standardised this will not be possible.

Other and/or Non-Legislative Management Actions

- Coastal Zone Fishery Management Area (CZFMA) and other areas: The purpose of the CZFMA is to create a buffer zone that will link the marine parks with surrounding coastal regions and encourage sustainable fishing methods that will preserve fishery livelihoods for generations to come. This zone will be under the regulations governing all areas within the Anguilla Marine Management Area (AMMA), the Fisheries Protection Act, but will be designated as a buffer zone under the BHCA. DFMR will initially concentrate its surveillance and enforcement efforts within the CZFMA until more resources become available to allow it to patrol AMMA more inclusively. The CZFMA is designed to be a specially managed area used to compliment the Marine Park System, and includes (but is not limited to) all coastal areas less than 10m in depth (figure 5.4).

AMMA, despite its size, still forms an area that can (depending on resources) be realistically patrolled jointly by DFMR and the Marine Police, and therefore can be effectively managed. It is also encouraged that the aquaculture potential be fully explored within this area. A number of such projects have been proposed in the past, but to date none have been successfully established. DFMR will also encourage pelagic fishing in Anguillan waters in an effort to move away from more ecologically damaging reef fishing practices currently used. Some of these proposed activities will likely occur further offshore in Anguilla's EFZ and thus be more relevant for inclusion within the AFDP rather than this document.

- Fee structure revisions: Some fees are included in the legislation, while others are not. Revision of the fee structure is suggested in order to provide revenue for the marine parks and relevant authorities. This is important for the longevity and successful management of the Marine Park System. Suggested fee structures that need review include (but are not limited to): *Dive Fee* - currently set at \$1US per person per dive. This fee has not changed since its introduction in the early 1990's and is based on an honour system where dive operators pay every three months. Previously, diver operators had agreed to change this fee to a one off \$10US fee per diver; *Marine Park Mooring Buoy User Fee* - currently collected when vessels check in at Customs and as such is not recorded as revenue created by the Marine Park System. This revenue needs to be recorded separately, and the fee structure increased for foreign vessels. These vessels are usually larger in size with a much higher number of visitors on board, therefore they put more pressure (wear and tear) on the moorings and the natural environment; *Sport Fishing Fee* - currently set at \$30US per person (not per vessel) for three months. It is known that many operators do not pay this, reportedly because it is seen as unfair to have to buy a three month licence for charter clients who only want to fish for one day. It would be fairer to increase the three month fee but for it to cover a maximum of three fishing charter passengers at any one time on the registered vessel. Most sport fishing occurs primarily in the deeper water parts of AMMA, although it is still known to sometimes take place within marine park boundaries.
- Tourism and fisheries enhancements: Enhancements should attract more paying visitors and help fund the Marine Park System, without harming the ecosystems the parks are designed to protect. Snorkelling trails incorporating underwater fisheries enhancement features (lobster casitas, sculpture gardens etc) in Little Bay, Shoal Bay and/or

Rendezvous would be educational and prove popular among visitors. Underwater sculptures, as well as being attractive to visitors, can be designed to encourage coral growth and attract fish and other marine species. Equally, a sunken wreck, if placed at a suitable depth (and therefore in a carefully selected location) can be visited by snorkelers and divers alike, while again attracting and sustaining fish populations. Lobster casitas too can be designed in an attractive manner and placed in large groups within park boundaries and form 'Lobster Sanctuary Villages' to enhance local and regional recruitment. Swimming areas will also need to be established in locations with high levels of boat activity to protect bathers from collisions. If conflicting user groups arise, agreements and/or buoyed swimming zones (or similar) will need to be created (potential areas where such conflicts may arise have been identified in figure 5.4). Notwithstanding this, water-skiing is already banned in marine park areas, and it is recommended that this be mirrored by prohibiting any other 'collision-risk' water sports. This is especially relevant if the current ban on jet-ski's is lifted, as the majority of marine parks are popular swimming/snorkelling areas and so collision risk is heightened.

- Fishing methods outreach campaign: The campaign should encourage fishers to move away from the more laborious, environmentally damaging and economically limiting fishing methods. Sport fishing and long-lining/trolling fishing methods yield a catch more favourable to sell to the tourist industry, thus commanding higher prices. These practices also do less damage to the environment as they do not involve setting traps, negotiating shallow reef areas, or setting nets. Sport fishing can offer the greatest return for fishers as no catch is required to earn a living, only a paying client. Catch can either be returned to the ocean or sold to client/restaurant for extra earnings. An outreach campaign should also include materials on: the damage traps do when placed directly on the reef; why unregulated spear-fishing is harmful to the marine ecosystem; and why juvenile fish do more good in the ocean than they do on someone's plate. Due to the restrictions to be placed on fishing within the marine parks these aspects will only be relevant to other areas within AMMA. It is also recommended that workshops be held and DFMR demonstrate the use of alternative fishing methods not widely practiced in Anguilla, such as floating fish aggregating devices for pelagic fishing and vertical long-line fishing rigs for deep water snapper species and Diamond Back Squid (*Thysanoteuthis rhombus*) fishing.

- Terrestrial areas, coastal setbacks and pollution: The ridge-to-reef management approach adopts the principle that all habitat types are interlinked and so terrestrial area management is integral to the health of the marine habitats that surround them. Such an approach however involves cross agency cooperation and so is predominantly beyond the scope of this management plan, although recommendations for other agencies to follow can be made. The development of terrestrial areas is currently legislated under the Land Development (Control) Act (2000). Other legislation is relevant here also, with responsible agencies including, but not limited to: the Department of Environment; the Department of Physical Planning; the Anguilla Air and Sea Ports Authority; and the Anguilla National Trust. All current policies should be adhered to, and the following is strongly recommended: development of official set-back legislation, especially within the marine parks and other sensitive coastal habitats; introduction of beaching lighting regulations to protect nesting sea turtles; working to ensure current legislation that protects natural beach flora and dunes is enforced; conducting regular septic tank inspections to ensure leeching into marine systems is limited; protection of mangroves and salt ponds important for sediment/nutrient entrapment; a full assessment of terrestrial pollution sources, especially the Corito Bay landfill site; and regulations that relate to connecting salt ponds to the ocean via subterranean pipes. Some of these factors/issues will need to be incorporated into new legislative revisions, and be the subject of separate management plans that should incorporate the goals laid out in the current document. Furthermore, the ANT and DoE will be encouraged by DFMR (in terms of help offered) to continue with any enhancement/rehabilitation programs within marine park terrestrial zones conducted in the past, for example: recent rat eradications on Dog Island (ANT, 2012); and bird/salt pond research island wide (Johnson *et al.*, 2014; Lloyd & Mukhida, 2014). If cooperation is possible with land owners a fully integrated management model is beneficial to be adopted
- The Cruising Permits Act: Although not under DFMR jurisdiction it will be necessary to make some minor amendments to the Cruising Permits Act in order for it to harmonise with the Marine Parks Act and the recommendations within this management plan. The typographical error naming Great Bay as a no anchoring zone needs to be updated, and it is suggested that, due to how circumstances have developed over the years, Rendezvous Bay no longer be classified as a no anchoring area, with anchoring merely restricted in the western end of the bay.

- Continuation of DFMR work: The importance of the work conducted by DFMR as it relates to this management plan cannot be overstated and as such all of their current programmes should continue. Aside from day-to-day Departmental duties these include, but are not limited to: annual seagrass and reef monitoring at fifteen sites; installation and maintenance of mooring fields within the marine parks; quarterly beach monitoring at over sixty sites; collection of fish catch data from landing sites around Anguilla; weekly in-water turtle population assessments; lionfish eradication from reported hot-spots; and at least one other independently conducted research project per year. These latter annual projects are chosen depending on perceived prioritisation by the Department with considerations given to resource constraints. Suggested projects for the coming years can be found in the time-line in the following Section. Current priorities are fisheries assessments and the encouragement of fishers to move away from trap-fishing and spear-fishing on shallow reef areas and towards exploitation of pelagic and/or deeper water fisheries. Budget and manpower increases would greatly aid this work load while at the same time allowing effective surveillance of AMMA to take place. This surveillance, which for full effectiveness will require an additional vessel at some point in the future, is essential for the success of this management plan.

Section 6: Time-line & Implementation of Management Plan 2015-2025

This time frame has been chosen as it ties in with the vision developed by DFMR staff for the fisheries sector in Anguilla, the proposed lead agency for the implementation of this plan.

DFMR 'Vision 2025' is “a respected fisheries sector with informed fishers, fishing in a sustainable manner utilising improved fishing facilities and boats, supported by a Department of Fisheries and Marine Resources that impacts positively on all publics and manages the sector, in a participatory way, for the benefit of all stakeholders.” (from Fisheries Management Training Workshop 28th April 2008). It is felt the Marine Park System is an integral part of achieving this vision.

The stages are laid down following the model described in chapter 4, recognising that with the case of Anguilla Stages 1 through 3 have already been completed and so Stage 4 (Adaptive Management) is now being entered. At the end of each year a review of the progress made towards management goals will take place, along with the identification of any recommendations as they relate to adaptations and work priorities for the following year. At this

time an 'interim' version of the management plan will be produced that incorporates these adaptive updates and inserts all achievements into a tabulated time-line. This will provide a documented chronology on the management plans development, its successes and/or failures, and pave the way for improved decisions making capacity on into the future. This time-line is presented below in a bulleted form, but it is suggested that when this plan becomes finalised it is presented in tabular format to facilitate the insertion of progress updates.

2015

- DFMR to produce draft management plan and submit for initial review with non-stakeholder experts and/or consultants. DFMR to update management plan as necessary.
- DFMR to draft and submit legislative amendments as they relate to marine parks and associated fisheries and shallow water habitats.
- Develop a Fisheries Development Plan which will act as a sister document to this management plan and pave the way to move the fisheries sector away from the current over exploitation of near-shore and/or shallow reef areas, and develop the currently under exploited deeper water and/or pelagic fisheries resources.
- Distribution of new draft of management plan among all DFMR staff, ANT, DoE and other departments as necessary, with discussions related to management plan contents and any further amendments needed. Identification of key stakeholder groups and representatives from these groups that will be invited to join future meetings and/or workshops before wider town hall style stakeholder meetings are held.
- Workshop/meetings on MPA development strategies held by key DFMR staff with stakeholders invited, which will incorporate final review of management plan. All feedback received to be addressed and final 2015 draft of plan produced.
- DFMR to conduct rapid assessment of Sombrero Island marine habitats and report produced with recommendations for management.
- Queen Conch (*Lobatus gigas*) fishery assessment to be conducted by DFMR, including population assessments and collection of targeted landing data.
- Fish-trap distribution study and collection of data via DFMR fish catch data collection and landing site patrols to establish general understanding of numbers of fishers who currently fish within marine park boundaries.

- DFMR to conduct island-wide lionfish (*Pterois volitans*) population studies and re-assess Lionfish Response Plan.
- Feasibility studies and/or funding proposals for the development of underwater attractions for both tourism enhancement and fisheries enhancement within the marine parks, for example wrecks, lobster casitas, underwater sculptures etc.
- Production of public awareness materials to sensitise public about new legislation: for example, posters depicting recommended minimum landing sizes for all relevant species and explanation how minimum landing sizes can help sustain fish populations for future generations.

2016

- Research, demonstrations and outreach produced to publicise vertical long-line fishing method to develop deep water snapper fishery, and other deep water/pelagic fisheries.
- DFMR to continue pushing for new legislation as necessary. Relevant agencies to conduct literature reviews as needed to justify changes. This should include at this stage those amendments that may be needed in terms of setbacks, beach flora removal and septic tank integrity. It may also be relevant at this stage for DoE, in consultation with the ANT, to draft legislative amendments as they relate to terrestrial areas.
- Installation of marine park boundary marker buoys, primarily around Prickly Pear, Sandy Island and Little Bay Marine Parks. These three areas have been identified as a priority due to high tourist boat traffic in the area.
- Spiny lobster (*Panulirus argus*) fishery assessment to be conducted by DFMR including population assessments; map of lobster grounds visited by fishers; and collection of targeted landing data (including CPUE). Include stakeholder opinion surveys on closed season and closed areas.
- Meeting to discuss and propose water activity zones within AMMA. Initial zones to be discussed are swimming areas where bathers are safe from other water craft within the marine parks. The areas are not to be legislated, just buoyed.
- Produce public awareness materials to sensitise public about new legislation: posters depicting Anguilla's Marine Park System and associated shallow water habitats, together with recommended practices to conserve these resources for future generations.

2017

- Undertake a ten year re-evaluation of the thirty baseline sites within the Marine Park System, if possible using original survey team (DFMR & ANT). Report produced and new management recommendations made.
- DFMR to continue pushing for new legislation if the necessary changes still haven't been made.
- Training of Fisheries Officers and other officials as necessary to prepare them for surveillance and enforcement of new legislation.
- Meeting to discuss findings of 'ten years on' study and other monitoring work, and discussion as to the need for a revised management plan. Production of interim report, or if necessary adapted management plan based of the findings of the last three years.

2018-2020:

- Begin increased surveillance & enforcement of new/existing legislation to begin within Marine Park System in combination with public awareness campaigns and stakeholder meetings headed by DFMR.
- DFMR to produce proposals for rapid assessment of offshore areas (for example Old England fishing grounds) to facilitate their potential inclusion within future adaptations of management plan, or to better manage them under the Fisheries Development Plan. Consideration given to expand the size of the Anguilla Marine Management Area (AMMA) to include these areas. This will only be possible if funding can be found to increase DFMR surveillance capabilities.
- Continued monitoring and assessment of all management plan facets including the consideration of other areas being included under increased protection. Suggested examples potentially being Scrub Island, Limestone-Black Garden Bays and Anguillita-Blowing Rock. Report produced.
- Further meetings at all stages as necessary with the production of interim annual reports, or if necessary adapted management plan based of the findings of the last three years.

2021-2025:

- Assessment of compliance rates of new legislation and socio-economic monitoring of positive/negative effects and opinions. Report produced.
- Establishment of new management areas within AMMA based on the results of area assessment conducted previously.
- Continued monitoring and assessment of all management plan facets with stakeholder meetings to discuss progress and suggestions.
- Development of a 2025-2035 AMMA management plan encompassing all the progress made over the last ten years and directions for future goals.

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Chapter 6

Final Discussion

Final Discussion

Region-wide habitat degradation across Caribbean coral reefs has been documented for a number of decades (Gardner *et al* 2003; Paddock *et al.*, 2009). Of the proposed causes of this, eutrophication is sometimes downplayed in significance (Koop *et al.*, 2001; Szmant, 2003) or only cited as influential where a local nutrient source effects local ecology (Lapointe *et al.*, 1997; Goreau, 2008), at times in combination with other factors such as overfishing (Jessen *et al.*, 2014) or paucity of key herbivores such as *Diadema antillarum* (Liddell, 1986; Lapointe, 1999). Recent evidence however suggests that eutrophication may be affecting the Caribbean on a more regional scale (Gower *et al.*, 2013; Johns *et al.*, 2014), where large annual sources of nutrients enter the region producing effects in areas where local nutrient inputs are minimal. There is also recent evidence that these nutrient rich waters may in part become trapped or recycled back into the Caribbean region, thus producing a slow build-up of nutrients over time (Jury, 2011). This background buildup of nutrients would explain some of the signs of eutrophication recorded in Anguilla (British West Indies) over recent years. Anguilla has no industry or dense urban centers, and little agriculture, thus local sources of nutrients are limited to: a small number of aging septic tanks that may be leeching into the ocean; a landfill site that is relatively close to the coast; and salt ponds that are either permanently or sporadically connected to the sea. The signs of eutrophication in Anguilla are wide ranging, from so called ‘Green Water Events’ (GWE) to algal proliferations and increased incidence of disease (see Appendix 1 for photographic examples).

Although it is recognized that there are a great many potential sources for this regional scale eutrophication, which includes myriad small local point sources, it is proposed that much of that potentially emanating from the Gulf of Mexico and American Gulf States passes through the Florida Straits and into the Atlantic Ocean²⁰. Here it enters the North Atlantic Gyre, feeding blooms of pelagic Sargassum that give this area its name, the Sargasso Sea. A different situation entirely takes place for nutrients emanating from the coast of South America, especially the huge river plumes from both the Orinoco and Amazon rivers. These plumes combine and travel northwards along the Leeward Island chain gradually dispersing to the west into the Caribbean basin (Fratantoni & Richardson, 2006). This phenomenon has been known since at least 1979 when the first satellite images of it became available (Muller-Karger, 1979). Although the full implications of it are only now beginning to be recognized, it has also long been known that

²⁰ As such these sources are suggested to have little to no influence on the Caribbean

these river plumes influence the productivity of the area. For example, Mahon (1993) summarises the oceanography of the Lesser Antilles region and notes the importance of the outflow plumes from the Orinoco and Amazon rivers in determining local productivity. The paper goes on to state that this is likely to be a major determinant of fish distribution, probably accounting for the apparent higher and more predictable abundance of Yellowfin Tuna and other species in the southern part of the region.

Over the last decade there has been growing evidence that increased levels of nutrients may increase the severity and likelihood of various coral diseases (Bruno *et al.*, 2003; Thurber *et al.*, 2013), which is interesting to consider in terms of the South American river plumes. According to limited records White Band Disease first affected the USVI and neighboring Anguilla in 1976 (Peters *et al.*, 1983; Bythell & Buchan, 1996) and was responsible for the widespread die-out of *Acropora palmata* and *Acropora cervicornis* throughout the region (Aronson & Precht, 2001). This timing correlates closely to when deforestation started to impact the Amazon basin, and when an increasing amount of nutrients would have entered the Caribbean due to increased rain water run-off and fertilizer use through agriculture. Historically, although these plumes would have been more nutrient rich than the waters in the Caribbean, entrapment by forest flora and an overall lack of intensive agriculture means it would have been minimal and somewhat naturally regulated. This deforestation is recorded to have begun in the late 1960's, although figures prior to 1977 are limited and those presented for the years 1978-1987 are grouped together as annual averages (FAO, 2015). By 2005 overall deforestation rates in the Brazilian Amazon begin dramatically declining in terms of large scale plot clearing, although rates for plots <25 hectares have remained relatively stable since before 2002 (INPE, 2014). It follows that although overall rates have declined, area clearance for agriculture is still occurring, and thus nutrient inputs into the Amazon River still increasing, especially in light of potential increases in agricultural intensity and changes in livestock vs arable farming ratios.

Whatever the case is in terms of an increase in nutrient levels in the river plumes, events that have occurred during the current decade seem to suggest that a threshold has been reached: in 2009 and 2010 notable GWE occurred that spread northwards across the Caribbean beyond 18°N (Johns *et al.*, 2014); and unprecedented *Sargassum spp.* blooms occurred in 2011 and 2014/15 that all reportedly originated from the Orinoco and Amazon river plumes (Gower *et al.*, 2013). This, when combined with the recirculation theory proposed in chapter 1 that provides a mechanism for a regional build-up of nutrients, suggests that these events signify the verge of a phase-shift within the region. This phase-shift from oligotrophic to eutrophic regional conditions

has the potential to increase the severity of the first reported Caribbean phase-shift: that between corals and algae (Aronson & Precht, 2001), which has predominantly been attributed to local sources of nutrient input and overfishing/loss of key herbivores (Angelo & Wiedenmann, 2014). Such a phase shift will involve a dramatic reduction in water quality and clarity that has the potential to reduce Caribbean reefs to the weedy tolerant species of Scleractin corals (Côté & Darling, 2010), Octocorallia, or other non-reef building Hydrozoan/Anthozoan coral species.

This phase shift will have dramatic implications for management. First and foremost, as the nutrients are arriving from a regional background source, management can only be mitigative, as it is against other regional increases in sea surface temperature or future changes in terms of ocean acidification. Overall, increasing reef resilience is considered key, despite some studies stating otherwise (Côté & Darling, 2010). However, as in all cases, before management measures are implemented it is key to first establish the regular collection of ecological data. This should aim to fill any knowledge gaps and allow the undertaking of a threat assessment to study which (if any) threats can be managed in a way that may lead to an increase in this resilience.

Anguilla, as with many small island developing nations, has financial and logistical limitations that mean that these important steps are often a challenge to achieve. Due to this, protected areas that could be used as key managerial units for 'resilience reserves' often remain as 'paper parks' in that management measures are limited or unsuitable to achieve overall goals. The former was the case in Anguilla where a network of marine parks had been created in the early 1990's, but since then limited ecological data had been collected and no new management measures introduced. By developing a protocol that maximized human resources while minimizing financial burden, the Department of Fisheries and Marine Resources in Anguilla initiated the Anguilla Marine Monitoring Programme in 2007. This programme served to collect a suite of ecological data both inside and outside of the protected areas, and designed in such a way as to be time efficient and thus allow multi-tasking in combination with other Departmental work. Upon analysing four years of data collected and comparing with best professional judgement of the areas surveyed (chapter 2), it was possible to propose a protocol that other small island nations with similar limitations could follow that only relied on collecting five reef habitat variables. These variables, although seemingly obvious, have yet to be justified and used in such a way in the scientific literature. They are: low coral cover; high macro algae cover; lower than expected reef fish size, abundance, and overall species diversity. In the past it has been problematic to use variables in this was due to lacking historical data, and attempting to use data

from other islands becomes problematic due to varying environmental conditions. The protocol developed overcomes these limitations by establishing a “Relative Health Percentage”, where variables collected are assessed as a percentage score of the highest (and therefore healthiest) value recorded across sites. Thus sites can be ranked compared to one another and conservation priorities identified. Over time as monitoring continues, temporal changes will become clear and historical assumptions able to be inferred. One of the main advantages of this protocol in terms of outcome is that it is not necessary to wait for these temporal inferences before management recommendations can be made. In the case of Anguilla it was found that reef fish are smaller and less abundant than one might expect at healthy sites and that coral cover is low and macroalgae high. This points to a downward cascade (even when not considering regional background eutrophication) where herbivorous species of reef fish are overfished and so coral has reduced chance of competing with faster growing macroalgae. With added eutrophic conditions this situation will be accentuated, as illustrated recently by Suchley *et al.* (2006). In this paper data from eighty five long-term monitoring sites on Mesoamerican reefs were analysed and found that 48% of them exhibited an increase in macroalgae cover even though herbivorous fish biomass also increased. Their conclusion was that these results were primarily due to nutrient enrichment and the relative importance of nutrient availability over herbivory, although data relating to such variables were not available. However, once again this study concluded the nutrients in question would be derived from urban and agricultural run-off, and no consideration given to an additive effect from regional sources.

In a similar way to ecological assessments, fishery assessments are often prohibitively expensive and so not undertaken by small island nations with limited financial and logistical resources. Such assessments provide important information for economically or ecologically important species, but can also provide insights into management of wider habitat types, including those within protected areas. Again, a methodology was developed that would allow assessment of an understudied yet important fishery resource on Anguilla, that of the Spotted Spiny Lobster (*Panulirus guttatus*). By building up a rapport with local fishers and restaurant owners a minimally invasive research protocol was developed that only measured three variables (chapter 3) to assess size at maturity, breeding seasons and catchability within the fishery. This method can be easily adopted by other Caribbean islands with a similar fishery, or used for other future lobster fishery assessments, for example that of the Caribbean Spiny Lobster (*Panulirus argus*). The assessment also yielded some important insights into management of the fishery and local protected areas in terms of setting minimum size limits, closed seasons and/or closed areas.

Once the collection of ecological data and key fishery data has taken place, the next challenge is assimilating this information into justifiable management decisions by identifying the mitigative measures that might be the most effective. To do this, threats need to be identified and assessed: both in terms of if they are a real threat; and if they are a real threat that can actively be managed against. This process is key, and if not conducted can lead to ineffective management measures that are potentially a waste of financial and logistical resources in an already limited scenario. In the case of Anguilla a framework was suggested that managers could follow to enable a systematic threat assessment prior to the production of a management plan. This framework can be followed in virtually all managerial situations. Indeed there are parallels with processes such as the European Marine Strategy Framework. Under the MSFD there is an assessment of status including an evaluation of threats (or ‘pressures’). The MSFD is broader than the approach in the current thesis in that there are more pressures considered (e.g., noise) and an attempt to define quantitative indicators of status (rather than a prioritization of sites for action). It remains to be seen how effectively the MSFD will work as indicators with links to status judgments are still being developed and the development of management (‘programmes of measures’) are behind schedule in most member states²¹. As systematic assessment can be related to the establishment and successful management of marine protected areas, in turn each potential threat identified through ecological monitoring is assessed for severity and possible beneficial management measures tested. Chapter 4 presented examples of this process where:

- i) Threat of low coral recruitment was identified and tested via placement of terracotta tiles. Recruitment was found to be low on the south side compared to the north side of Anguilla. Thus resilience measures are best introduced on the north side reefs where natural recruitment is most likely.
- ii) Threat of poor water quality was identified and tested via water sampling. A protocol was developed in partnership with a local coastal hotel development to reduce costs and the need for staff training. Of the variables tested nitrate and phosphate levels were elevated and turbidity higher on the south side than on the north side, possibly explaining recruitment results. It was confirmed that nutrient levels were high enough to be considered eutrophic, and that this is island wide suggesting a background, regional source. Results from salinity measures suggest the island might be influenced by two different water bodies, which affect Anguilla to varying degrees depending on weather forcing or seasonality.

²¹ http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/scoreboard_en.htm

- iii) Threat of reduced herbivores was identified, particularly (aside from reef fish herbivores) *Diadema antillarum* that has yet to fully recover after the 1980's mass mortality event. Logistically easy and financially viable methodology tested to translocate individuals from a threatened habitat to areas with *D. antillarum* paucity. The experiment was a success although some mortality was observed so it was only recommended to pursue if further healthy populations were threatened by coastal development.
- iv) Threat of reduced coral cover and increased macroalgae cover was identified, and tested by undertaking a comparative study. A limited ecological assessment was conducted in 1990 prior to the establishment of Anguilla's Marine Park System. A 68% hard coral loss was recorded between study periods, although macroalgae had remained relatively unchanged. As most study sites were however on the south coast robust ecological conclusions were not possible, although results do corroborate previous conclusions relating to north vs south coast overall health.
- v) Threat of limited legislation was identified, with Anguilla's current legislation concluded to be lacking when compared to other parts of the Caribbean, especially that under U.S. control. A list of legislative amendments were proposed that would form the backbone of future managerial priorities and the development of a marine management plan for Anguilla.

In terms of applying the results of the threat assessment to the management of coral reefs and associated habitats in the Caribbean it is interesting to note that there are still a number of competing hypotheses that attempt to account for the lack of recovery in the region after disturbance events (storm damage, disease outbreaks etc). The hypotheses are an attempt to address the failures of reef resilience that has led to coral cover loss and overall habitat degradation in Caribbean on a level that is not observed in other reef areas around the world (Roff & Mumby, 2012; Pawlik *et al.*, 2016). For example, Roff and Mumby (2012) found, following a meta-analysis of 41 multi-year studies in the Indo-Pacific and 74 from the Caribbean that 46% of those in the Pacific showed recovery, but none did from the Caribbean. They go on to offer six different (sometimes interlinked) hypotheses that might account for this lack of resilience:

- i) Lack of fast growing coral species to out-grow algae. For example, there are only two species of *Acropora* in the Caribbean as opposed to 30 in the Indo-Pacific.

- ii) Lack of herbivorous fish diversity. For example, there are only three species of surgeonfish (Acanthuridae) in the Caribbean as opposed to 84 in the Indo-Pacific.
- iii) Potential for faster recruitment of algal propagules onto bare rock in the Caribbean than in the Indo-Pacific.
- iv) More nutrients available in Caribbean waters that enable faster growth rates of algae than in more nutrient poor regions.
- v) Increased trace elements such as Iron important for algae growth may be more available in the Caribbean region due to input from African dust.
- vi) A higher absolute rate of grazing in the Indo-Pacific due to differences in composition and abundance of overall fish community structure.

Pawlik *et al.* (2016) adds to this list of six hypotheses based on the results of studies that do not fit criteria for those suggested by Roff and Mumby (2102). For example, where algal growth was seen to be independent of herbivorous fish abundance (as in the previously mentioned study by Suchley *et al.*, 2016) or may even have been enhanced where fish were prolific due to their excreted nutrients that may facilitate algae growth. Their main hypothesis is based around the fact that sponges are typically more abundant on Caribbean reefs than in the Pacific, and that they are mostly heterotrophic, while those in the Pacific are predominantly phototrophic. They introduce the concept of a ‘sponge loop’ where sponges metabolise dissolved organic carbon (DOC) and release particulate organic carbon (POC) through cellular detritus. This POC is then consumed by corals and other detritus-feeding invertebrates that in turn release more DOC.

Pawlik *et al.* (2016) then goes on to point out that sponges can metabolize certain forms of DOC that are common in river water and not easily utilized by plankton or other marine organisms. These types of DOC are much more common in the Caribbean than the Pacific due to inputs from three major rivers: the Mississippi, Amazon and Orinoco. This provides a previously unappreciated mechanism for importing organic carbon to the reef system that, when combined with other trace nutrients arriving via African dust, enhances possible metabolic rates for various organisms, including algae. The conclusion by Pawlik *et al.* (2016) is that, due to the higher abundance of sponges, the Caribbean is more trophically dynamic than the Pacific and algae are capable of growing more rapidly as a result. This will especially be the case if herbivore numbers have been artificially reduced by fishing or disease, but that in the more nutrient limited Pacific, even if herbivory is reduced in a similar way, algae cannot grow as aggressively.

In terms of Anguilla, it certainly seems that one hypothesis does not ‘fit all’ and that in fact it is a combination of all (or most) hypotheses that has led to the observed situation. Either way, based

on the previous chapters of this thesis it is clear that the greatest challenge to coral reef management in the Caribbean, and the protected areas they exist in, are effects of eutrophication and its ultimate influence on habitat degradation. These effects may be further accentuated by synergisms with other variables, although as discussed in chapter 4, these interactions are often difficult to discern, possibly due to a lack of data (Ban *et al.*, 2014), or the interactions are less common than might be expected (Côté *et al.*, 2016). Where stresses occur at different scales, it may be difficult to separate them and identify interactions. For example, regional eutrophication has a number of effects that can interact with more local processes in different ways and there are no controls for the non-eutrophic case. Even so, from the observable evidence in locations such as Anguilla, where run-away habitat degradation appears to be occurring, such interactions seem likely and so the precautionary principle should be applied when it comes to management. Indeed, in the past much emphasis has been placed on bleaching events (and therefore increasing sea surface temperature) combined with over-fishing being the main driving force behind habitat degradation (Côté & Darling, 2010), although from an Anguillian standpoint this does not appear to be the case. Over the last decade, only minimal bleaching has been recorded (one or two scattered colonies – S.Wynne, pers.obs.) despite reports of ‘global’ bleaching events occurring in 2010 and 2015 (NOAA, 2015). This time span also includes the Caribbean’s 2005 ‘major’ coral bleaching event (Wilkinson & Souter, 2008) that was focused around the northern Antilles, although many of the bleaching reports made at the time were qualitative. The same applied in Anguilla, where even though some bleaching was observed no quantitative data were collected as the event took place before regular survey work had been initiated. This highlights the importance of regular ecological monitoring and the value of the programme that began in Anguilla in 2007. Even so, from the qualitative data available for Anguilla, what has become clear is that even the ‘major’ 2005 bleaching event caused, at worst, only minor damage to the living coral resources here. This damage appears far less detrimental to the remaining hermatypic corals in the region than those attributed to elevated nutrients as presented in Appendix 1.

For this reason it was concluded that the greatest challenge facing the management of Anguilla’s marine resources, would be how to mitigate against those effects of eutrophication that are not due to manageable local factors. The topic of mitigating against regional stressors on a local level has become one of controversy over recent months however with the publication of a paper by Bruno and Valdivia (2016). This paper notes that the global decline of reef-building corals is thought to be a combination of local and regional stressors (or in this case global), but goes on to conclude that local management alone cannot increase the resilience of reefs to large-scale

impacts. Whilst this thesis recognizes the need to encourage international intervention and regional policies, it is felt counter-productive to suggest to decision makers that local management does not serve an important purpose. The Bruno and Valdivia paper makes these conclusions by failing to correlate reef degradation with nearby human population density, combined with the absence of a signal of local impacts. This approach is essentially describing the Anguilla situation, where reef decline is accompanied by low population densities. However, the global scale of the analysis and associated variations between sub-regions, combined with management regimes within sub-regions not being taken into consideration, mean these conclusions are tentative at best. With regional stressors such as eutrophication being gradually recognized as having a deeply entrenched effect on corals, not just through observable interactions such as macroalgae competition, but also on early life history stages (Humanes *et al.*, 2016), downplaying local management in this way could be highly damaging. In small island nations where limited financial and logistical resources mean management measures are already treated with skepticism in terms of cost-benefit payoffs, any doubt in efficacy placed in the minds of decision makers will mean even the simplest recommendations stand a high chance of rejection.

Chapter 5 presents a management plan that attempts to address this problem in a way that may be applied to other Caribbean small island nations in a similar situation. The key to the proposed strategy is one of minimizing financial and logistical constraints while promoting simplicity: where data gaps have been filled in the most cost effective ways and the current marine parks are used as core managerial units, with other associated shallow water habitats and fisheries also considered as integral units. Simplicity is key, as over complicated systems with elaborate zoning schemes and regulatory mechanisms are liable to fail due to stakeholder confusion and implementation challenges. Where possible, although each marine park will be considered a zone within its own right (in terms of long-term goals and user orientation), each is proposed to be legally bound by common legislation. To further simplify implementation, current legislation was proposed to be amended rather than new legislation established. Beyond the existing marine parks two further zones were proposed. The first of these was suggested to encompass shallow coastal regions (<10 m) and serve as a corridor between some of the marine park zones and be where enforcement of regulations is initially concentrated. As with all other marine areas, this zone would be regulated under existing legislation that only needs slight amendments to achieve overall area goals. The second zone was to encompass further offshore areas, but those within a close enough distance to the mainland that they can still be regularly patrolled by enforcement vessels.

In terms of direct management, a three-pronged approach was used. First and foremost it would be necessary to establish if there are any notable leeching sources, especially from aging septic tanks. A septic tank policy was suggested to address this. Secondly, in line with ridge-to-reef principles, removal of beach vegetation, set-back zones for coastal development, and agricultural development were all given consideration. The final aspect were in-water considerations, with limitations to fishing within marine parks, minimum sizes for many reef fish species, user restrictions (anchoring, charter boat waste water dumping etc), and fine tuning of certain fishing gear usage throughout all of Anguilla's waters. Due to the regional scope of the threat, little more can be done in terms of management. Despite the potential for coral restoration efforts to aid recovery, in the case of Anguilla it was felt that until decreases in coral diseases and algal growth are observed, such endeavors will likely prove a waste of the already limited financial and logistical resources available. It was concluded far more realistic in terms of success to focus on fisheries enhancement measures for the marine parks (once fully protected), so that they could seed surrounding areas. Such measures include lobster casita and other artificial structures that would serve as fish aggregation devices. Such features could also form snorkeling trails and provide a revenue stream that could help finance the increased surveillance and enforcement that would be necessary.

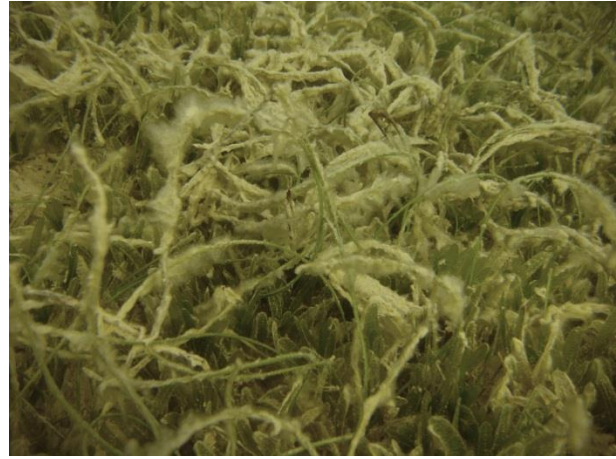
The ultimate success of this plan will only be discerned with time. However, as an important first step, the management document was accepted by the Anguillian Executive Council as an official policy document in May 2016. This marks a ground breaking moment for marine biodiversity conservation in Anguilla, as it is the first such management document on record to reach this stage. It is hoped that the processes followed to get to this point can act as a model in other parts of the Caribbean, or indeed other small island nations around the globe.

Appendix 1

Signs of eutrophication in Anguilla. All photographs taken by the author.



Algae covered reefs/rocks: These images were all taken in different areas in and around Shoal Bay and Island Harbour Marine Park in 2007 and 2008. Highlighted in the top left image is a high level of macroalgae despite the presence of numerous herbivorous fish. In other sandy areas, such as that pictured in the bottom right image, *Dictyota sp.* (one of the most prolific genera growing on Anguilla's reef systems) is free floating but still appears to be thriving.



Algae and cyanobacteria on seagrass: Fine filamentous green algae growing on seagrasses in Island Harbour in 2007 and cyanobacteria growth on those in Crocus Bay in 2016. As illustrated, these growths often completely smother the seagrass which will ultimately restrict its capacity to photosynthesise.



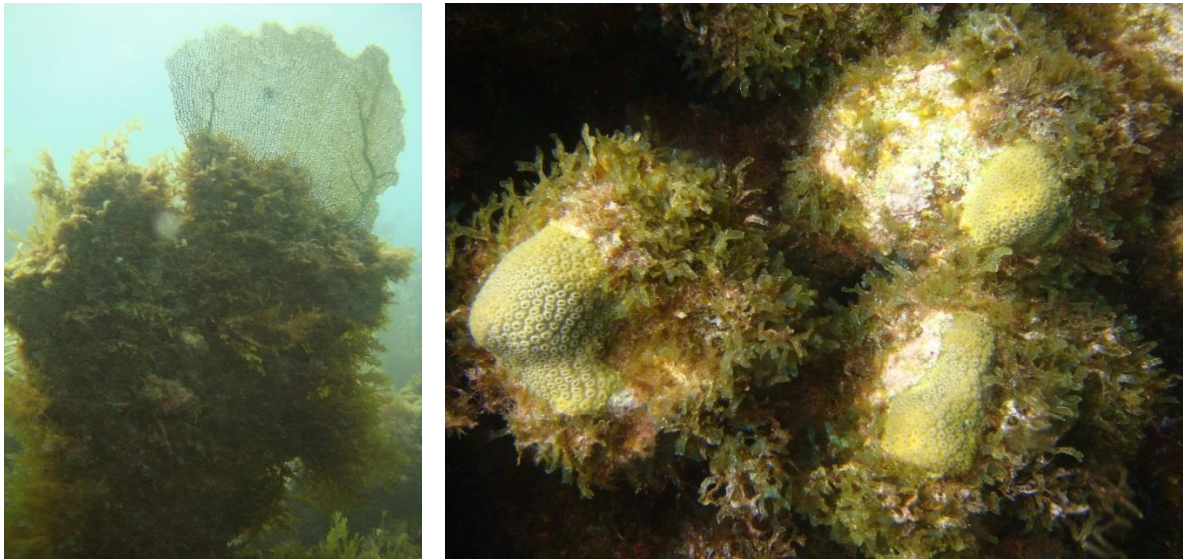
Filamentous green algae growth: On occasion unprecedented amounts of this algae appear from nowhere, as on this occasion in June 2008 at Sandy Ground.



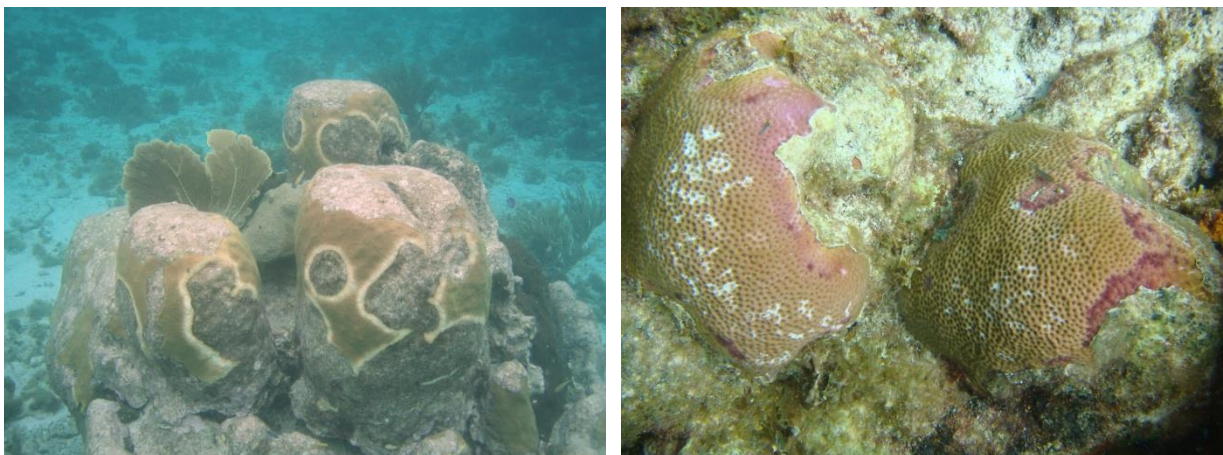
Green water events: Minor localized green water events are becoming a regular occurrence in Anguilla, as illustrated in the right hand image photographed in Little Bay Marine Park in October 2015. One severe regionally based green water event has so far affected Anguilla, as illustrated in the left hand image taken at Anguillita Island in July 2010.



Sargassum inundations: The first recorded notable event happened region-wide in 2011. In 2014 the second such event took place and continued on into 2015 as pictured above at Forest Bay in July 2015 (right) and Dog Island in September 2015 (left). By the end of the year inundations had reduced in severity, although they still continued on until mid-2016.



Algae overgrowth: Two examples of algae overgrowing and smothering of both soft and hard corals at Island Harbour Reef (left) in June 2016 and Sile Bay (right) in June 2010.



Coral disease and/or infections: Over the years coral disease has become a common sight in Anguilla, and now affects all species, including those that were once though resistant to these conditions such as *Porites astreoides*. Pictured here is Yellow Blotch Disease on *Orbicella annularis* in 2007 and an unidentified syndrome affecting *Siderastrea siderea* in 2010. More illustrated examples are presented in chapter 1 or can also be obtained by contacting the author.

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