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# Developing an Ecologically Based Rapid Site Ranking Tool to Identify Coral Reef Habitat Health Gradients and Conservation Priority Areas in Anguilla, British West Indies

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ABSTRACT

Ecological monitoring is an essential precursor when developing comprehensive management plans for marine protected areas and their surrounding habitats. In small island nations that lack historical baseline datasets, ongoing monitoring programmes, and associated threat assessments, paper park scenarios are common, with marine protected areas usually existing under little or no effective management. This is often due to limited resources and other constraints. To address this, a ranking 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. Although a close relationship was found between the ten variable model and BPJ, it was concluded that 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 habitat health gradient maps. In the absence of a full suite of ecological data, these maps will allow informed management decisions to be made when designating conservation areas and protection levels, 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, due to potential 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). Often, 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, papers parks could 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 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 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 took place. This was 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 locating the 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 Wynne (2015) 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 monitoring beyond that conducted by Oxenford & Hunte, and was never officially adopted. Furthermore, a disparity of data between parks existed as Little Bay and Dog Island were the only designated parks that were surveyed during the Oxenford & Hunte (1990) study.

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: ensure all research staff were properly trained; begin the development of a monitoring methodology that would be feasible given financial and logistical constraints; and assess areas to prioritise for proposed ecological monitoring. This monitoring was planned to encompass not just the marine parks, but also other nearshore shallow water habitats. The ultimate aim for the proposed ecological monitoring was threefold: establish a reliable baseline dataset for fifteen sites around the island that would permit future temporal analysis; reignite managerial processes within the marine parks and surrounding shallow water habitats; identify conservation priorities and any knowledge gaps that may inhibit managerial effectiveness.

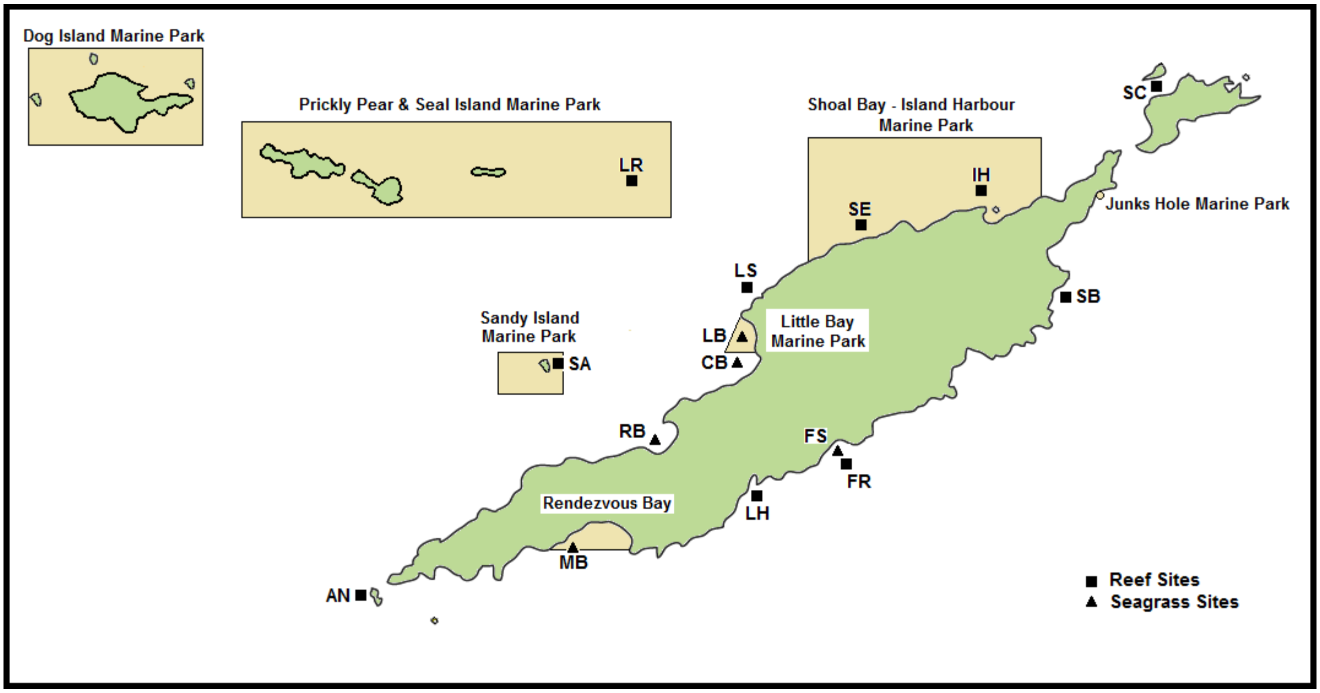


**Figure 1:** Map of Anguilla showing location of marine parks and study sites: Triangles represent seagrass sites (LB=Little Bay, CB=Crocus Bay, RB=Road Bay, MB=Merrywing Bay, FS=Forest Bay); and squares reef sites (SC=Scrub Island, IH=Island Harbour, SE=Shoal Bay East, LR=Long Reef, LS=Limestone Bay, SA=Sandy Island, AN=Anguillita Island, LH=Little Harbour, FR=Forest Bay, SB=Sile Bay).

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 paper 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 paper 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 (Shin *et al.*, 2005).

## Methods

*Protocol Development and Site Establishment*

A survey protocol was developed in 2007 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.

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 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.

Note: The initial four years of study that this paper covers (2007-2010) also included 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' (pipes cut to known length and placed underwater). It was essential to ensure that staff would be able to continue monitoring and train future staff after the initial four year study period was completed. For these reasons data collected during the pilot study (Wynne, 2008) were not used within the ranking tool assessment. Although monitoring continues to the present day (Wynne, 2017), only those data collected during these initial three years were used for this assessment so as to represent the original baseline situation.

*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 perpendicular to the coast and one 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. 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 using the 2007-2010 data alone. The present work assessed various ranking models for their suitability, using best professional judgement (BPJ) and an understanding of ecosystem function to find a balance between model reliability and the least amount of variables needed to achievable this.

To conduct the assessment of the protocol ten ecological variables were chosen for analysis. Variables were selected for inclusion if they were perceived to have the potential to serve as a habitat 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. In other words, 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 RHP) to 10 (highest 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 used to assessed overall ecosystem health, and to explore the protocol's use as a stand-alone fish analysis tool. Finally, research staff were asked to rank the sites from 1 to 10 in order of health. These ranks were combined to produce a 'perceived' health rank for each site, 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.

Note: It is important to appreciate that all models produce 'relative' health results, not 'absolute' values. Also, it should be noted that this analysis was primarily conducted on the ten reef sites only, but ultimately, with a little modification, it may prove viable for use on seagrass sites also.

**Results**

The scores of survey variables relative to the highest RHP values seen are shown in table 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. Table 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 presents a visual representation of these scores. From the results in table 2, figure 3 was produced to illustrate proposed ecosystem health categories (or zones) and thus provides a visualisation of health gradients around Anguilla's coastal and shallow water areas.

**Table 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 2nd highest RHP, and pale orange 3rd 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:** Reef ranking analysis presenting final RHP values and RHI rank obtained from the health ranking analysis (table 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 |

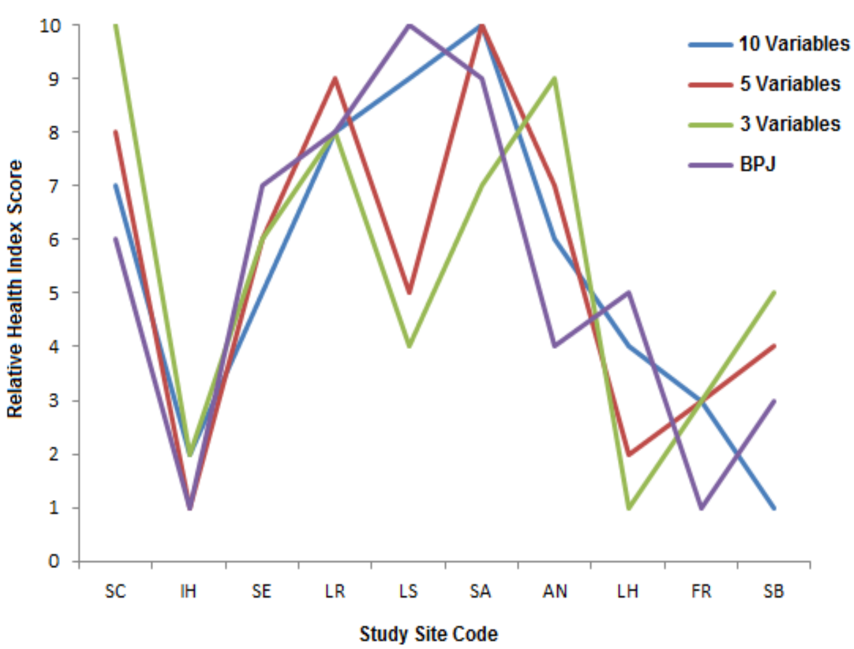


**Figure 2:** Relationships between variable treatments and BPJ. Generally correlations between treatments are high, but weakest were between 10 and 3 variables and BPJ and 3 variables. This illustrates confounding/conflicting information associated with increased number of substratum variables as discussed in the following ranking tool evaluation. The close association between 10 variables and BPJ is also likely due to this reason.

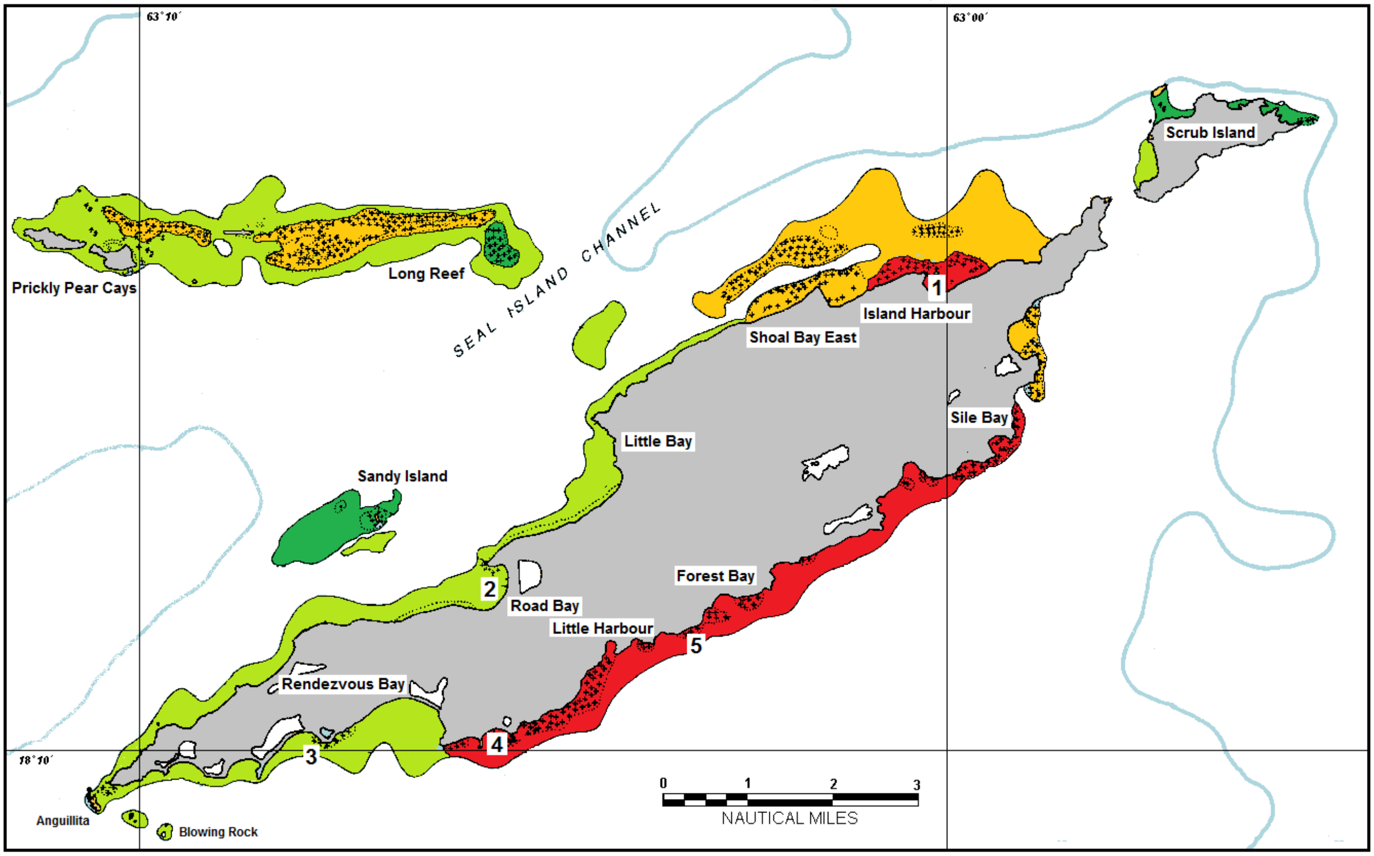


**Figure 3:** Ecosystem health zoning around Anguilla based on RHP analysis. Only areas in water <10 m were assessed, with health zones split into four categories: red - high level of degradation (RHP <60%); orange - moderately high level of degradation (RHP 60-70%); pale green - moderate level of degradation (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 potentially. 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 could potentially be less likely to have 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 (figure 2). 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 BPJ, 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 mean a ranking of 9 is not realistic. By examining raw data (not presented) 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. 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, 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 when fisheries management decisions are needed in marine park areas. For example, identifying sites with the 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.

Interestingly, in a similar way, experts familiar with the study areas 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 extensive study, is still open to much debate. For example, there is potential for researchers to consider high biota cover as to constitute a 'healthy' habitat, compared to those sites 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 for 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 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 will enable them to conduct targeted research work quickly and relatively cheaply, 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 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 since the study by Oxenford & Hunte in 1990 was completed, where anecdotal reports of decreasing health in south coast areas, combined with pockets of degradation in north coast areas, have been made. Potential reasons for this require more study but the south coast sites are more exposed in nature than the north coast sites, with the latter being partially leeward and 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, although it is thought that hurricane damage combined with white band disease was the initial destructive force (Bythell & Buchan, 1996). The continued presence of the disease, combined with a reduced resilience of corals to it and other stressors, likely continues to be of influence. Coral recruitment levels are low (Wynne, 2010), 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). 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. Due to this, it would be more prudent to focus management efforts in Anguilla 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 where the existing marine parks are located, and thus there is already good infrastructure for future legislation. It is recommended that these areas 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 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 under sufficient management.

The ecosystem health zoning map (figure 3) also highlights differences between sites located close to the mainland and those located further offshore. The offshore areas are generally less degraded that 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 human related stressors will be greater at the near-shore sites, and of these stressors fishing practices and coastal development are likely the most significant. How these local stressors interact with regional ones (i.e. eutrophic waters) might also be crucial: if regionally sourced eutrophication is playing a role, even minimal local nutrient sources may be influential, as suggested in Wynne (2017).

Furthermore, it is probable that the removal of herbivorous species and the associated drop in grazing potential may accentuate nutrient impacts on macroalgae growth, and thus increase pressure on corals. Through this knock-on process, variations in fishing pressure may lead to variations in macroalgae growth and coral cover, and if eutrophic conditions persist the overall effect could be exaggerated. Indeed, there is an apparently strong relationship visible on figure 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). Variations in fishing pressure are largely due to the accessibility of these sites from shore to spearfishing. This suggests that this unregulated practice 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. Despite this, sites on the south coast interestingly did not have a similarly high diversity of sponges or soft corals, although this may be due to increased wave action limiting their growth. Whatever the case, the clear message is that coastal areas around Anguilla are decreasing in health a process that has been ongoing for at least the last three decades. Even though much of this decrease may be due to regional factors, it is also clear that local stressors are playing an important role in this process, and without correct management there is little chance for these ecosystems to recover and thrive on into the future.

*Conclusion*

By using the tool described in this paper 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.

**References**

Anonymous (2001). Paper parks: Why they happen, and what can be done to change them. MPA News Vol.2 No.11 (June). p.1-4. Published online at www.mpanews.org

Babcock R. & Smith L. (2000). Effects of sedimentation on coral settlement and survivorship. *Proceedings 9th International Coral Reef Symposium.* Bali, Indonesia. p.245-248.

Berg C., Ward J., Luckhurst B., Nisbet K. & Couper F. (1992). Observations of breeding aggregations of Queen Conch in Bermuda. *Proceedings of the 42nd Gulf and Caribbean Fisheries Institute*. p.161-171.

Birrell C.L., McCook L.J., & Willis B.L. (2005). Effects of algal turfs and sediment on coral settlement. *Marine Pollution Bulletin* **51**. p.408–414.

Bruno J.F., Precht W.F., Vroom P.S. & Aronson R.B. (2014). Coral reef baselines: How much macroalgae is natural? *Marine Pollution Bulletin* **80**. p.24-29.

Bythell J. (1995). The Anguillan Marine Resources Atlas. Natural Resources Institute, University of Greenwich, Kent, UK.

Bythell J.C. & Buchan K.C. (1996). Impact of hurricane Luis on the coastal and marine resources of Anguilla. Marine ecological survey produced for the British Development Division of the Overseas Development Administration by the University of Newcastle, United Kingdom.

Darwall W.R.T. & Dulvy N.K. (1996). An evaluation of the suitability of non-specialist volunteer researchers for coral reef fish surveys. Mafia Island Tanzania – A case study. *Biological Conservation* **78**. p.223-231.

English S., Wilkinson C. and Barker V. (1997). Survey manual for tropical marine resources (2nd Edition). © Australian Institute of Marine Science, P.M.B. No. 3, Townsville Mail Centre, Qld, 4810, Australia.

Friedlander A., Sladek-Nowlis J., Sanchez J.A., Appeldoorn R., Usseglio P., McCormick C., Bejarano S., and Mitchell-Chui A. (2003). Designing effective Marine Protected Areas in Seaflower Biosphere Reserve, Colombia, based on biological and sociological information. *Conservation Biology* **17**. p.1769-1784.

Frisch A.J., Cole A.J., Hobbs J-P.A., Rizzari J.R. & Munkres K.P. (2012). Effects of spear-fishing on reef fish populations in a multi-use conservation area. *PloS ONE* **7**: e51938. pp.11.

Godley B.J., Broderick A.C., Campbell L.M., Ranger S. & Richardson P.B. (2004). Chapter 4: An Assessment of the status and exploitation of marine turtles in Anguilla. Published in: An assessment of the status and exploitation of marine turtles in the UK Overseas Territories in the Wider Caribbean. p.39-77.

Gov Axa (c.1978). Policy statement on marine parks for Anguilla. Produced by the Government of Anguilla (anonymous).

Hoggarth D. (2006). Management plan for the marine parks of Anguilla. Prepared for the OECS National Resource Management Unit, St Lucia.

ISRS. (2004). The effects of terrestrial run-off of sediments, nutrients and other pollutants on coral reefs. Briefing Paper 3, International Society for Reef Studies, pp.18.

Jackson J.B.C. (2001). What was natural in the coastal oceans? *PNAS* **98**. p.5411–5418.

Kelleher G., Bleakley C. & Wells S. (1995). A global representative system of Marine Protected Areas. Volume II: Wider Caribbean, West Africa and South Atlantic. Produced by the Great Barrier Reef Marine Park Authroity, World Bank & International Union for Conservation of Nature.

Kramer P., Lang J., Marks K., Garza-Pérez R. and Ginsburg R. (2005). AGRRA Methodology v. 4.0**.** University of Miami. Available online at http://www.agrra.org

Lirman D, Herlan J., Langdon C. & Capo T. (2008). Exposure to nutrient-enriched sediments mitigates the negative impacts of sedimentation on coral growth in the Caribbean corals *Porites astreoides* and *Siderastrea siderea. Proceedings of the 11th International Coral Reef Symposium.* Ft. Lauderdale, Florida. p.900-904.

McClanahan T.R. & Obura D. (1997). Sedimentation effects on shallow coral communities in Kenya. *Journal of Experimental Marine Biology & Ecology* **209**. p.103-122.

McClanahan T.R., Verheij E., & Maina J. (2006). Comparing the management effectiveness of a marine park and a multiple-use collaborative fisheries management area in East Africa. *Aquatic Conservation: Marine & Freshwater Ecosystems* **16**. p.147-165.

Mora C., Myers R.A., Coll M., Libralato S., Pitcher T.J., Sumaila R.U., Zel-Cler D., Watson R, Gaston K.J., Worm B. (2009). Management effectiveness of the world's marine fisheries. *PloS Biology* **7**. Ref: e1000131. pp.11.

Oxenford, H.A., and Hunte, W. (1990). A survey of marine habitats around Anguilla, with baseline community descriptors for coral reefs and seagrass beds. Report for the Department of Agriculture and Fisheries, Government of Anguilla, by the Bellairs Institute, McGill University, St. James, Barbados.

Paddock M.J., Reynolds J.D. Aguilar C., Appeldoorn R.S., Beets J., Burkett E.W., Chittaro P.M. Clarke K., Esteves R., Fonseca A.C., Forrester G.E., Friedlander A.M., Garcia-Sais J., González-Sansón G., Jordan L.K.B., McClellan., Miller M.W., Molloy P.P., Mumby P.J., Nagalkerken I., Nemeth M., Navas-Camacho R., Pitt J., Polunin N.V.C., Reyes-Nivia M.C., Robertson D.R., Rodgríguez-Ramírez A., Salas M.A., Smith S.R., Spieler R.E., Steele M.A., Williams I.D. Wormald C.L., Watkinson A.R. & Côté I.M. (2009). Recent region-wide declines in Caribbean reef fish abundance. *Current Biology* **19**. p.1-6.

Risk, M. J. (1972). Fish diversity on a coral reef in the Virgin Islands. *Atoll Research Bulletin* **193**. p.1-6. Available at: http://www.aoml.noaa.gov/general/lib/CREWS/Cleo/St.%20John/St_John2.pdf

Schmitt E.F., Sluka R.D. & Sullivan-Sealey K.M. (2002). Evaluating the use of roving diver and transect surveys to assess the coral reef fish assemblage off south-eastern Hispaniola. *Coral Reefs* **21**. p.216-223.

Shin Y-J., Pochet M-J., Jennings S., Field J.G. & Gislason H. (2005). Using size-based indicators to evaluate the ecosystem effects of fishing. *Journal of Marine Science* **62**. p.384-396.

Teixeira H., Borja A., Weisberg S.B., Ranasinghe J.A., Cadien D.B., Dauer D.M., Dauvin J.C., Degraer S., Diaz R.J., Grémare A., Karakassis I., Llansó R.J., Lovell L.L., Marques J.C., Montagne D.E., Occhipinti-Ambrogi A., Rosenberg R., Sardá R., Schaffner L.C. & Velarde R.G. (2010). Assessing coastal benthic macrofauna community condition using best professional judgement – Developing consensus across North America and Europe. *Marine Pollution Bulletin* **60**. p.589–600.

Thompson B., Weisberg S.B., Melwani A., Lowe S., Ranasinghe J.A., Cadien D.B., Dauer D.M., Diaz R.J., Fields W., Kellogg M., Montagne D.E., Ode R.P., Reish D.J. & Slattery P.N. (2012). Low levels of agreement among experts using best professional judgement to assess benthic condition in the San Francisco Estuary and Delta. *Ecological Applications* **12.** p.167-173.

Wolanski, E., Richmond, R., McCook, L. & Sweatman, H. (2003). Mud, marine snow and coral reefs. *American Scientist* **91**. p.44–51.

Wynne S.P. (2007a). Ecological baseline survey of Anguilla's five marine parks. Produced by the Department of Fisheries and Marine Resources for the Anguilla National Trust as part of an Overseas Territories Environmental Programme funded project. pp.40. Copies are available at www.gov.ai/documents/fisheries

Wynne S.P. (2007b). Anguilla Marine Monitoring Programme Survey Protocol. Produced by the Department of Fisheries and Marine Resources for the Government of Anguilla. pp.26. Copies are available at www.gov.ai/documents/fisheries

Wynne S.P. (2008). Anguilla Marine Monitoring Programme (AMMP) pilot study. Produced by the Department of Fisheries and Marine Resources for the Government of Anguilla. pp.21. Copies are available at www.gov.ai/documents/fisheries

Wynne S.P. (2009). Progress report on sea turtle research conducted by The Department of Fisheries and Marine Resources during 2007 and 2008 in Anguilla. Produced by the Department of Fisheries and Marine Resources for the Government of Anguilla. pp.13. Copies are available at www.gov.ai/documents/fisheries

Wynne S.P. (2010). Status of Anguilla's Marine Resources 2010. 2009 AMMP Report. Produced by the Department of Fisheries and Marine Resources for the Government of Anguilla. pp.13. Published by Lambert Academic Publishing ISBN 978-3-659-17781-1

Wynne S.P. (2015). Developing an adaptive management plan for Anguilla's Marine Park System and associated shallow water habitats and fisheries 2015-2025. Produced for the Government of Anguilla by the Department of Fisheries and Marine Resources. Copies are available at: www.gov.ai/documents/fisheries

Wynne S.P. (2017). Trends and other temporal changes recorded during ten years of the Anguilla Marine Monitoring Programme. *Anguilla Fisheries and Marine Resources Research Bulletin **06***. pp.37. Copies are available at www.gov.ai/documents/fisheries