Coastal Infrastructure and its Effects on Local Social-Ecological Systems: A Case Study of Ashton Lagoon, Union Island, St. Vincent and the Grenadines

By

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Abstract:

Coastal infrastructure is extensively in place across coastlines throughout a variety of geographical regions around the globe, with the rate of coastal development projects predicted to increase in the future. Oftentimes, coastal development projects are situated within semi-sheltered areas with reduced water flow, which is lessened further by many forms of hard coastal infrastructural emplacements. Ashton Lagoon, of Union Island, St. Vincent and the Grenadines is one such place. A coastal development project, although incomplete due to bankruptcy, was partially constructed in 1994. This lead to the severance of lagoon halves, a severe reduction in water flow and consequently, extensive environmental changes. This study examined the impact of hard coastal infrastructure by analyzing the biophysical (habitat, fauna and sediment) and social components of the lagoon. This was done by emulating a past biophysical study for a cross comparison of modern and historical data sets. Additionally, historical and contemporary human use patterns in the area were assessed in relation to the failed development project. Social ecological-systems theory was utilized to analyze the biological and social datasets as they pertain to the functioning of ecosystem services, so that recommendations for management of Ashton Lagoon could be made, as the area is expected to experience more development in the years to come.

Keywords: Ashton Lagoon; social-ecological systems; habitat complexity; inner section; outer section; spatial; temporal

List of Abbreviations:

SVG: Saint Vincent and the Grenadines
SusGren: Sustainable Grenadines Inc.
ESC: Ecological spatial connectivity
ES: Ecosystem services
SES: Social ecological system
NGO: Non-governmental organization

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1.0 Introduction:

Approximately 40% of the human population lives within 100 km of a coastline (U.N., 2007), with the highest population densities also occurring in this zone (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015). This is further exemplified by the fact that the majority of the worlds' megacities are situated within the coastal region (Neumann et al., 2015), such as: Jakarta, Kolkata, Tokyo, New York, and Istanbul (IGBP, 2014). Human presence in these areas is likely to continue increasing, as future projections point toward a rise in global coastal migration rates due to an ever expanding population, as well as a mixture of economic, political and geographic factors (Bulleri & Chapman, 2010; Neumann et al., 2015). With so much of the global population residing in coastal areas human expansion and infrastructural development has gone beyond the terrestrial realm and entered into nearshore waters. This is clearly evident in places such as Asia, Australia, Europe, and the United States, as about 50% of the coastline in these regions is already highly developed with some form of hard coastal infrastructure (Dafforn et al., 2015). While coastal infrastructure exists along much of the world's coastlines, it can take a variety of forms depending on the desired use for the coastal area. Some types of infrastructure that can be found along coastlines includes: marinas, jetties, pilings, breakwaters, groynes, and ports (Bulleri & Chapman, 2010; Dafforn et al., 2015).

Even though most coastal infrastructure is built to aid both local and international populations, it is solely that of the local or regional populations that bear the brunt of the negative effects associated with the coastal infrastructural emplacements (Bulleri &

Chapman, 2010; Dafforn et al., 2015). This is because coastal infrastructure is designed to modify the local environment in some way to suit the needs of a particular human use, which often requires the physical alteration of the area through activities such as dredging, or the installation of physical works (Bulleri & Chapman, 2010; Walker et al., 2013). This means that during the construction phase certain habitats generally experience some form of change, or even complete eradication, which invariably has numerous effects on local flora and fauna species (Heery et al., 2017). Oceans are comprised of a series of highly interconnected habitats (Henderson, Gilby, Lee, & Stevens, 2017), so any changes to flora and faunal communities often occur at regional levels (Dafforn et al., 2015).

Similarly, many natural processes are affected not only through this change in habitat, but also by physical presence of engineered structures. One natural process that is often heavily disturbed by physical coastal works is water circulation (Dafforn, 2017). For example, breakwaters built around marinas can lead to a 30% reduction in natural flow rates (Dafforn et al., 2015). Reduced flow rates can have a number of consequences, including but not limited to: changes in sediment deposition, shifts in benthic community assemblages, disruption of larval recruitment, and an inability to flush nutrients from the system (Dafforn et al., 2015; Dafforn, 2017; Rivero et al., 2017). These biophysical changes are often felt most heavily at the local level, but can have regional implications (Dafforn et al., 2015) due to the high degree of ecological spatial connectivity (ESC) between biota populations and energy dynamics found in marine systems (Carr et al., 2017). While these changes are related to the physical and ecological component of the ocean, these alterations can also affect social systems (Sorensen, 2007).

Coastal infrastructure is put in place around the globe as a means to enhance humanities capabilities on the edge between land and sea; however, these same structures can also lead to a decrease in local capacity pertaining to ocean use, depending on how the natural systems are affected (Sorensen, 2007). Each of the social impacts that can be incurred through environmental changes caused by human intervention can be traced back to a particular ecological issue, or a combination of them (López-Angarita, Moreno-Sánchez, Maldonado, & Sánchez, 2014). These social issues stemming from coastal infrastructure and the associated biophysical changes can be wide ranging, and include problems such as: the loss of a fishery, the loss of a site of recreation, food security issues, and a drop in tourist appeal and the associated economic damages (Price & Price 1998; Sorensen, 2007). Conversely, unintended social benefits can also be accrued, such as tourist opportunities brought about from the sheltered conditions provided by infrastructure (SusGren, 2017a). Hence, social impacts depend on what biophysical changes have occurred through the development and ongoing use of a particular kind of coastal infrastructural emplacement, as well as how the area is utilized by local and visitor populations. This interplay between social and ecological factors is better understood through the use of social-ecological systems theory (SES).

SES theory posits that human and ecological systems are both in an ever-shifting relationship seeking some state of equilibrium (Pérez-Soba & Dwyer, 2016). This is a marked departure from the past, as prior to the year 2000 the majority of views seeking to understand humans and nature tended to view them as separate and distinct entities (Pérez-Soba & Dwyer, 2016). By looking at both human and ecological systems as parts to a larger whole, the true network of relations can begin to be unraveled (Pérez-Soba & Dwyer, 2016). It is through improved understanding of these connections that more holistic and effective management decisions can be made, which makes the use of this theory very salient in the face of continued human development in coastal zones (Leslie, Basurto, Nenadovic, Sievanen, & Cavanaugh, 2015).

The Caribbean region of 30 different unique nations and overseas entities is comprised of over 7,000 different islands, reefs, islets, and cays, which makes up one of the world's 34 biodiversity hotspots, mainly due to the large array of endemic species that can be found in these remote places (European Commission, 2016). In total, there are around 7,500 endemic plant species, with a further 880 unique vertebrate species (European Commission, 2016). Additionally, the region supports about 6% of globally threatened or endangered species (European Commission, 2016). In order to support all of this life the Caribbean region plays host to a diverse collection of habitat types, such as: coral reefs, seagrass beds, cactus scrublands, mangrove forests, tropical forests, and seasonal forests (European Commission, 2016). Nonetheless, there are a variety of pressing threats currently facing Caribbean ecosystems, which includes factors such as: habitat destruction and fragmentation, the spread of invasive alien species, pollution, extreme weather events and climate change, as well as the overexploitation of natural resources (European Commission, 2016).

When looking at the social component of the Caribbean it quickly becomes apparent that human society in this region relies strongly on a variety of ecosystem services (ES) to function. It is estimated that $1.7 trillion USD in ES are generated on an annual basis within the Caribbean region (European Commission, 2016). ES can be classified according to four different categories, which include: provisioning services like that of fresh food and water, regulating services such as the moderation of extreme weather events, habitat or supporting services and the ability to sustain biodiversity, and cultural services such as tourism (Curtin & Prellezo, 2010).

Two of the areas of greatest benefit to Caribbean society when looking at ecosystems services are the provision of food and the facilitation of the fisheries, and the tourist industry (Bhat, 2017; European Commission, 2016). First off, the rich waters of the Caribbean support a commercial fishing industry that can occasionally account for 8% of certain island states GDP, as well as sport and recreational fisheries (European Commission, 2016). At the same time, the tourist industry largely drives the region's economy, with 50% of the GDP coming from the tourist sector, accounting for 30% of available employment opportunities (Bhat, 2017). A large portion of this tourism industry is related to eco-tourism, in both terrestrial and marine environments (European Commission, 2016). Thus, it is clear that human society in the Caribbean is quite heavily influenced by local and regional natural systems, as the basic needs for survival, and the underpinnings of the economy are both sustained through the functioning of ES (European Commission, 2016).

Ashton Lagoon is a 605 ha area on the south coast of Union Island, and is the largest wetland area in all of Saint Vincent and the Grenadines (SVG) (Sorensen, 2007; SusGren, 2012). Ashton lagoon is comprised of several different habitat types, including: wetlands (mangroves, salt pond, mud flats and scrub forest) seagrass beds, as well as barrier, fringing and, patch reefs (SusGren, 2012). As part of the Grenadine island chain, the North Atlantic gyre flushes oxygen rich water, larval recruits and nutrients throughout the waters of Union Island, including Ashton Lagoon, from a north-westerly direction (Sorenson, 2008). To protect such a biologically diverse area the Lagoon was designated as a marine conservation area, under the SVG Fisheries Act of 1986 (Price & Price, 1998). Even with this protection the entire ecosystem has been degraded after a failed development project occurred almost 23 years ago, which saw the construction of a 300 berth marina on the inside of the lagoon (Price & Price, 1998). In particular, dredging during its formation, as well as the subsequent reduction in water flow once the structure was in place has likely caused habitat loss amongst the mangroves, seagrass beds, and coral reefs (Price & Price, 1998). In turn this has led to a stark reduction in biodiversity, degraded water quality conditions, and a number of social impacts including the loss of a subsistence fishery (Sorenson, 2008). A remediation project began physically opening the walls of the marina infrastructure in the fall of 2017, in an effort to try to restore water flow to the area (SusGren, 2018).

The ecological health of Ashton Lagoon has seen a marked decline since the introduction of a 300 berth marina in 1995 (Price & Price, 1998). This is in line with much of the academic literature surrounding coastal infrastructure, as both the construction and mere physical presence of man-made structures in the marine environment can have far reaching and wide ranging effects on local biological systems (Bulleri & Chapman, 2010; Dafforn, 2017). Moreover, these biological changes alter the human systems that depend upon the local environment to function (Sorensen, 2008). As has already been shown, the Caribbean is an area where human based development is prevalent and ongoing (Bhat, 2017), with Ashton Lagoon being no exception. Three research questions will be used to determine how the failed development project in Ashton Lagoon affect local social-ecological systems.

1. How has the introduction of hard coastal infrastructural works in Ashton Lagoon affected available habitat, spatially and temporally?
2. How have local flora and fauna been affected by hard coastal infrastructural works present in Ashton Lagoon, spatially and temporally?
3. How have biophysical changes to the environment impacted local social-ecological systems, spatially and temporally?

Additionally, the transect data collected to inform the biophysical portion of this study helped determine the current ecological state of Ashton Lagoon, as well as spatially matched past biophysical assessments to ensure data was temporally relevant.

2.0 Methods:

A mixed method approach that collated quantitative and qualitative data was used, including a literature review of contemporary and historical documents, marine transect line surveys, and meeting minutes from several community meetings during summer 2017.

2.1 Literature Review:

A reconstruction of the recent history of the lagoon, since 1986, was performed by reviewing existing peer reviewed journal articles, non-governmental organization (NGO) reports, unpublished scientific papers, and engineering reports. To obtain specific information on Ashton Lagoon, and its current ecological state, a variety of reports conducted by two NGO's, The Nature Conservancy, and SusGren were consulted. In addition to biophysical data, such as water flow rates, reports also had insights into social components of the uncompleted development project (Sorenson, 2008; SusGren, 2012). Furthermore, the reports highlighted some of the past management and monitoring efforts within the last decade, as well as the ongoing process for remediation that began in 2007 (Sorenson, 2008). These reports (Figure 1 and Table 1) provided the basis from which to develop this study from, as the data collection for this study was designed to provide temporal continuity.

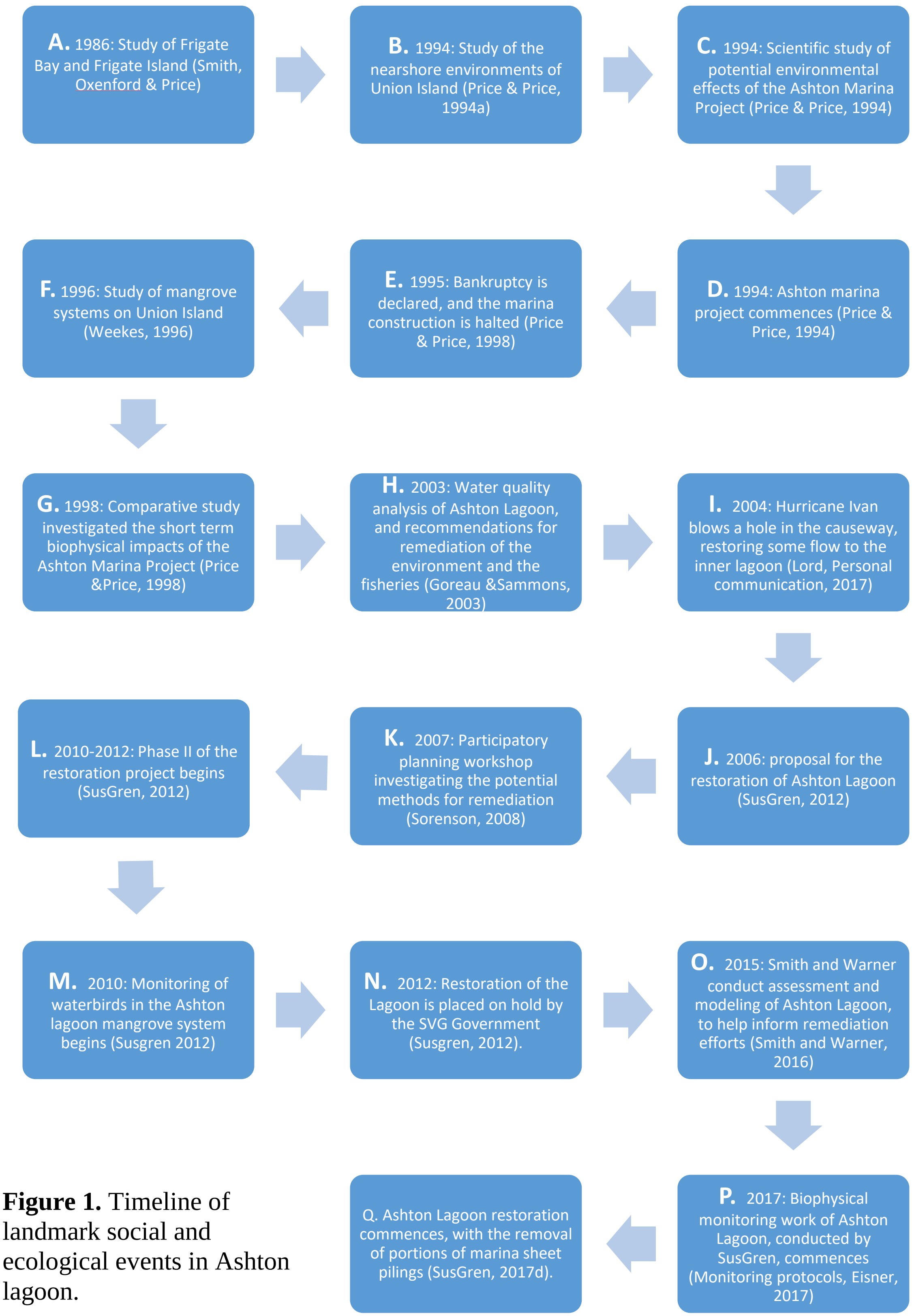

Figure 1. Timeline of landmark social and ecological events in Ashton lagoon.

Table 1. Legend for Ashton Lagoon Timeline

Timeline Section	Year	Report Name/Major Event	Explanation
A	1986	*A Preliminary Survey of Frigate Island and Frigate Bay, Union Island, St. Vincent and the Grenadines*	Marine and terrestrial assessment of Frigate Bay (Ashton Lagoon) and Frigate Island (Smith, Oxenford & Price, 1986). Five underwater transects and three stations were surveyed using snorkel gear, while being pulled behind a dingy (Smith, Oxenford & Price, 1986). First known biological assessment of areas flora and fauna species, as well as benthic structure (Smith, Oxenford & Price, 1986).
B	1994	*A Survey of The Nearshore Environment of Union Island, St. Vincent and the Grenadines*	The entire nearshore environment of Union Island is surveyed with 29 different 30m transects, 11 of which are in and around Ashton Lagoon (Price & Price, 1994a). The research focused on classifying reef building corals (Scleractinian), but also recorded the presence of algae, fish, gorgonians, and sponges (Price & Price, 1994a).
C	1994	*Ashton Marina Project Potential Ecological Impact on Union Island, St. Vincent and the Grenadines*	A follow up document to the "A Survey of The Nearshore Environment of Union Island, St. Vincent and the Grenadines", which utilized transect data to predict the ecological changes likely to be incurred from the development project (Price & Price, 1994b). The document stated that the project should not go ahead, otherwise grave ecological consequences would follow (Price & Price, 1994b).
D	1994	Development in Ashton Lagoon commences	Marina Construction by the Italian company Valdetarro begins. Original plans included a 300-berth marina, 50 acre golf course over the mangrove system, and a

			condominium complex over the outer coral reefs (Price & Price, 1998).
E	1995	Development in Ashton Lagoon ceases	Valdetarro declares bankruptcy, leaving only a partially constructed marina in Ashton Lagoon (Price & Price, 1998).
F	1996	*Union Island Mangroves*	An analysis of the mangrove systems on Union Island, including Ashton Lagoon (Weekes, 1996). While it does not directly attribute the marina for the cause, it does mention a patch of inland black mangroves that have grown back due to constant flooding of the area. This effect would later amplify, killing off a large patch of the black mangroves (Goreau & Sammons, 2003; Sorenson, 2008).
G	1998	*Paradise Lost: A Postmortem of the Ashton Marina Project Ecological Impact on Ashton Lagoon, Union Island, St. Vincent and the Grenadines*	A follow up to Price & Price's earlier 1994 transect study, this report documents the changes to Ashton Lagoon three years after the failed development project ceased construction. The manta tow technique was used for data collection, with information gathered on benthic structure, coral and seagrass health, as well as present or absent fish and invertebrate species (Price & Price, 1998).
H	2003	*Water Quality in Ashton Harbour, Union Island, St. Vincent and the Grenadines: Environmental Impacts of Marina and Recommendations for Ecosystem and Fisheries Function*	An overall assessment of ecosystem health in relation to the failed development project. Water quality was the main mode of analysis. They found that the disruption of flow had resulted in a number of ecological changes, such as increased sedimentation in the Outer section of the lagoon, and lower oxygen concentrations in the inner section (Goreau & Sammons, 2003).
I	2004	Hurricane Ivan breaks causeway	A section of the causeway that has cut off flow to the inner section of

			Ashton Lagoon is blown open by hurricane Ivan, thereby restoring some flow to the area (Lord, Personal Communication, 2017).
J	2006	Restoration Phase I	$38,170 USD is awarded to conduct stakeholder meetings, and a participatory planning workshop, in 2007 (SusGren, 2012).
K	2007	*Participatory Planning Workshop for the Restoration of Ashton Lagoon: Proceedings and Final Report*	Participatory planning workshop goes ahead as planned (SusGren, 2012).
L	2010-	Restoration Phase II	Phase two of the restoration project begins.
M	2010	Water bird monitoring	In partnership with Birds Caribbean, bird monitoring begins in the Ashton wetlands (SusGren, 2012).
N	2012	Restoration project delays	Government delays means that many areas of the restoration project are put on hold (SusGren, 2012).
O	2015	*Final Report for the Ashton Lagoon Restoration, Union Island*	At the behest of The Nature Conservancy, Smith Warner International Ltd. performed an assessment on flow rates within Ashton Lagoon. Three remediation scenarios were highlighted through the use of particle and wave modeling (Lord, Personal Communication, 2017)
P	2017	Baseline ecological data collection	A monitoring protocol for Ashton Lagoon is formed, which includes: water quality monitoring, rover dive surveys, transect surveys, mangrove monitoring, and bird monitoring (Eisner, 2017). The ongoing monitoring of the area will help establish baseline data that can be compared to new data sets formed after the restoration project is complete, so as to reveal any ecological changes that may take place.

2.2 Transect Surveys:

When developing the marine related fieldwork portion of this study a method needed to be used that could be compared to past data sets conducted by Price and Price, two of the main authors responsible for most of the early reports (Smith, Oxenford, Price, 1986; Price & Price, 1994a, 1994b, 1998). However, each study employed inconsistent methods, including transect surveys in 1986 and 1994 that were in completely different locations, and a manta tow survey in 1997 that followed a non-linear path across Ashton Lagoon (Appendix 1).

Accordingly, no single method was available for temporal comparison of biophysical data. Nonetheless, all previous surveys recorded similar types of biophysical data. Biophysical data collected for each survey included factors such as: coral species, benthic structure, microalgae, fish, benthic invertebrates, gorgonians, and sponges (Smith, Oxenford, Price, 1986; Price & Price, 1994a; Price & Price, 1998).

The 1986 transect survey was not chosen due to limited number of transects within the footprint of the failed development project (Smith, Oxenford, Price, 1986). Similarly, transects from the Price & Price (1994a) study were not chosen since scuba gear was not available to sample the deep transects. Hence, the spatial design carried out during the manta tow survey from 1997 (Price & Price, 1998) was the most appropriate choice for performing data collection.

Certain issues, particularly with available equipment, meant a manta tow survey could not be undertaken. Instead, transect line surveys over the same transects as the previously conducted manta tow survey (Price & Price 1998) was chosen, as it allowed for an assessment of identical biophysical characteristics over the same data collection sites. Furthermore, Price & Price had compared their 1997 manta tow survey (Price & Price, 1998) with their 1994 transect surveys of Union Islands' nearshore environment (Price & Price, 1994a), which adds another layer of depth to the cross comparison available between historical and modern datasets (Table 1). Transect survey data was collected on August 8 and 9.

Figure 2. Transect pathways, 30m each, which were surveyed in the summer of 2017 (CNES/Airbus, 2017; Eisner, 2017). The green transect point's represent locations in the outer section of the lagoon, while the red transect points are those that are situated in the Western half.

The first step in conducting transect surveys was to determine coordinates of ten unique transect line pathways (Figure 2). This was accomplished by overlaying an image of the 1997 manta tow survey (Price & Price, 1998) on top of Google Earth by matching key landmark features, as the original manta tow map had no GPS coordinates. Once the manta tow map was in place the ten transect lines were drawn over the singular manta tow pathway, each of which being 30 m in length (Eisner, 2017). Six of the 30 m transects were in the outer section of the Lagoon, while four transects were placed in the inner half. The demarcation of outer and inner sections is taken from the 1997 manta tow survey (Price & Price, 1998).

Size calibration training for fish and invertebrate surveying was also performed, and was designed to allow the researcher to collect sizing data for fish and benthic invertebrates (Eisner, 2017). Calibration training included estimating sizes of stationary objects underwater and recording estimates on a slate attached to a T-square, prior to determining the actual size using a T-square (Eisner, 2017). This process was repeated until accurate size estimates were achieved (+/- 2 cm) (Eisner, 2017). By completing the training, the researcher was then able to accurately determine which sizing category to input the fish or benthic invertebrate species into, which included: 0-20cm, 25-45cm, 50-70cm, and 75-95cm (Eisner, 2017).

Once training was completed, and the researchers were on the water, a GPS unit (Garmin 72H) was used to locate the initial and final points for each transect (Eisner, 2017). Upon arrival, weighted floats were set out to mark the fixed locations of the initial and final transect points. The researchers then entered the water with recording slates, pencils, a plastic bottle for sediment collection, and one weighted transect measuring tape. Next, the weighted tape measure was laid out by one of the researchers between the initial and final transect points, making sure that no unusual obstructions, like that of rocky outcroppings, were obscuring the line (Eisner, 2017). This ensured that the tape measure was taught along the seabed, and a true 30 m transect was achieved.

Once transects were established, four swims along the transect were performed, with researchers alternating recording responsibilities (Eisner, 2017). The four swims consisted of recording different data sets in the descending order of: fish species, invertebrate species, benthic structure, and photographs of the seafloor along every meter of the transect (Eisner, 2017). Fish and invertebrate sweeps recorded data within 2 m on either side of transects, as well as 2 m above within the water column (Eisner, 2017). Benthic structure sweeps recorded bottom types present (e.g. coral, coral rubble, seagrass, sand, or rock) every meter along transects and marked with silver duct tape. The final swim collected photographic data from 1 m intervals along transects, as well as 1 m above (Eisner, 2017). All transects could be accessed at any time of day, except for transect location 1, 2 and 3, which were only safely accessed during high tide (Eisner, 2017).

Once swims were completed, a sediment sample was collected from point a of each transect (Eisner, 2017). Point a was chosen due to the corresponding GPS coordinate, allowing for sediment collection to be consistent and replicable, as well as the partially randomized placement on each transect that removed sampling bias. The collection of sediment was at the surficial range of 0-2cm in depth (USGS, 2013). The sediment samples were analyzed back in the lab, in which relative grain size was estimated using the Wentworth scale (Figure 3). This was done by physically examining the sediment between fingers to discern relative grain size, as well as through a visual examination. While this system is somewhat rudimentary, and did not employ the use of filters for sediment separation, it still allows for a general understanding of sediment size, and with it, whether the area is a high or low energy environment (Walker, Personal Communication, 2017).

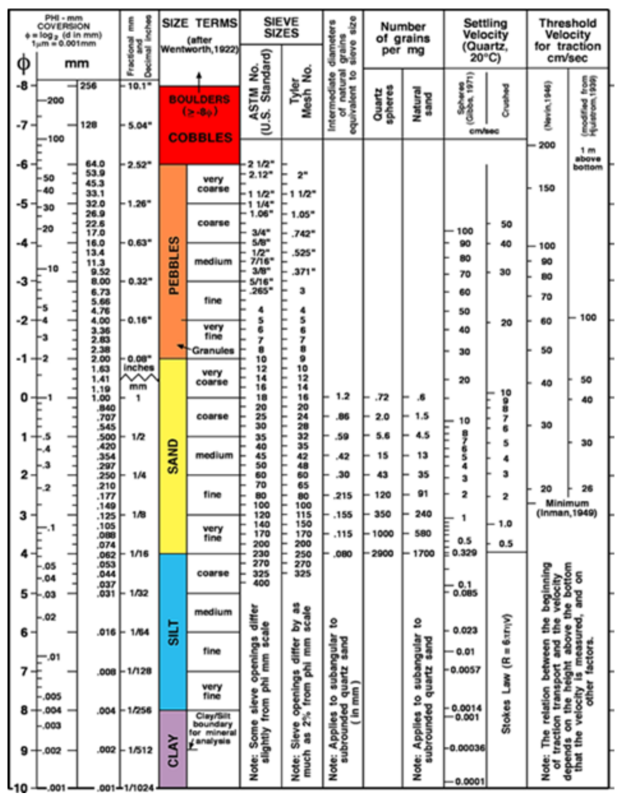

Figure 3. Wentworth chart for grain size estimation of sediments (USGS, 2013).

Photographs of the sediment were also taken for later analysis of bacterial composition and sediment health. This was accomplished by looking at the colour of the sediment. Lighter colours (white to tan) represent a healthy oxic composition, a mix of light and dark (tan with some black) is indicative of a hypoxic environment, while sediment that is primarily black is categorized as anoxic (Nova Scotia Fisheries and Aquaculture, 2011). The photos were promptly taken after the samples were transported back to the lab, so as not to alter the bacterial composition of the sediment, as this could skew the results.

While four swims were initially conducted for the first three transects, water leakage in the underwater housing of the GoPro Hero 4 camera system meant that the fourth photographic swim could no longer take place moving forward. In total, two different sets of transect data is available from several fieldwork sessions. All of the data collected using transects was then analyzed so that it could be spatially displayed (fish and invertebrates, benthic structure and sediment samples). This allowed for an examination of biophysical factors in relation to spatial proximity with hard coastal infrastructural works present in Ashton Lagoon. By reviewing the spatially displayed data, noted differences between transect sites was ascertained. Additionally, analyzing the transect data spatially meant that comparisons with past studies could be completed, as they too chose to use spatial representations of data as a central method of analysis (Price & Price, 1998).

2.3 Community Engagement:

To understand human use patterns in the area, and how they are spatiotemporally represented, two different sources of meeting minutes were consulted. The first meeting minute source came from a community consultation session concerning the restoration of Ashton Lagoon, which took place on May 22, 2017 (SusGren, 2017a). The meeting was attended by a variety of community members on the Island, with the meeting being held in the town of Clifton, Union Island (SusGren, 2017a). On top of concerned community members some of the individuals that attended the meeting were from groups such as a local NGO known as The Environment Attackers, staff from the Tobago Cays Marine Park, local business owners, fisherman, and kitesurfing school operators. Similarly, meeting minutes from a seamoss stakeholder meeting that took place in the town of Ashton, on June 21, 2017, was also incorporated into the study (SusGren, 2017b). This group of seamoss harvesters consisted only of those that used aquaculture as a means for cultivation and did not have any wild harvesters present.

3.0 Results:

3.1 Transect Surveys:

3.1.1 Fish

Five unique genera were observed in the outer half of the lagoon (T1-6) (Figure 4, Appendix I): fry (65.4%), wrasse (22.6%), damselfish (10.9%), parrotfish (0.7%), and surgeonfish (0.4%). Conversely, only six unique genera were observed in the inner half of the lagoon (Figure 4, Appendix I): parrotfish (33.3%), wrasse (27.3%), snapper (15.2%), unknown juveniles (12.1%), silvery (9.1%), and stingray (3%). A total of 764 individuals were recorded in the outer section, and 33 in the inner section (Figure 4). In the outer sector fish counts ranged from two at T-4, to 522 at T-6 (Appendix I). Conversely, fish counts in the inner area ranged from one at T-7, to 20 at T-9 (Appendix I). Most fish were categorized between 0-25 cm, except for a stingray at T-7, which was 25-45 cm (Appendix I). Additionally, most (~95%) fish were in their juvenile phase, based on their size, or through colouration.

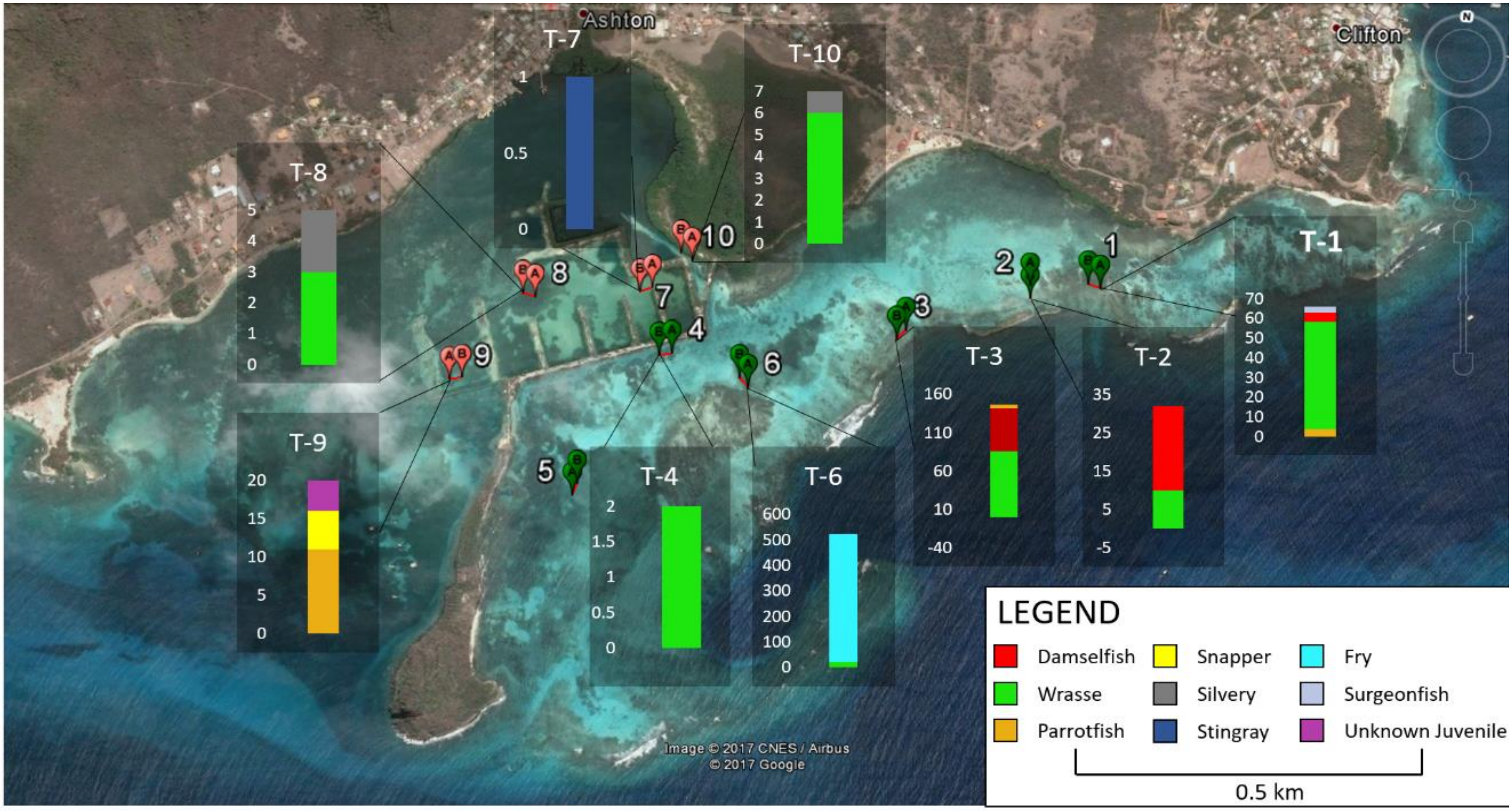

Figure 4. Fish distribution. Fish species, and number of individuals sited during the first data collection period of transect surveys. Aerial photograph not taken at time of sampling.

3.1.2 Invertebrates:

Five unique genera of invertebrates were recorded in the outer section (Figure 5, Appendix I): southern lugworm mound (56.3%), rock-boring urchin (15%) giant-sea anemone (13.7%), white urchin (13.7%), and crab (1.3%). However, only three unique invertebrate genera were found in the inner lagoon (Figure 5, Appendix I): southern lugworm mound (66%), upside-down jellyfish (33.3%) and sea cucumber (0.7%). A total of 80 unique sightings were recorded in the outer portion, and 135 in the inner portion (Appendix I). Outer section lagoon invertebrate counts ranged from one at T-1, to 33 at T-4 (Appendix I), whereas inner half counts ranged from 36 at T-9, to 58 at T-7 (Appendix I). Invertebrate sizes were generally between 0-25 cm (Appendix I), except on T-7, which had five upside-down jellyfish and on T-9, with one sea cucumber and a single upside-down jellyfish between 25-45 cm (Appendix I). While sizes of all southern lugworm mounds were between 0-25 cm, mounds within the innermost area of the marina (T-7) were noticeably larger compared to other transect sites.

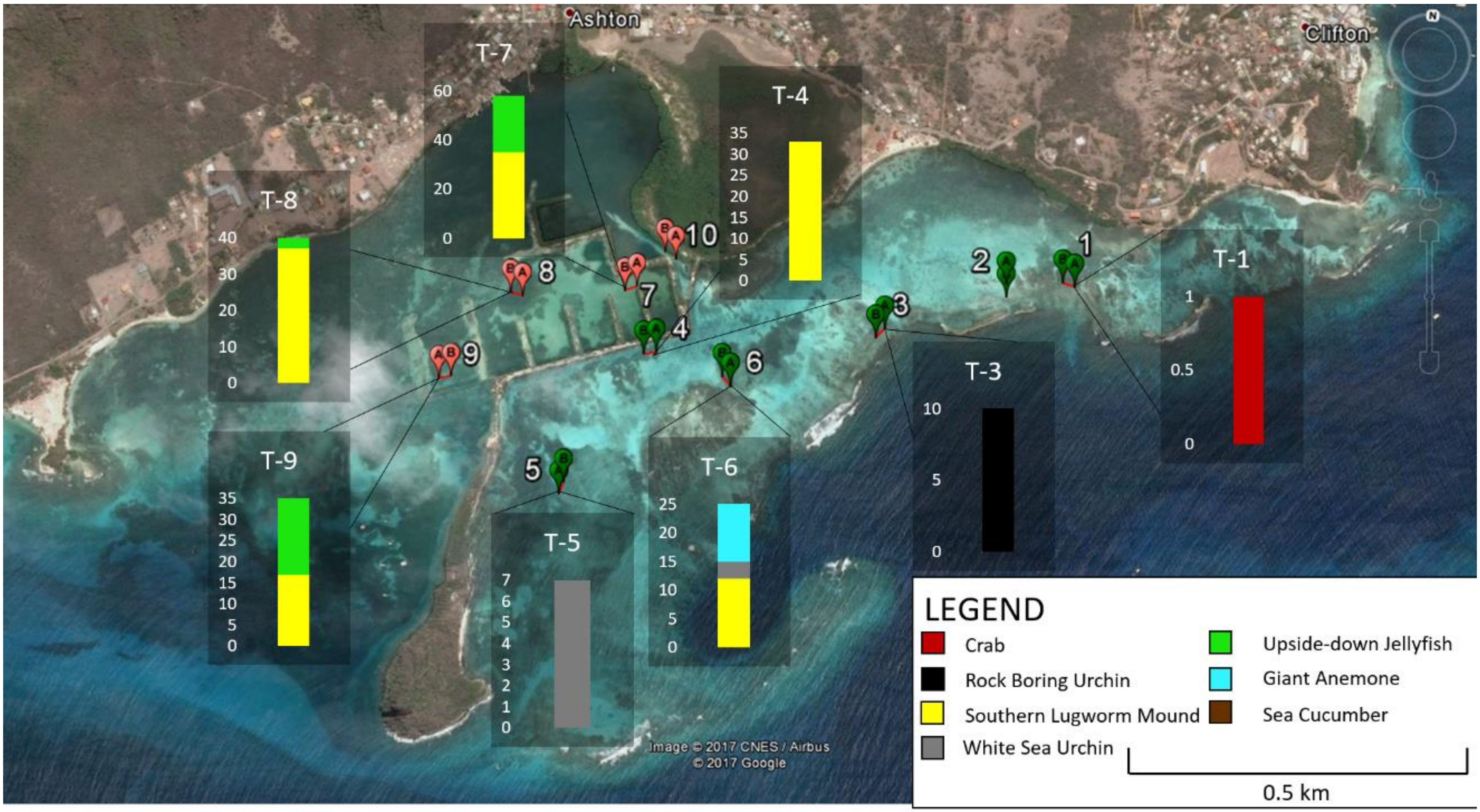

Figure 5. Invertebrate distribution. Invertebrate species and individual animal sightings for the first data collection period of transect surveys. The aerial photograph was not taken at the time of sampling.

3.1.3 Benthic Structure:

From the transect surveys, five different benthic types were recorded (Figure 6). Coral rubble was only documented in the far eastern side of the lagoon (T-1 and 2). Furthermore, most (~80-90%) of the coral structures had algal growth. Transects in the far eastern portion of the lagoon (T-1 and 2) contained sand, and a small amount of rock. Transects closer to the marina on in outers area (T-4, 5 and 6), were dominated by seagrass beds, with only a small percentage of sandy bottom present (Figure 6). The inner half of the lagoon was predominately sand (T-7, 8 and 10), with only a small portion of rock. Farther west, and towards the edge of the inner marina area (T-9), seagrass again was the dominate type of benthic structure, followed by sand, and a small percentage of silt (Figure 6).

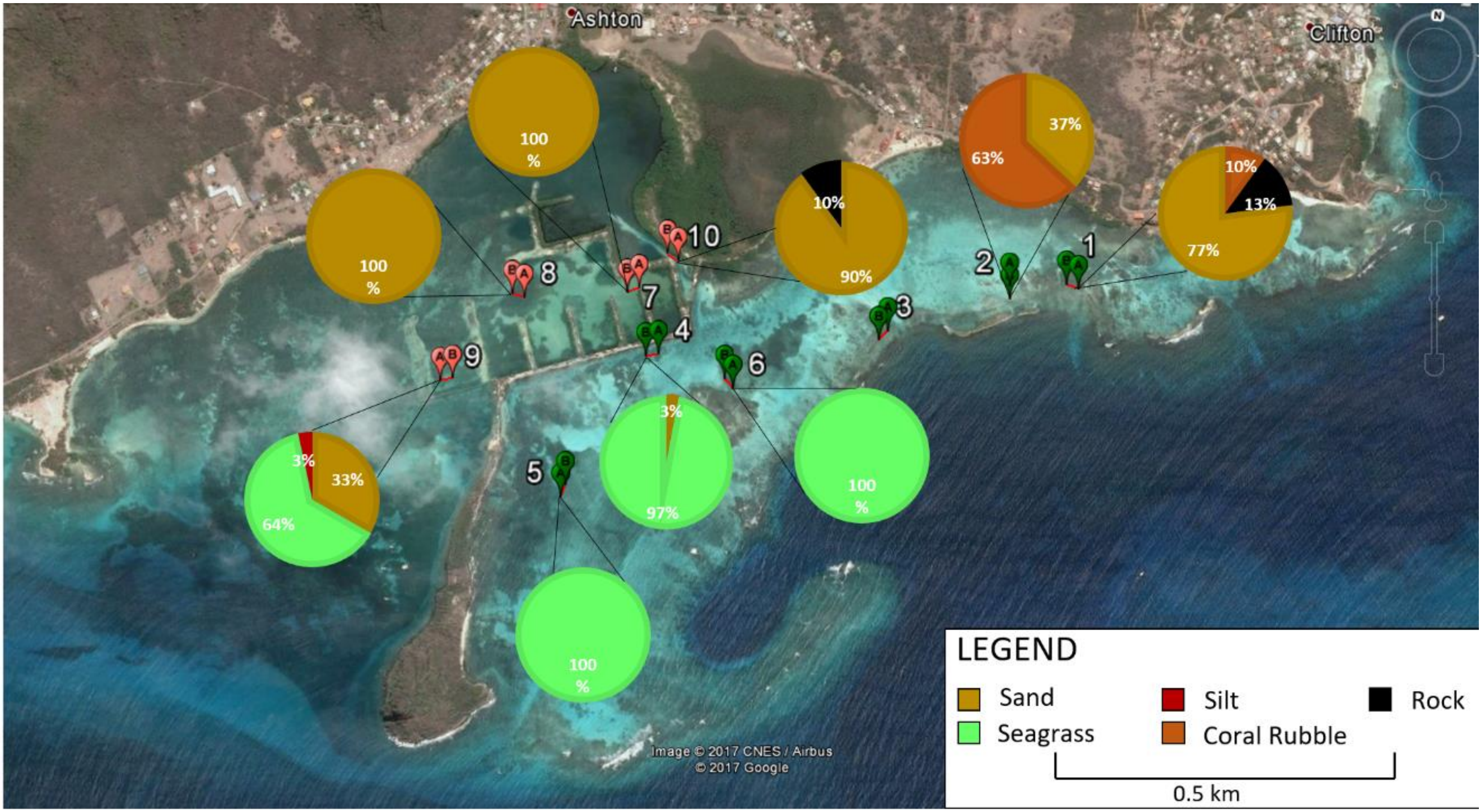

Figure 6. Benthic habitat map. Percentage coverage of benthic habitat found at each transect, with each transect consisting of 30 individual points of recording. Data not available for T-3. Aerial photography not taken at the time of sampling.

3.1.4 Sediment:

Sediment samples taken in the outer portion of the lagoon (T-2 to T-6) were all light-medium tan in colour (Figure 7, Table 2). Likewise, T-10, next to the destroyed section of causeway in the inner half of the lagoon, was also light-medium tan in colour. These light tan colours found in the outer half (T-2, 3, 4, 5, and 6), as well as in T-10 are indicative of an oxic environment. The other transects in the inner portion (T-7, 8 and 9) were all dark grey to black in colour (Figure 7, Table 2), potentially indicating hypoxic to anoxic conditions. Sediments in the outer half of the lagoon were either medium to coarse sand (T-2 to T-6) (Table 2). The sediment in the inner portion of the lagoon had more variety, with T-7 and T-10, having medium and coarse sand, respectively. T-8 and T-9 are the only two transects to have silt deposits, with both samples falling under the coarse silt size range. Sulphuric odours were observed with several sediment samples, including T-6, T-7, T-8 and T-9 (Table 2).

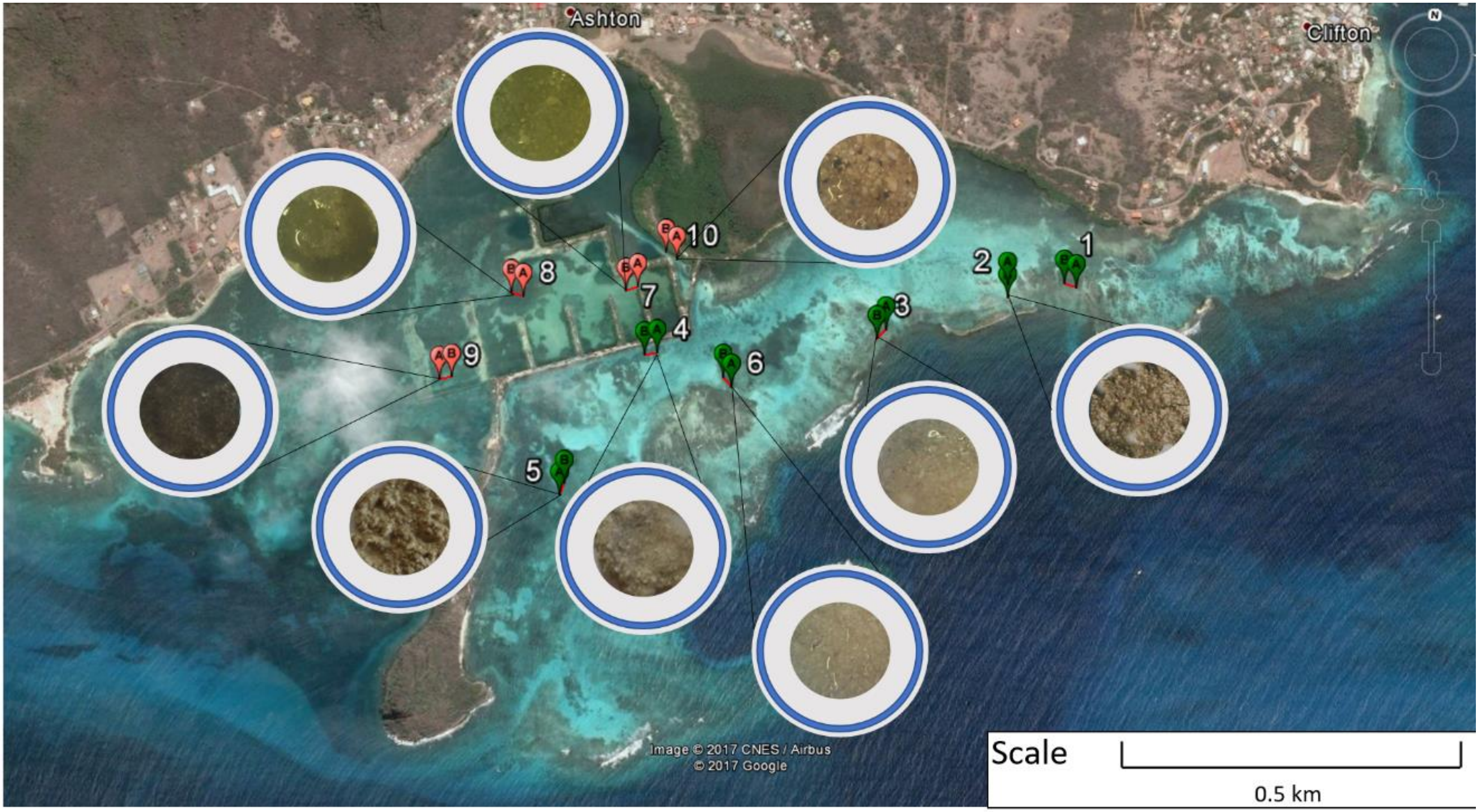

Figure 7. Sediment sample photographs. Photographs of sediment samples taken from the first data collection period (August 8 and 9). T-1 to T-6, and 10 are indicative of an oxic state, while transects 7, 8 and 9 show cues suggesting a hypoxic to anoxic state.

Table 2. Sediment type and additional points of note for each transect. T-1 did not have a sediment analysis performed.

Transect #	Sediment Type	Notes
2	Coarse sand	Sand intermixed with pebble sized (very fine-fine) ground rock and/or coral fragments.
3	Medium sand	Sand intermixed with ground rock and/or coral fragments.
4	Medium sand	Sand intermixed with ground rock and/or coral fragments.
5	Coarse sand	Sand intermixed with pebble (very fine) sized ground rock and/or coral fragments.
6	Medium sand	Sand intermixed with pebble (very fine-fine) sized shell fragments. Sulphur odour present.
7	Medium sand	Sand intermixed with pebble (very fine) sized ground rock and/or coral fragments. Dull grey colouration. Sulphur odour present.
8	Coarse silt	Almost black in colour. Strong sulphur odour present.
9	Coarse silt	Silt intermixed with pebble (very fine) sized ground rock and/or coral fragments. Dark grey/black in appearance. Strong sulphur odour present.
10	Coarse sand	Sand intermixed with various pebble sized pieces of ground rock and/or coral fragments.

3.1.5 Human Use Patterns:

Eight unique human uses were identified to be practiced during the sampling period (summer 2017: August-September). In the outer portion of the lagoon, the only human activities present were seamoss aquaculture, and a mangrove restoration project (Figure 8). At the interstice between inner and outer sections is a small vessel passageway that runs through the broken causeway, and is utilized by speedboats to enter and exit the lagoon. In the inner portion there were five other uses, including: recreation, a community dock for commercial and recreational purposes (fishing, transport of goods, and transport of people), wild seamoss harvesting, kitsesurfing, and the mooring of yachts (Figure 8).

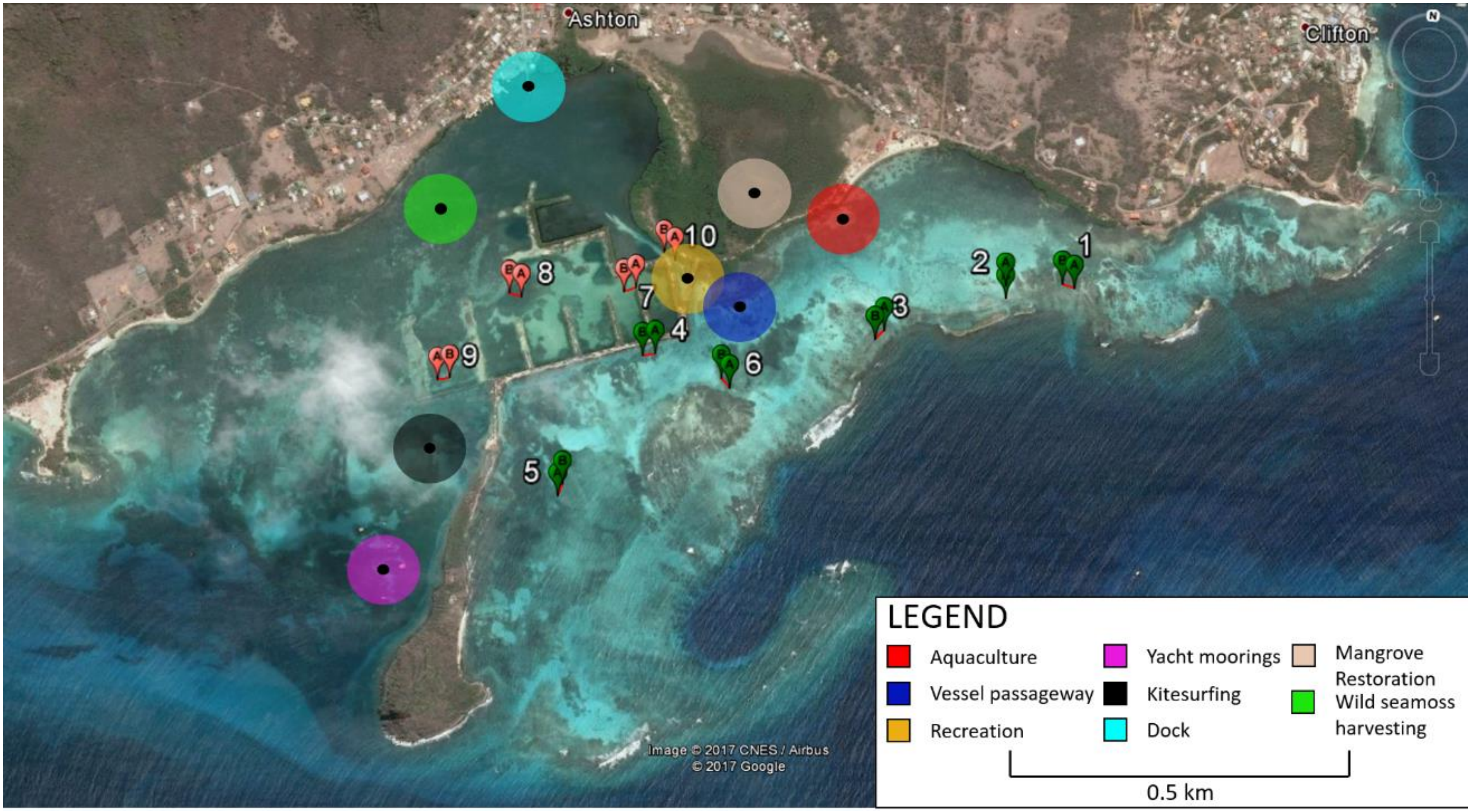

Figure 8. Map of human activities. Human uses in the area as recorded during the summer of 2017. These are approximate areas, as some activities may shift locations over time. Aerial photograph not taken at the time of sampling.

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It should be noted that previously, other human uses of the environment were present, but due to environmental changes, are no longer observed. It was expressed at the community meetings a cricket pitch was located on a dry area of salt pond adjacent to mangroves. However, since the marina and causeway construction the area has seen mangrove growth that has taken away the ability to use the area for recreational purposes. Fishing in the area also no longer occurs, as according to local knowledge, conch, lobster and a healthy fish population are no longer established in the lagoon. Tourist activities, such as: fishing, boating, swimming, and birding were also impacted through adverse environmental conditions in Ashton Lagoon (Sorenson, 2008).

4.0 Discussion:

The development of hard coastal infrastructure can compromise ES in coastal areas (Brander et al., 2012; Vilardy et al., 2017). This study seeks to improve the understanding of environmental and social changes that have occurred after the partial construction of a marina, and causeway, within the highly integrated social-ecological system of the Ashton Lagoon. This was addressed by comparing biophysical data (fauna, habitat, and sediment type) spatially, inside (T7-10) and outside (T1-6) the marina, as well as temporally, prior to the initiation of construction to the present day. Additionally, the social-ecological component is composed of an examination of human use patterns, both spatially and temporally, in relation to known ecological conditions and available ES.

4.1 Fish:

The spatial comparison of fish showed the outer section (T1-6) had a higher fish count and greater diversity than the inner portion (T7-10) (Figure 4). Approximately 95% of all fish sighted were juveniles, so habitats and their suitability as nursery grounds is discussed. Preferential nursery habitat in the marine environment includes, but is not limited to: mangroves, seagrass beds (Nagelkerken, Roberts, Velde, Dorenbosch, & Riel, 2002; Nagelkerken, Dorenbosch, Verberk, Van der Velde, 2000; Carr et al., 2017), patch reefs, algal beds and boulders (Mumby et al., 2004). Similarly, habitat complexity, or rugosity and the ability of benthic structures to provide shelter and foraging opportunities for fish, was examined, as it can affect fish distribution and diversity (Nagelkerken et al., 2002; de Anchieta C. C. Nunes & Barros, 2013; Nelson, Kuempel, & Altieri, 2016).

The highest fish abundance in Ashton Lagoon, located in the outer section, can be partially explained through the presence of preferential nursery habitat, including: coral rubble (~90% skeletal patch reefs), rock, seagrass beds, and algal beds (Figure 4 and 6). These benthic structures increased habitat complexity through high rugosity (Nagelkerken, et al. 2000), allowing for shelter, as well as the provision of food for herbivorous and omnivorous fish (Pratchett, Coker, Jones, & Munday, 2012; De Anchieta C. C. Nunes & Barros, 2013) from algal growth on ~90% deceased coral structures. Additionally, habitat uniformity in the outer section was low, providing a range of benthic types for fish communities (Figure 6).

The inner Lagoon areas lower fish abundance may be due to several factors, such as low habitat complexity, high turbidity and disrupted ESC (Figure 6). Habitat complexity was low, as benthic structure was uniformly bare sandy bottom, except for T-9 (seagrass: 66%, sand: 33% and silt: 3%) and T-10 (sand: 90% and rock: 10%) (Figure6). Hence, juvenile fish lacked ample sources of shelter from predation (Nagelkerken et al, 2000; Selfati et al., 2018), particularly within infrastructural emplacements, potentially leading to avoidance of the area (Figure 6).

Another environmental factor influencing fish assemblages within the innermost marina area (T-7 and 8) was high turbidity, a known impact associated with marinas (Heery et al., 2017), with lagoon visibility reduced to ~1.5-2 m. The higher light attenuation at these sights may be prohibiting plant colonization, as such conditions can inhibit seagrass growth (Yaakub, Chen, Bouma, Erftemeijer, & Todd, 2014). Therefore, habitat complexity could be low partially due to water quality conditions. Also, turbid waters are thought to be less advantageous for fish which rely on visual stimuli for survival, such as when procuring food, or evading predation (Nagelkerken, et al., 2000; Nagelkerken et al., 2002). Therefore, some fish species that are sight dependent may avoid the inner marina, leading to lower fish abundance and diversity.

Alongside habitat preferences, spatial distribution is also limited by ESC. Certain types of infrastructure, such as causeways, can completely restrict the movement of biota between locations, thereby, disrupting ESC (Bishop et al., 2017). Hence, the lower species abundance and diversity found within the innermost section of infrastructural emplacements (T-7 and 8) may be partially attributed to the physical severance of lagoon halves, with species abundance and diversity increasing along the western fringe of the inner section, where ESC amongst seagrass beds is unobstructed.

Many environmental factors influence fish spatial distribution, including: nursery habitat (Nagelkerken, et al.,2002; Mumby et al., 2004; Nagelkerken et al., 2000; Carr et al., 2017), benthic structure and habitat complexity (Nagelkerken et al., 2002; De Anchieta C. C. Nunes & Barros, 2013; et al., 2016), turbidity (Nagelkerken, et al., 2000; Nagelkerken et al., 2002), and ESC (Bishop et al., 2017). These environmental parameters have been directly or indirectly impacted by coastal infrastructure in Ashton Lagoon, and consequently, fish spatial distribution across inner and outer areas, with 95.9% of sightings in the outer section, and 4.1% in the inner section (Figure 4).

4.2 Invertebrates:

Spatial distribution of invertebrate assemblages also varied between outer and inner sections, with higher abundance in the inner section, and greater diversity in the outer section (Figure 5). All recordings were benthic invertebrates, including upside-down jellyfish (Jantzen, Wild, Rasheed, El-Zibdah, & Richter, 2010), however, upside-down jellyfish can enter the water column if disturbed. Similar to fish, invertebrate spatial distribution can be explained through habitat preferences.

The highest invertebrate abundance was recorded in the innermost lagoon area (T-7, 8 and 9), which may be attributed to sediment composition and flow rate. This innermost section was dominated by sandy bottom, comprising 77.7% of benthic type at surveyed sites, with sediments becoming finer inside infrastructural emplacements (Figure 6 and Table 2). Finer sediments are associated with marinas, as slower flow rates can result in fine sediment accumulation, and higher levels of organic enrichment (Heery et al., 2017). Sediment samples at T-7, 8 and 9 exhibited colours and odours (Figure 7 and Table 2) that were consistent with low oxygen conditions and high organic load (Mees & Stoops, 2010; Tamminen, Karkman, Corander, Paulin, & Virta, 2011). Upside-down jellyfish and southern lugworms, the two dominate benthic invertebrates found at these transects, both extract nutrients from fine anaerobic sediments with high organic content (Jantzen et al., 2010; Sweat, 2010). Also, fine sediment at these sites indicates low flow, another habitat condition favoured by upside-down jellyfish, as it enables anchoring onto the seafloor to feed on plankton, as well as allows symbiotic zooxanthellae to photosynthesize through the extraction of nutrients (Jantzen et al., 2010; Stoner, Layman, Yeager, & Hassett, 2011). Hence, the infrastructure may be influencing environmental conditions within the inner lagoon area (T-7, 8 and 9) that are highly favourable to upside-jellyfish and southern lugworms, yet unfavourable to other resident benthic invertebrates (Figure 5, 6 and 7).

The lower abundance, but high diversity of invertebrates in the outer section may be associated with benthic structure, and sediment composition. The varied benthic structure of the outer section meant favourable habitat was available for several different types of benthic invertebrates, such as, giant-sea anemone and white sea urchin in seagrass meadows (Scheibling & Mladenov, 1987; Sheridan, Fautin, & Garrett, 2015), rock-boring urchin on rocky outcroppings and deceased coral structures (Sweat, 2012), and southern lugworm on sandy bottom (Figure 5 and 6). Additionally, Southern lugworm were concentrated in locations of organically enriched sediment (Table 2), with a population increase recorded closer to coastal infrastructure (Figure 5). Hence, varied benthic structure and sediment with high organic load were conducive to harbouring a range of invertebrate species, albeit in smaller numbers than the isolated inner section (Figure 5).

Environmental factors related to habitat preferences heavily influence invertebrate spatial distribution, including: benthic type (Heck & Wetsone, 1977; Scheibling & Mladenov, 1987; Sheridan et al., 2015; Heery et al., 2017), flow rate (Jantzen et al., 2010; Bulleri & Chapman, 2010; Stoner et al., 2011; Rivero et al., 2017), and sediment composition (Jantzen et al., 2010; Sweat, 2010; Heery et al., 2017). In Ashton lagoon, the aforementioned environmental parameters linked to habitat preferences are directly, or indirectly influenced by coastal infrastructural emplacements, leading to higher invertebrate concentrations (63% of recordings) but lower diversity in the uniform habitat conditions of the inner section, and fewer individuals (37% of recordings) but greater diversity in the varied outer area (Figure 5 and 6).

4.3 Ecological Temporal Comparison:

Across multiple reports, ecological changes correlated with the addition of infrastructure in Ashton Lagoon have been documented (Table 1). Prior to initiating construction in 1994, Ashton Lagoon was labeled as a healthy system with high biodiversity, partially attributed to multiple habitat types (coral reefs, seagrass and mangroves) (Price & Price, 1994a), with the inner section more biologically rich than the outer (Price & Price, 1998). Aside from abundant fish species, the lagoon also housed several invertebrates important to local fisheries (white sea urchin, conch and lobster) (Sorenson, 2008). Furthermore, white sea urchins were regionally rare (1994), and Ashton Lagoon was a possible refugium for the 100-300 individuals observed (Price & Price, 1994a).

A variety of short term ecological changes were observed in 1997, three years after construction halted. In the outer section: infrastructure severed natural flow causing increased sedimentation; increased sedimentation led to higher temperatures; mass coral death possibly due to sedimentation, increased water temperature and new algal growth (30-70% corals affected by algae in far eastern portion, and 100% closer to infrastructure); loss of seagrass beds near infrastructure; “very low” fish population, all of which were juvenile, and relegated to deeper patch reefs (Price & Price, 1998, p. 12); “few” lobster also found at deeper patch reefs (Price & Price, 1998, p. 14); southern lugworm established densely populated fields close to infrastructure; and displacement of upside-down jellyfish and giant sea anemone from inner to outer section (Price & Price, 1998). In the inner section: removal of seagrass beds and associated fauna; accumulation of fine sediments; increase in turbidity; all organisms associated with the seagrass beds “disappeared” (Price & Price, 1998, p. 18); dense patches of southern lugworm mounds replace seagrass; only healthy zone west of infrastructural emplacements, where more stable sediments facilitated the growth of seagrass, supporting greater biodiversity (Price & Price, 1998).

When comparing ecological data collected after development cessation to results from this project, numerous long term changes to the system are apparent. The complete loss of subsistence fishing in the outer section (SusGren, 2017a), which was present in a reduced capacity post-construction (Price & Price, 1998), indicates fish abundance has not likely increased since 1998. Similarly, the inner area has seen minimal increase in fish population, as 64 fish were recorded in 2017, compared to zero in 1998 (Price & Price, 1998).

Invertebrate assemblages also changed in composition in relation to system conditions present in the contemporary context. In the outer section, no lobster was present compared to a “few” in 1998 (Price & Price, 1998, p. 14. Furthermore, no conch was recorded, with no sightings post construction (Sorenson, 2008). Conversely, remaining seagrass beds support a recuperating white sea egg population (23 in 2017, compared to 0 in 1997), and continue to harbor giant-sea anemone (Figure 5). Southern lugworm has remained spatially constant in the outer section since 1998, close to infrastructure (Price & Price, 1998).

The modified habitat in the inner section remains occupied by southern lugworm patches, consistent with findings in 1998, when they were first observed (Price & Price, 1998).Upside-down jellyfish are now prolific in the inner areas low energy environment containing sediments with high organic content (Figure 5, 7 and Table 2), but diverges from 1998 findings in which they were only found in the outer section (Price & Price, 1998). This spatial and temporal shift in upside-down jellyfish is likely the result of available suitable habitat, and total phosphorous levels (Stoner et al., 2011), with current inner area conditions highly favourable to upside-down jellyfish populations. High densities of upside-down jellyfish, like that found in the inner section, can compete with flora species for sunlight, such as seagrass, to nourish their symbiotic zooxanthellae (Stoner et al., 2011). Thus, contemporary inner lagoon conditions are favourable to southern lugworm and upside-down jellyfish, which have altered benthic structure, and consequently benthic biodiversity.

While the factors listed above describe how fish and invertebrate distribution may be related to the coastal infrastructure and available habitats present in Ashton Lagoon, other confounding variables could not be discarded as drivers of these changes. For example, terrestrial and ongoing anthropogenic pressures may also contribute to differences in spatial distribution between lagoon sections. As the inner portion of the lagoon is adjacent to the town of Ashton, and as raw sewage is fed into the lagoon, changes in water chemistry through nutrient overloading may be impacting fish abundance (DeGeorges, Goreau, & Reilly, 2010). Contrariwise, many invertebrates are resistant to such pressures (Stabili, Terlizzi, & Cavallo, 2013), and may even benefit from added nutrients (Stoner et al., 2011). For example, organic loading from human settlements has been linked to greater size and densities of upside-down jellyfish (Stoner et al., 2011).

Similar to sewage outfall, fishing and boating operations at the community dock may be further altering water chemistry in the inner section, through release of chemical discharges, and leaching of contaminants from antifouling paint during vessel operation (Dafforn et al., 2015; Dafforn, 2017). Moreover, the lower flow rates in the inner section, as evidenced by higher deposition of sediment and organic matter compared to outer transects (Table 2), potentially causes the accumulation of nutrients and contaminates in the inner half, and concomitant changes in fish and invertebrate assemblages (Dafforn, 2017). Hence, lower fish abundance and diversity, as well as low diversity but high invertebrate abundance in the inner section, may be partially influenced by external anthropogenic drivers, and not only to the development of coastal infrastructure in Ashton Lagoon.

4.4 Environmental Monitoring Summary:

From the results of this project, as well as a temporal comparison with past reports, it is evident Ashton Lagoon experienced numerous ecological changes over 31 years (1986-2017). Prior to construction the natural system had a high degree of biodiversity (Smith, Oxenford & Price, 1986; Price & Price, 1994b), and was labeled as healthy (Price & Price, 1998), but suffered a number of environmental changes shortly following development of coastal infrastructure (Price & Price, 1998). Furthermore, many environmental changes first recorded in the 1990's are still present in the cotemporary context. While it can be difficult to directly implicate coastal infrastructure as a driver of change in marine environments, when natural system fluctuations occur in fragile and relatively undisturbed locations, determining and delimiting impacts can facilitate an improved understanding of coastal infrastructural impacts (Rivero et al., 2017). By examining environmental changes spatially and temporally, this report attempted to ascertain the ecological impacts associated with the introduction of infrastructure in Ashton Lagoon. Findings showed numerous environmental shifts observed are likely correlated with the introduction of coastal infrastructure in Ashton Lagoon, as severe impacts occurred closest to infrastructural emplacements, as well as changes originating during, and after construction.

4.5 Limitations:

While a large amount of data from a wide variety of sources was able to be collected for this study, there were many factors that constrained data collection efforts, and with it the project's scope. Many of the issues were related to working within a remote island setting, such as: a lack of equipment, equipment failure (e.g. two underwater cameras), knowledge and capacity related issues, and travel logistics. These issues combined to create a number of difficulties for the study. One example, was the inability to increase the frequency of data collection dates to procure more biophysical data, due to logistical issues pertaining to scheduling conflicts and monitoring training. Also, if the study is to be recreated in the future care must be taken to ensure that all of the necessary equipment is already on site, or able to be transported onto the island. Additionally, key pieces of equipment would benefit from having a secondary backup, or a repair kit with extra parts, in case maintenance needs to be performed on damaged gear.

Despite presenting data obtained using proven scientific methodologies, lack of consistency in methods of data collection across different studies, e.g. Price & Price (1998) and our study, limits the application of a robust statistical analysis. Consequently, this study, as well as reports utilized for temporal comparison, may not be seen as a quantitative analysis of system variability over time. Instead, this study should be viewed as a qualitative examination of Ashton Lagoons changes in relation to developing hard coastal infrastructural works within a highly integrated system.

4.6 Social-Ecological Systems:

Social-ecological systems are complex webs of relations between society and the environment at varying scales (spatial and temporal) that interact through direct relationships, as well as distal, or underlying drivers (Kittinger, Finkbeiner, Glazier, & Crowder, 2012). In marine systems, the two macro level relationships are human induced impacts and actions that alter natural systems, as well as ES that are accrued by individuals and groups within society (Kittinger et al., 2012). These relationships often form feedback loops, which are interactions between components of a system that continuously influence one another, and are triggered by an initial causal factor (Kittinger et al., 2012). These feedback loops can either have a reinforcing, or dampening effect on systems (Kittinger et al., 2012), which can affect ES (Reyers et al., 2013). To assess social-ecological systems in Ashton Lagoon in relation to coastal infrastructure, a historical perspective is required, as the initiation of feedback loops must be examined to understand ES in the contemporary context.

ES before construction commenced included: provisioning services (food for local and regional residents), numerous regulating services (erosion mitigation, water treatment, protection from inclement weather events, and carbon sequestration and storage), supporting services (nursery habitat, fish and invertebrate habitat, as well as migratory bird habitat), and cultural services (recreation, tourism and sense of place) (Sorenson, 2008). The area was so biologically diverse, as well as beneficial for local residents, that Ashton Lagoon was declared a conservation area under the SVG Fisheries Act of 1986 (Sorenson, 2008).

Conservation status was the initial causal factor in a feedback loop of national scale interaction with local ecological systems, as Cole and Brown (2015) state, regulation of social systems and governance structures can preserve reinforcing, or positive effects on natural systems, and by extension ES (Kittinger et al., 2012). However, acting as a distal driver, tourism at the global scale enacted another feedback loop in 1994, which influenced the national SVG government to accept external funding for tourist related coastal development in Ashton Lagoon (Price & Price, 1998). Moreover, distal pull from global tourism was powerful enough to alter national social systems, and outlined goals (conservation area), despite pushback from an environmental impact assessment and local knowledge that projected ES losses associated with the development in Ashton Lagoon (Price & Price, 1998; Sorenson, 2008). Hence, global tourism functioned as an initial distil driver, altering national policy and developmental trajectories (SVG), and consequently local social-ecological systems (Ashton Lagoon/Union Island).

4.7 Post-development: Short Term Effects:

The 300 berth marina and connecting causeway are correlated with numerous short term ecological changes, as was previously outlined, which diminished or eliminated many ES. Supporting services, such as habitat for local and regional species, was heavily disrupted shortly after development halted, and by extension, provisioning services (food/fisheries) (Sorenson, 2008). Additionally, disruption of provisioning services, through a decline (Price & Price, 1998) and eventual loss of fisheries in Ashton Lagoon (Sorenson, 2008), disproportionately affected those already disenfranchised (Price & Price, 1998), as low income families unable to afford owning and operating a vessel faced added food security risks. Regulating services were also lost, or poorly functioned from ecological shifts, including: erosion mitigation, water treatment and carbon sequestration from poor flushing in mangrove system and associated dieback (Sorenson, 2008), protection from inclement weather events from mangrove and coral reef loss (Sorenson, 2008), as well as biological control from introduction of hard coastal infrastructure (Dafforn et al., 2015). Disruption of aforementioned ES meant many recreational and tourist activities were no longer viable, which invariably altered local and global interpretations of sense of place (Sorenson, 2008).

The loss of previously available tourist activities (snorkeling, swimming, diving, fishing, and birding) (Sorenson, 2008) began a dampening feedback loop between local ecological systems, and global social systems (tourism). Moreover, the loss of potential tourist revenue was not only restricted to lagoon activities, as the sale and marketing of local products was also affected (Sorenson, 2008). Hence, ecological conditions in Ashton Lagoon post-development led to a dampening feedback loop at the global scale (tourism), which in turn affected local social systems (sale of goods and services).

Additional social-ecological feedback loops, at the local level, were generated from shifts in sense of place. Sense of place are the values, symbols and beliefs that an individual or group holds towards a particular locale, which can affect individual and group identity formation, as well as stewardship practices (Chapin & Knapp, 2015). After coastal infrastructure was built in Ashton Lagoon, place dependence, or a locations capability of meeting individual and group needs in relation to available alternatives (Chapin & Knapp, 2015), was altered with ES loss (food provisioning and recreation).

Social groups on Union began mobilizing to restore ecological conditions within Ashton lagoon (Price & Price, 1998) as many residents were cognizant of the wide range of negative social-ecological impacts caused by the failed construction project (Sorenson, 2008). This initiated a reinforcing feedback loop, through the creation of environmentally conscious community groups (Price & Price, 1998), local environmental non-governmental organizations, as well as regional and international partnerships (Sorenson, 2008). Hence, shifts in sense of place through ES loss likely resulted in reinforcing feedback loops, which ultimately would lead to the formation of the NGO SusGren (Sorenson, 2008), and the restoration of Ashton Lagoon in fall 2017 (SusGren, 2018).

4.8 Post-Development: Long Term Effects:

In the contemporary context, continued social adaption to altered ecological conditions led to restoring certain ES, and the development of new feedback loops. Fisheries as a provisioning ES has not returned to Ashton Lagoon (SusGren, 2017a). Nonetheless, food provisioning has been partially restored through wild harvesting of seamoss in western fringes of the inner section, as well as seamoss aquaculture in the outer section (Figure 8). Seamoss aquaculture was attempted in the inner section, but failed, as sea moss growth was poor (SusGren, 2017b). This may be attributed to low flow and high sedimentation rate in the inner section (Table 2), as seamoss aquaculture is sensitive to sediment accumulation, even in high flow areas (Smith, Nichols & McLachlan, 1983).

Regulating services that were diminished or lost post-development (erosion mitigation, water treatment and carbon sequestration (Sorenson, 2008), protection from inclement weather events (Sorenson, 2008), and biological control (Dafforn et al., 2015)) have not returned, or have been partially restored through social adaptations. For example, mangrove restoration was initiated in summer 2017 (SusGren, 2018), which may fully, or partially restore regulating ES functionality, such as, erosion mitigation, water treatment and carbon sequestration (Sorenson, 2008), and protection from inclement weather events (Sorenson, 2008). Nonetheless, exclusively marine based ES associated with the mangrove system (habitat and supporting services: nursery habitat, and provisioning: food) require restoration of natural flow and ESC to reestablish functionality (Bishop et al., 2017).

Altered environmental conditions and habitat loss also impacted cultural ES (recreation, tourism and sense of place) (Sorenson, 2008), but adaptations in local social systems have mitigated the dampening feedback loops. Recreational ES have been partially restored through utilization of fast flowing waters at the interstice between lagoon halves for swimming (Figure 8). This provides swimmers with recreational space that is less impacted by sewage outfall from Ashton, due to high flow caused by opening in causeway, after hurricane Ivan in 2004 (Lord, Personal Communication, 2017). Another example is the growth of kitesurfing, one of the main sources of tourism on Union Island, with an established a base of operations in a semi-sheltered area west of infrastructural emplacements (Figure 8) (SusGren, 2017a). This adaptation generated a reinforcing feedback loop between global (tourism), and local (sale of goods and services) social-ecological systems.

The mooring of yachts is another tourist activity that occurs west of the small islet, Frigate Island (Figure 8). While yacht mooring can contribute to cultural ES (tourism), as the town of Clifton is used to restock supplies during yacht voyages, it can also contribute to dampening feedback loops. No moorings are in place (SusGren, 2017a), so anchors are repeatedly used by yachts, potentially affecting seagrass and associated ES (Collins, Suonpää, & Mallinson, 2010).

The final cultural ES affected in the contemporary context stems from a shift in sense of place, and place dependence from losing a cricket pitch. Post-construction, the causeway led to a restriction in mangrove flushing, allowing the colonization of mangroves in a previously dry salt pond (SusGren, 2017a). During a community meeting in 2017 discussing the planned restoration project, older individuals and environmentalist leaders expressed concern over the loss of a cricket pitch (SusGren, 2017a). As 6 hectares are required for the pitch (SusGren, 2017a), few alternative sites likely exist on the 10 kilometer squared (Price & Price, 1994a) and mountainous Union Island. However, younger individuals did not show interest in restoring the pitch, and associated the area with mangroves rather than recreation (SusGren, 2017a). Hence, place dependence, as well as identity formation (Chapin & Knapp, 2015) likely led to a fracturing between age groups within the community. As communities are not homogenous (Chaigneau & Daw, 2015), this contested developmental trajectory may have a reinforcing or dampening effect on social-ecological systems, depending on how development proceeds. Similarly, future changes brought about by the restoration works in fall 2017, through the removal of sheet pilings, will likely alter social-ecological feedback loops, including future development proceedings.

4.9 Social-Ecological Systems Summary:

Social-ecological systems are constantly shifting (Pérez-Soba & Dwyer, 2016) as historical and contemporary feedback loops interact (Kittinger et al., 2012). Feedback loops can be expressed at multiple scales, with global, regional and local interactions (Scholes, Reyers, Biggs, Spierenburg, & Duriappah, 2013). Moreover, feedback loops can have reinforcing or dampening effects on social-ecological systems (Kittinger et al., 2012). In Ashton Lagoon, conservation status prior to construction led to a reinforcing feedback loop, as ecological protection safeguarded ES. However, global tourism acted as an initial distal driver, which triggered numerous ecological changes, and consequently the loss of ES.

In the contemporary context, human use patterns have adapted to system conditions to restore certain ES (provisioning: food, regulating services: erosion mitigation, water treatment, carbon sequestration, and protection from inclement weather events, habitat and supporting services, as well as cultural services: recreation, tourism, and sense of place) (Figure 8). Additionally, new restoration work has removed sheet pilings from the marina infrastructure (SusGren, 2018), potentially affecting flow rate. Alterations in flow rate could lead to additional feedback loops, some being reinforcing, while others may be dampening.

5.0 Conclusion and Recommendations:

Development is meant to propel humanity forward and improve lives of citizens, however, when underlying drivers behind development do not consider the needs of resource users, both local and global, the loss of ES can incur negative consequences. In marine systems, development can have a wide range of ecological impacts, as ESC, or lack thereof, can increase the spatial footprint of unintended environmental harms. Moreover, the permanence of hard coastal infrastructural works means that negative environmental impacts often cross temporal scales, unless they are adequately addressed. Ashton Lagoon is an example of poorly planned coastal development that did not consider the needs of resource users, as an underlying distal driver (economic returns from tourism) was the main factor behind the development projects inception. While more severe ecological harm would have likely been incurred if the project was completed, numerous social and ecological damages still occurred, with no social benefits accrued. While social systems have been affected by the ecological changes post construction, social systems have adapted. This has led to new human use patterns, with some causing dampening effects on the system (anchoring in seagrass beds), while others initiated reinforcing feedback loops that have gradually improved ecological conditions (e.g. mangrove restoration).

While restoration may have improved ecological conditions, human use patterns continually shift, and new development projects could introduce dampening effects on the system. To mitigate this fact, it is recommended a co-management agreement be formed between the local community, and institutions that are environmentally conscious. Hence, instead of approaching development from the top down, which occurred with the construction of the marina and causeway, local citizens will be given a voice to influence future development projects. Moreover, co-management has been proven to be a salient development strategy, even with the complex management requirements of marine systems (Mahajan & Daw 2016). Thus, communities can empower themselves when given the right tools, and engage in environmentally sustainable practices, with the involvement of SusGren in activities occurring in Ashton Lagoon already initiating this process.

6.0 Bibliography:

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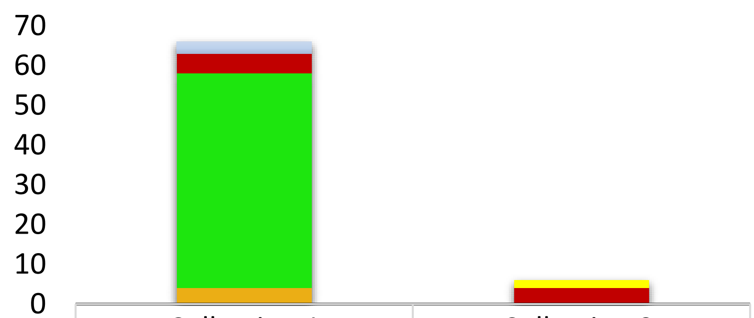
Appendix 1

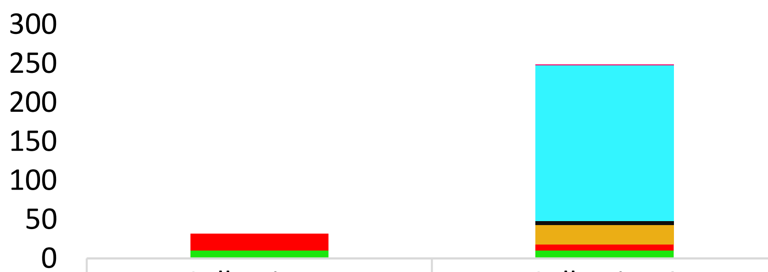
Fish:

Transect 1



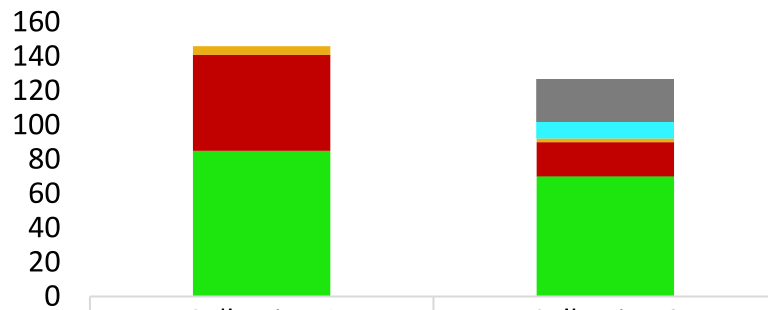
	Collection 1	Collection 2
Surgeonfish	3	
Snapper		2
Damselfish	5	4
Wrasse	54	
Parrotfish	4	

Transect 2



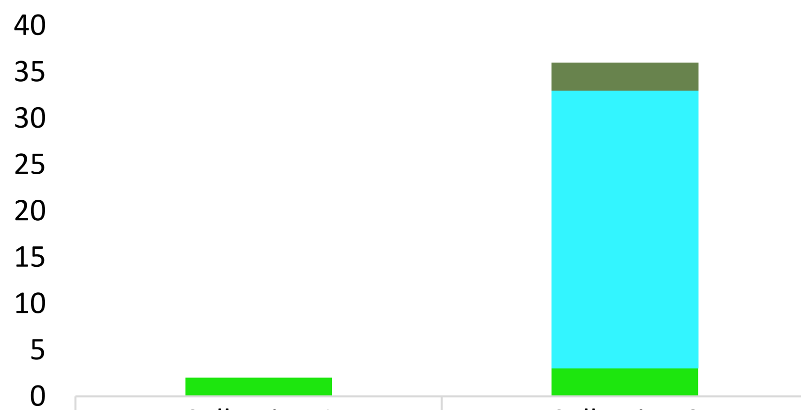
	Collection 1	Collection 2
Lizardfish		1
Fry		200
Grunts		5
Parrotfish		25
Damselfish	22	8
Wrasse	10	10

Transect 3



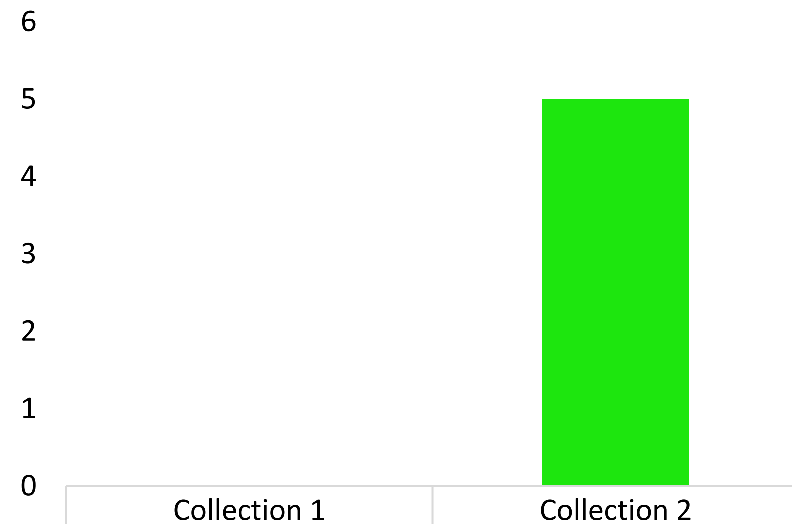
	Collection 1	Collection 2
Silvery Fish		25
Fry		10
Parrotfish	5	2
Damselfish	56	20
Wrasse	85	70

Transect 4



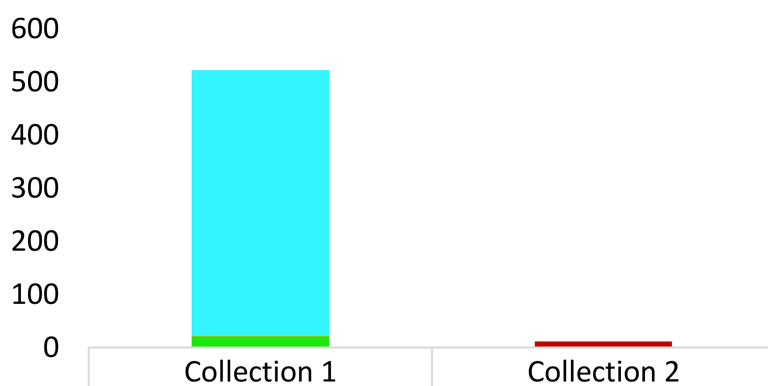
	Collection 1	Collection 2
Other		3
Fry		30
Wrasse	2	3

Transect 5

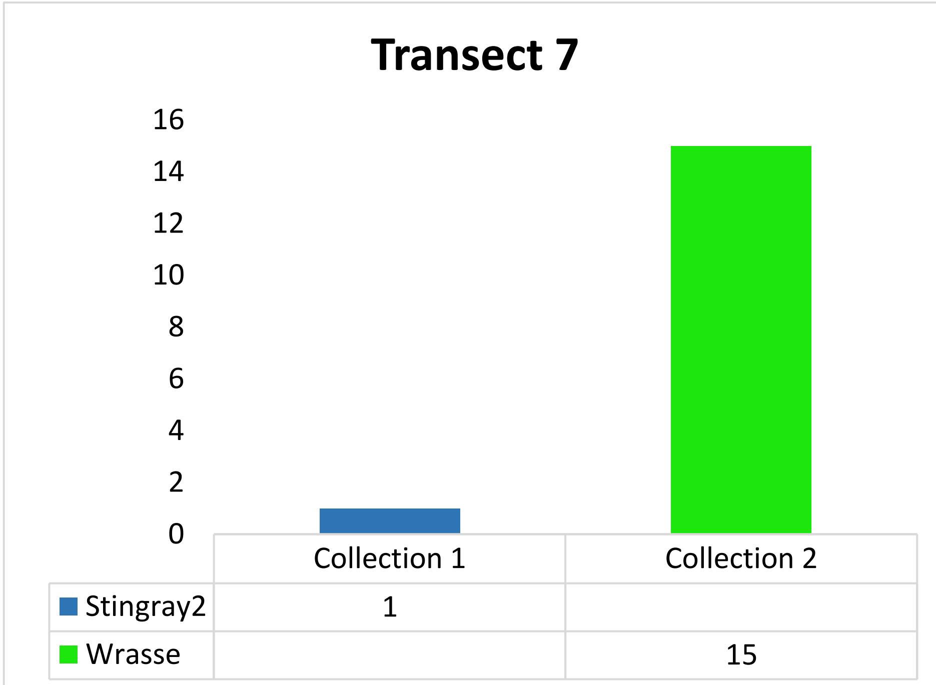


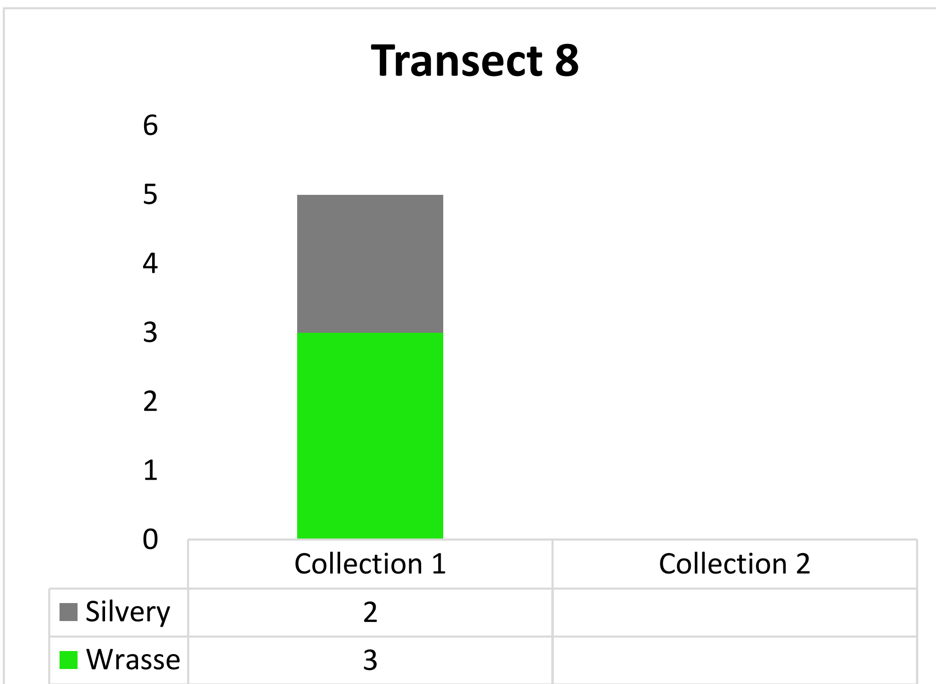
	Collection 1	Collection 2
Wrasse		5

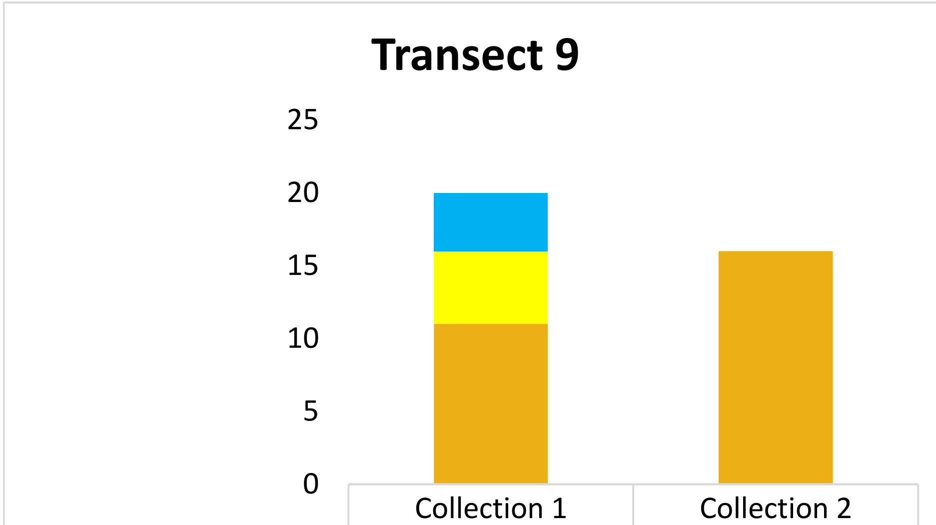
Transect 6



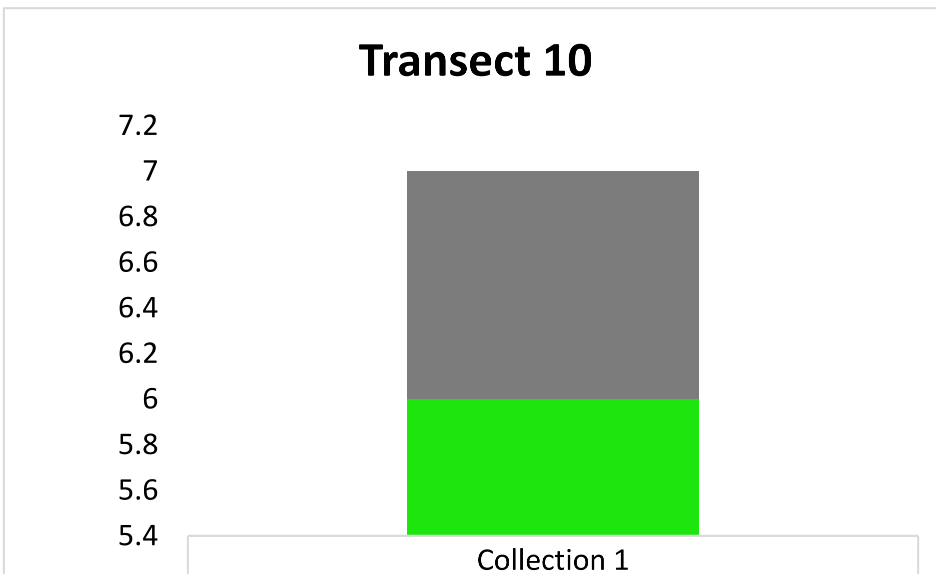
	Collection 1	Collection 2
Fry	500	
Parrotfish	1	
Damselfish		9
Wrasse	21	2


Transect 7
16
14
12
10
8
6
4
2
0
Collection 1
Collection 2
Stingray2
1
Wrasse
15


Transect 8
6
5
4
3
2
1
0
Collection 1
Collection 2
Silvery
2
Wrasse
3

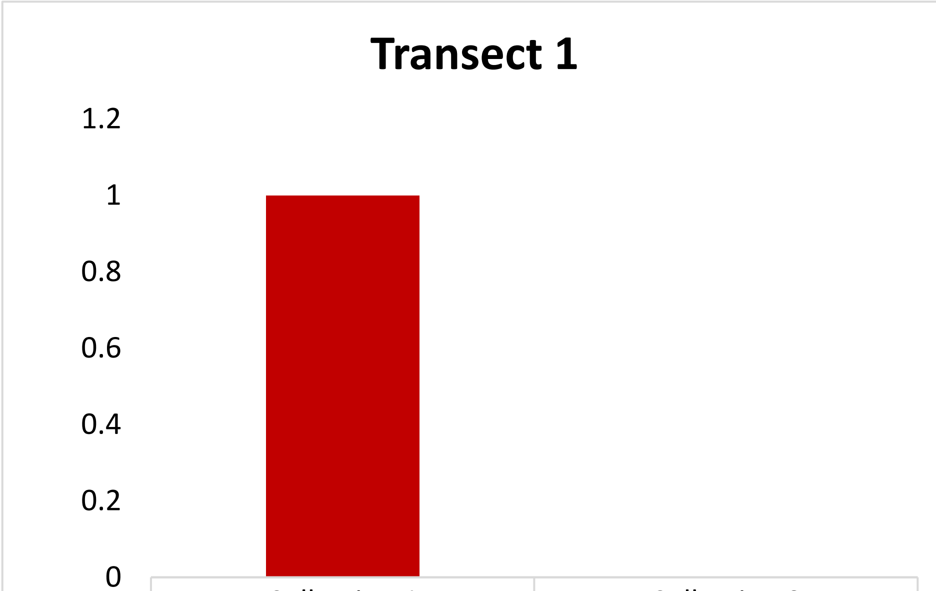


	Collection 1	Collection 2
Unknown Juveniles	4	
Snapper	5	
Parrotfish	11	16

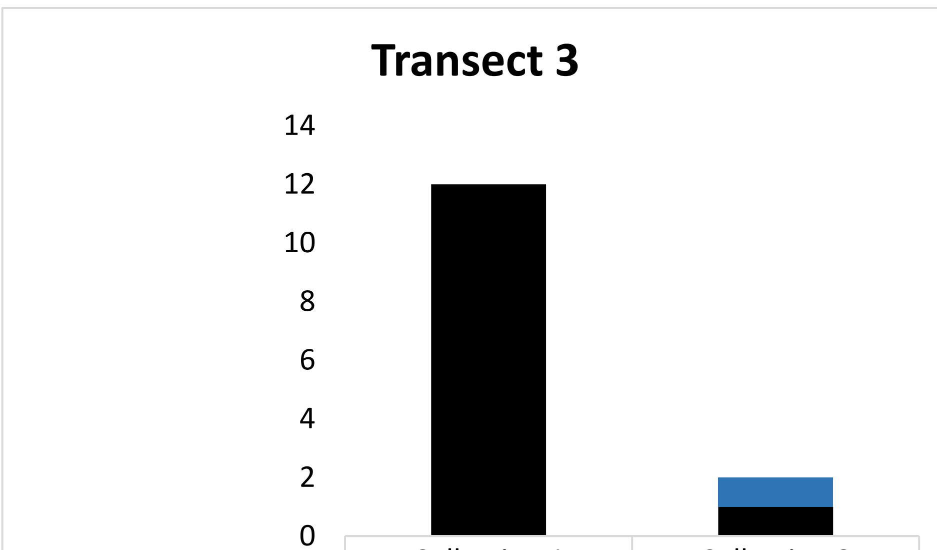


	Collection 1
Silvery	1
Wrasse	6

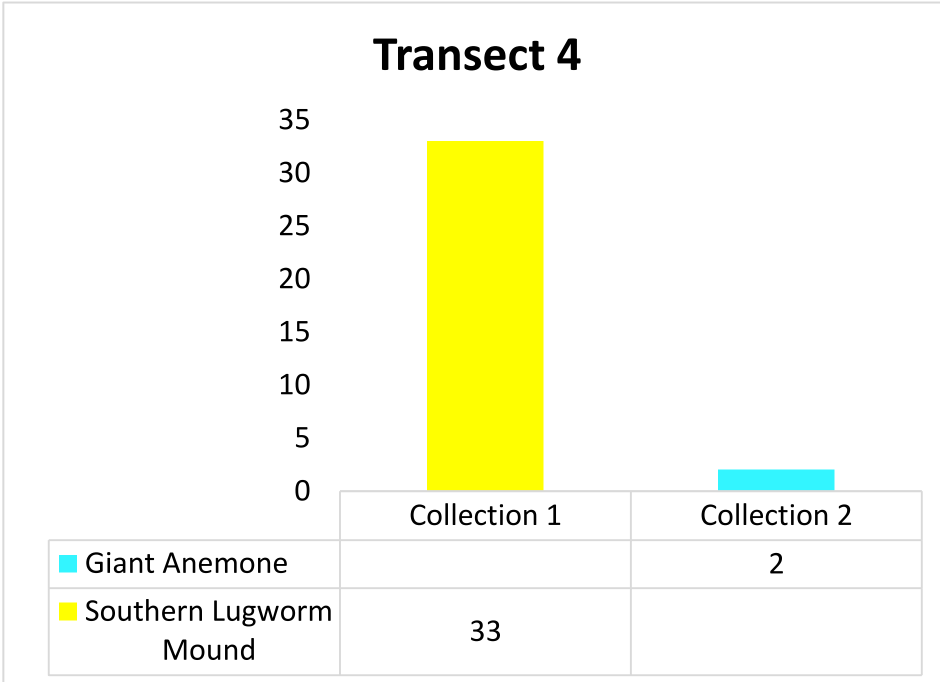
Invertebrates:

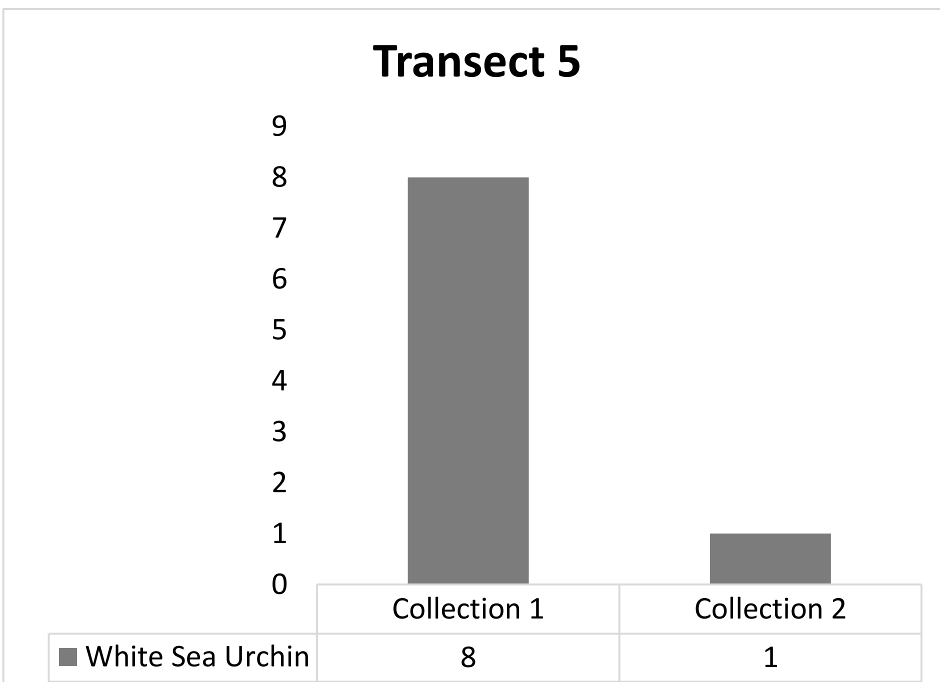


	Collection 1	Collection 2
Crab	1	

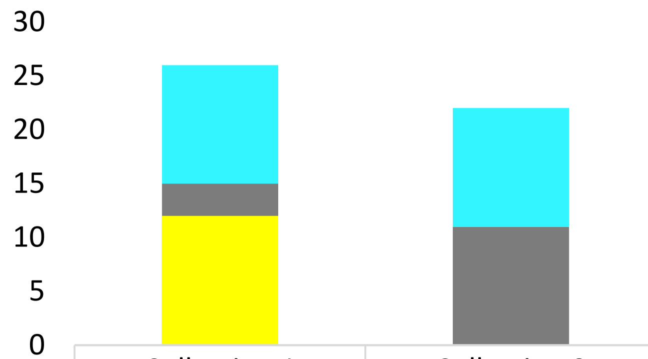


	Collection 1	Collection 2
Ctenophore		1
Rock Boring Urchin	12	1


Transect 4
35
30
25
20
15
10
5
0
Collection 1
Collection 2
Giant Anemone
2
Southern Lugworm Mound
33

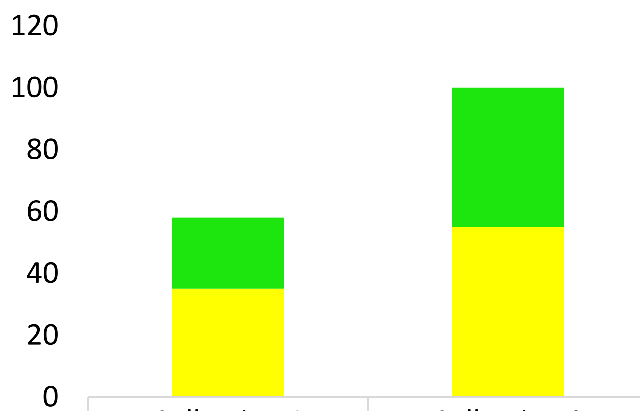

Transect 5
9
8
7
6
5
4
3
2
1
0
Collection 1
Collection 2
White Sea Urchin
8
1

Transect 6



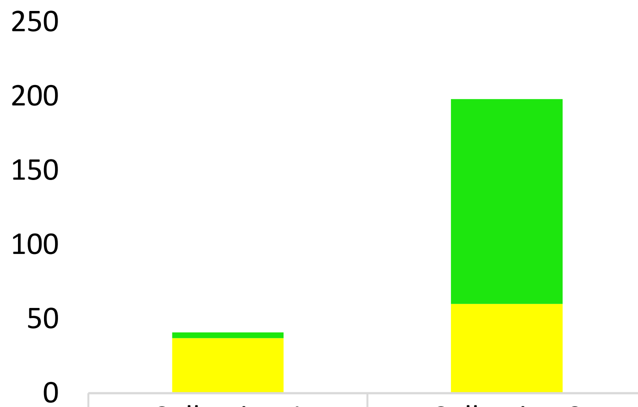
	Collection 1	Collection 2
Giant Anemone	11	11
White Sea Urchin	3	11
Southern Lugworm Mound	12	

Transect 7



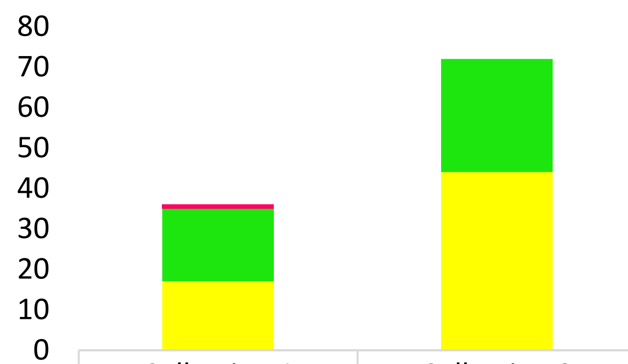
	Collection 1	Collection 2
Upsidedown Jellyfish	23	45
Southern Lugworm Mound	35	55

Transcect 8



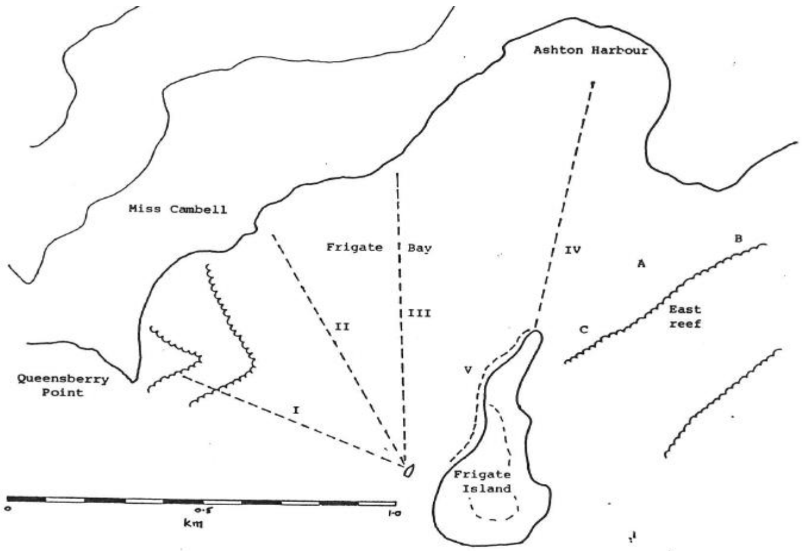
	Collection 1	Collection 2
Upsidedown Jellyfish	4	138
Southern Lugworm Mound	37	60

Transect 9

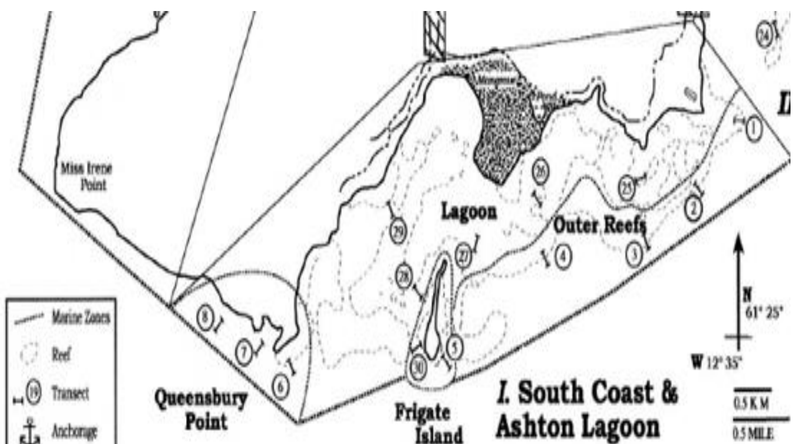


	Collection 1	Collection 2
Sea Cucumber	1	
Upsidedown Jellyfish	18	28
Southern Lugworm Mound	17	44

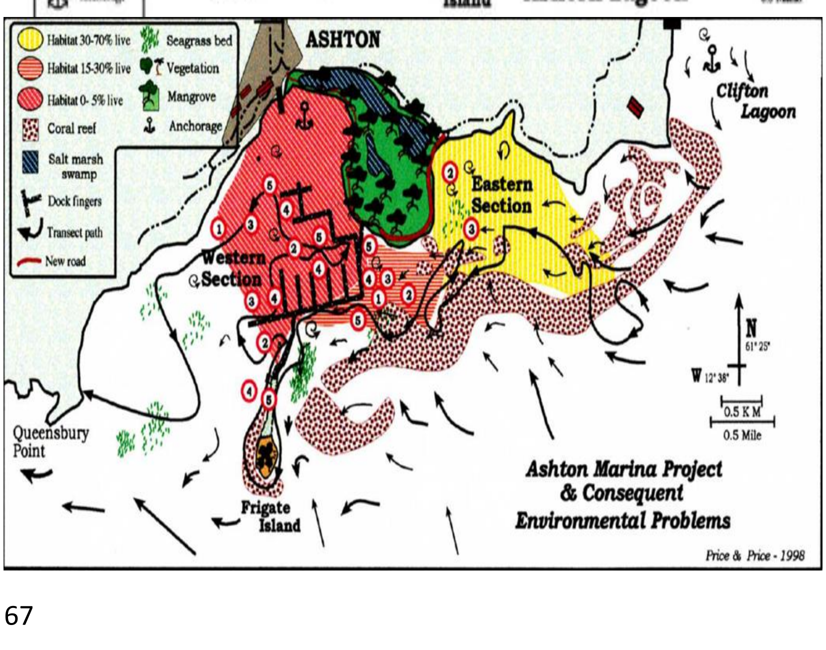
Appendix 2



Transect paths for the 1986 study of Ashton Lagoon (Smith, Oxenford, & Price).



Map of Ashton Lagoon showing a collection of 30m transect profiles conducted for the nearshore assessment of Union Island, in 1994 (Price & Price, 1994a).



Map of Ashton Lagoon, its habitat types, currents, and the path of the manta tow survey perfomred in 1998 (Price & Price, 1998).