Reef Balls as a Proxy Habitat for Fish Species in Lieu of Available Suitable Natural Coral Reef, off the South-West Coast of Barbados, Caribbean Sea.

By

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ABSTRACT

Understanding the habitat requirements for a variety of fish species with outstanding commercial and/or conservation value will become more important as managers develop an increasingly holistic approach to fisheries and nature conservation within the coastal zone, due to the rising human inflicted impacts. Barbados is home to many coral reefs, however, most are degrading due to overfishing, rise in sea surface temperature, and marine pollution. Artificial reefs have been used to try and help repopulate the coral habitat in Barbados, with the most recent being Reef Balls which are hollow concrete circular structures. This study investigates if Reef Balls could act as a proxy habitat for fish species in lieu of available suitable natural reef, by examining the fish species richness and fish abundance at a site off the south-west coast of Barbados, in the Caribbean Sea. The data for this study was collected from the Barbados Marine Trust for April 2004 to December 2005, and a professional diver collected data from February to May 2014, both using the reef-fish visual census. The Reef Ball fish abundance and species richness were compared with two different neighbouring natural reefs, and a site similar to where the Reef Balls were placed initially, using t-tests, ANOVA, MDS and ANOSIM. The Reef Balls attracted fish from the surrounding area which improved the fish abundance and species richness at the site. This produced similar fish abundance to the patch reef; however, the Reef Balls had significantly less species richness. When compared to the bank reef, the Reef Balls had significantly less fishes and species richness. However, the Reef Balls provided an essential niche for specific species as 11 out of 61 species were only found at the Reef Balls.

INTRODUCTION

Coral is composed of many polyps which are animals that have a symbiotic relationship with algae (zooxanthellae). The zooxanthellea provides 90 % of the corals energy while receiving shelter and nutrients from the coral (NOAA, 2011). A colony of coral polyps forms a coral reef, which provides habitat for a vast range of organisms

(Moberg and Folke, 1993); protect coastlines from storms and erosion (Hardy, 2003); and serves an as economic resource for tourism and fisheries (Hardy, 2003). Coral reefs are found in more than 100 countries in tropical regions (Côté and Reynolds, 2006). They cover a mere 0.1 % of the ocean's surface, yet host a disproportionate amount of the world's biodiversity, including almost a third of the world's marine fish species (Côté and Reynolds, 2006). Corals are highly susceptible to environmental changes and anthropogenic impacts such as pollution, climate change and overfishing (NOAA, 2011), due to their need for shallow, warm (21 - 29 °C), clear water conditions (Hughes, et al., 2007). Global coral cover has declined by approximately 5 % per year since 1997 (Reef check, 2007).

Coral reefs contain the richest biodiversity of macro-fauna in the seas (Figure 1) with approximately 50 % of individuals and 40 % of species cryptic (occupies crevices) (Ackerman and Bellwood, 2000). However, it is thought that only 10 % of the overall species are known (Sheppard et al., 2009). Due to major tectonic, geological, and climatic events (Veron, 1995) the Atlantic region, including the Caribbean, has only 10 – 20 % of the number of fish species compared to the most species rich regions of the Pacific (Karlson and Cornett, 1998). Diversity will be further affected at a local level due to currents and biological factors such as swimming capacity and length of larval phase (Sheppard, et al., 2009). This is why almost all fish species that inhabit coral reefs exhibit a bipartite life cycle with a pelagic larval stage (Robertson, 1973), therefore providing great dispersal distance and creating a wider variance of fish species (Bernardi et al., 2001). High rugosity is associated with reefs with a high abundance of hard corals, where the number and range of gaps can provide refuge and homes for various species (Lee, 2006; Friedlander and Parrish, 1998).

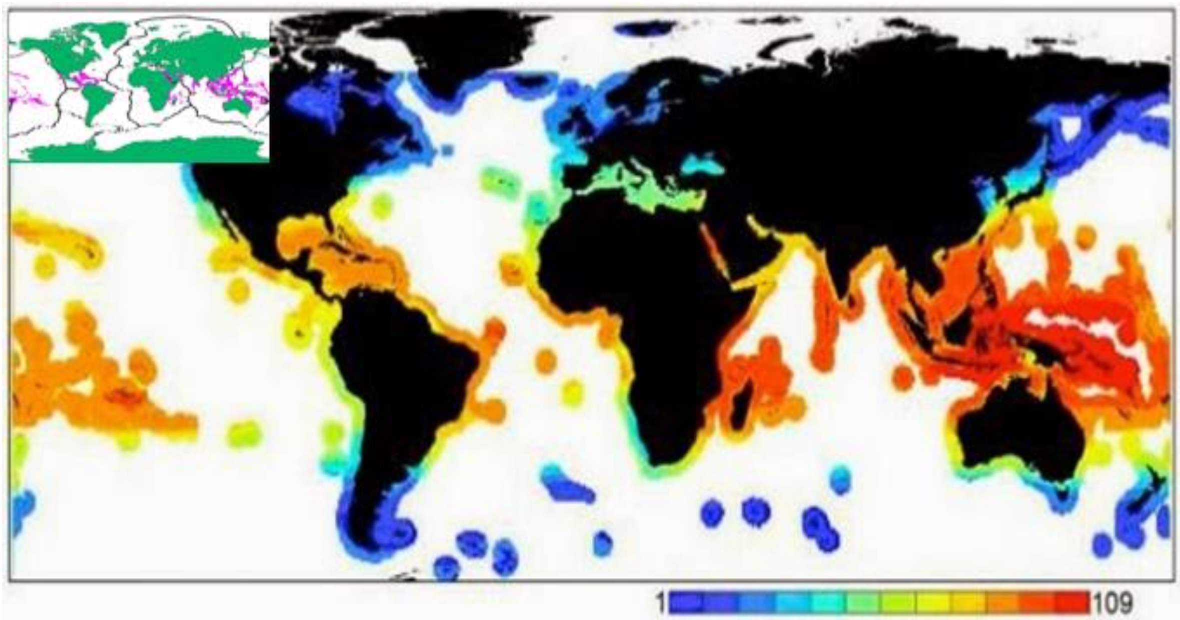

Figure 1. Global sea fish species diversity are shown to be the highest at coral reefs (map in the top left show the locations of coral reefs globally) (Malmquist, 2013).

An artificial coral reef is one method of ecosystem restoration, the objective of which is to return an ecosystem to a close approximation of its condition prior to disturbance (Cairns, 1995). In instances when restoring the reef through indirect action, reef repair and/or transplantation is not viable, installation of artificial reefs can be used. The main goals for this restoration method are; the mitigatation of reefs damaged by anthropogenic activity; the altering of currents; the restricting of rubble; the restoration of habitat by providing substrate and refuge; the conserving of biodiversity and the enhancing of the re-establishment of damaged reefs; and by providing aesthetically pleasing structures for tourism (Spieler et al., 2001; Hixon et al., 1999). There are two categories of artificial reefs; (i) materials of opportunity, and (ii) purpose-design reefs. Materials of opportunity are objects sunk to form reefs, such as car or ships/boats, but recent evidence suggests these can introduce pollutants which destroy the marine habitat (Tallman, 2006). This has led to the alternative, purpose-design reefs, being used more frequently. They can be made from materials such as concrete, limestone, and PVC, and can be made into a variety of shapes and sizes (Tallman, 2006; Oren and Benayahu, 1997). Spieler et al., (2001) suggested that one of the most successful artificial reefs are those which are composed of concrete, and they are one of the most commonly used, as it creates a similar framework to a natural reef. There are a variety of different artificial reef modules that are composed of concrete such as Reef Balls, Lindberg Blocks, and Reef Pyramids.

The size of artificial reefs can affect fish assemblage structure, but evidence is contradictory. Jordan et al (2005) stated large artificial reefs are expected to support greater abundance, biomass, and richness values, by offering food and shelter in order to establish permanent populations. However, other studies have stated that small artificial reefs have higher densities and richness values than large artificial reefs due to attracting fishes from a proportionally larger area as they have a higher perimeter-to-area ratio (Jordan et al., 2005; Ambrose and Swarbrick, 1989). Jordan et al., (2005) concluded that smaller modules that are widely spaced may support the most abundant and diverse fish assemblages. Walsh (1985) also reported increasing abundance in fish when artificial reefs were isolated from natural reefs. Comparative studies of artificial reefs and natural reefs show great similarities in species composition (Recasens et al., 2006), however, species abundance and biomass may differ considerably (Rilov and Benayahu, 2000). A study of Reef Balls off the coast of Brazil, found that fish abundance and fish species richness (51 species at artificial reef and 55 species at natural reef) between Reef Balls and a natural reef were comparable. However, the fish species diversity was significantly different with 24 species exclusive to natural reef, while another 20 species were solely in the artificial reef habitat (Hackradt et al., 2011).

Barbados is the most easterly of the islands in the Caribbean; it is an uplifted fossil coral island and is surrounded by 2 - 3 km wide shelf that supports a variety of coral reefs (Hoetjes et al., 2002). The total area covered by coral reef is approximately 90 km^2 (Burke and Maidens, 2004) (Figure 2). The coral reefs provide a wide range of goods and services including seafood, numerous recreation opportunities, habitat, and coastal protection, also benefits indirectly such as jobs, and tax revenue generated from fisheries and marine tourism (Schuhmann et al., 2008). The west and south coasts of Barbados have been identified as being exposed to significant anthropogenic threats, with reefs particularly threatened by over fishing and coastal development in Barbados (Cermes, 2012). In 2005 there was a major bleaching event throughout the Caribbean Region; this was caused by the sea surface temperature increasing 1 – 2 °C which caused the coral to expel their zooanthellae as a stress response (Rodrigues and Grottoli, 2007; Glynn, 1993). This one event alone killed 40 % of the coral in the Caribbean (Eakin et al., 2010) (Figure 3) with cumulative losses in Barbados being 42.4 % and 31.3 % of live coral cover from deep and shallow reefs respectively (Oxenford et al., 2008). Before this major bleaching event, the main threats to coral reefs were poor water quality caused by coastal construction; tourism infrastructure; inland agriculture; storms; and by the over-exploitation of fish and corals (Bouchon et al., 2005). The study site for this paper, known as “Asta”, is located on the south-west coast of Barbados as highlighted in Figure 2; therefore the natural coral reef located there will be particularly threatened from the anthropogenic threats mentioned. Asta consists of two different types of coral reefs; a patch reef and a bank reef. Patch reefs are small, isolated outcrops of coral, surrounded by sand or seagrass (Logan and Sealy, 2013). Bank reefs are similar to patch reefs, however, are larger in size and therefore have a higher and abundance of fish compared to patch reefs (Logan and Sealy, 2013). Within Asta it was observed to have 28 % sponge cover, 18 % algal cover and 12 % coral cover; this is one of the lowest coral covers in Barbados (FORCE, 2011).

Figure 2. Coral reefs around Barbados, with the Asta site highlighted in the black circle, (CZMU).

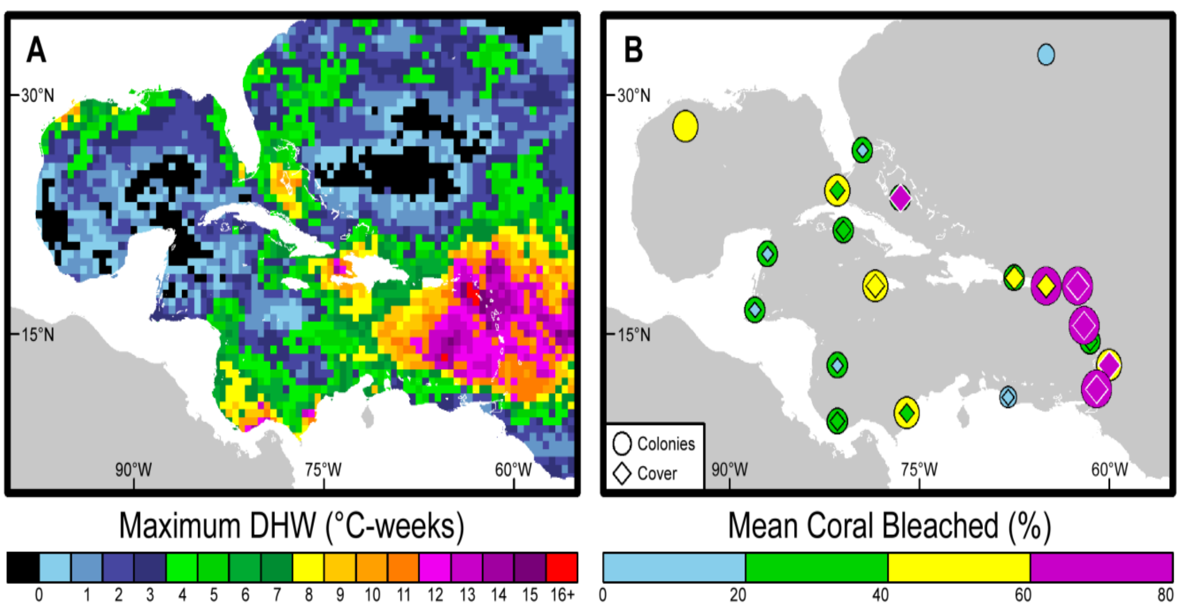

Figure 3. Bleaching event in 2005 in the Caribbean (Eakin et al., 2010). A) Degree Heating Week (DHW) values showing the highest thermal stress. Values >4 °C weeks typically result in significant bleaching; >8 °C weeks typically resulted in widespread bleaching and significant mortality. B) Jurisdictional coral bleached means; marker colour (blue: 0 – 20

%, green: 20 – 40 %, yellow: 40 – 60 %, purple: 60 – 80%) and size (bigger the size the higher the coral bleached mean) denote the severity measured as either percent live coral colonies (circles) or cover (diamonds).

Coral reefs in Barbados have a high density of parrotfish, but a low density of snapper (mahogany and yellowtail), and groupers (graysby and coney), however, they show signs of overfishing as these fish densities are all low compared to the wider Caribbean region (FORCE, 2011). Throughout Barbadian coral reefs, there is a high density of long spined urchin (*Diadema antillarium*) (FORCE, 2011), which suggests a high resilience in the coral, as they feed on macroalgae (this explains the low algal cover found) and therefore facilitates coral growth (Bruno and Bertness, 2001). FORCE (2011) did five line-transect surveys at Asta between 2nd to the 16th March in 2011, and the observed fish abundance was approximately 300, and there were 91 species of fish observed from the sites within the study. The main species of fish found in Barbadian coral reefs are surgeonfish (*Acanthuridea*), wrasses (*Labridae*), damsels (*Pomacentridae*), soliderfish (*Holocentridea*) and snappers (*Lutjanidea*) (King, 2007). Tupper and Hunte (1994) reported a pronounced peak in abundance of fish in Barbados in the period June to November. Likely causes of this seasonal peak include increases in adult spawning activity (Hunt von Herbing and Hunte 1991); seasonal changes in current patterns (Tupper and Hunte, 1994); and/or seasonal variation in survival of planktonic larvae (Tupper and Hunte, 1994).

Barbados uses both types of artificial reefs, all are on the south or west side of the island. There are seven shipwrecks most of which were sunk deliberately for the purpose of creating a habitat for marine life, and thus encourage tourist to visit the sites for snorkelling and/or scuba diving (Barbados.org). There are also three sites, all on the southern side of the island, that have Reef Balls, which is a type of purpose-design reef. Reef Balls are hollow cast cement hemispheres (Kaufman, 2006). The concrete used contains micro-silica which creates a high strength abrasion resistance and has a pH similar to natural sea water (Reef Ball Foundation, 2012). The surface has a variety of textures which enhances the settlement of marine life, and also has holes which allows organisms such as fish to go inside the Reef Balls, (Figure 4). The Reef Ball models used for all the locations were the standard/ultra model. At Asta there are 30 Reef Balls with dimensions of 1.8 m x 1.2 m, which were deployed in clusters of three with approximately 1 m between each Reef Ball module and with 10 metres between each cluster (Figure 5). According to Jordan et al., (2005) and Chittaro (2002) this is considered a large artificial reef, due to size of a reef being measured by volume. The main objectives for the deployment at Asta of the Reef Balls were to facilitate scientific research on the impacts of Reef Balls, and the creation of a habitat for coral and fish species, which would hopefully lead to the creation of a new snorkel and dive site (BMT, 2001). The reason for this was development activities along the west and south coasts of Barbados have been linked to a decline in the abundance and diversity in both the bank and fringing reefs (BMT, 2001).

Figure 4. Reef Ball with coral growth, (Blundell, 2010).

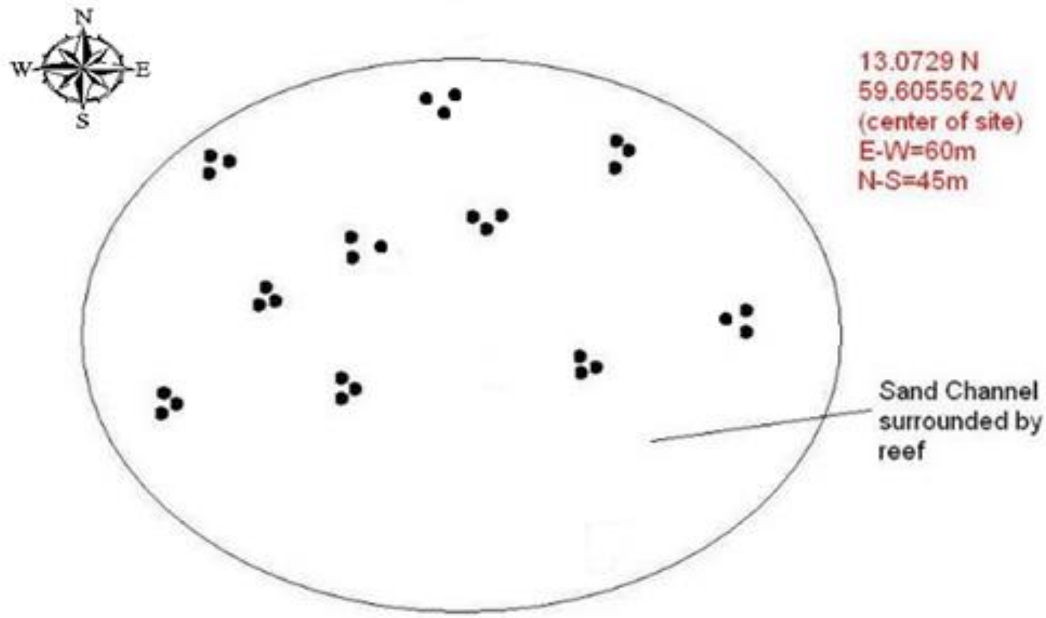

Figure 5. Reef Ball modules in clusters of three at Asta Site, Barbados.

Understanding the habitat requirements for a variety of fish species with outstanding commercial and/or conservation value, will become more important as managers develop an increasingly holistic approach to fisheries and nature conservation within the coastal zone (Jensen, 2002), due to escalating issues such as overfishing, increase in sea surface temperature, pollution and many others. Therefore artificial reefs will be one of the most important research topics of the future. This study investigates if Reef Balls could act as a proxy habitat for fish species in lieu of available suitable natural reef, by examining fish species richness and fish abundance at a site off the south-west coast of Barbados, in the Caribbean Sea. To test this I compared fish species and their abundance at the Reef ball site to sites without Reef Balls, such as neighbouring natural reefs and a sand channel similar to where the Reef Balls were placed initially.

MATERIALS AND METHODS

SITE DESCRIPTION

The study was conducted off the south-west coast of Asta, Barbados. There were four study sites, Reef Ball site; Natural Reef 1; Natural Reef 2; and Pre-Reef Ball Reference (Figure 6), each at approximately a 12 m depth. The area of each site was approximately 1963.5 m^2. Reef Balls were deployed in July 2004 to the eastern section of the wide sand channel, in an effort to increase fish abundance and aggregation in a previously unsuitable habitat. The Reef Ball site has 30 standard/ultra Reef Ball models with dimensions of 1.8 m x 1.2 m, which are in clusters of three with approximately 1 m between each Reef Ball module and with 10 metres between each cluster. Two natural reef control sites and the Pre-Reef Ball Reference site, were established for monitoring to allow comparison of their fish species richness and fish abundance with Reef Ball's fish species richness and fish abundance, in order to identify if Reef Balls can act as a proxy habitat for fish species in lieu of available suitable natural coral reef. Natural Reef 1 is a patch reef which borders the northern and shoreward section of the sand channel, and Natural Reef 2 is a bank reef that borders the southern and seaward section of the sand channel. The Pre-Reef Ball Reference is predominately a sandy area approximately 50 metres west of the Reef Ball site and is representative of the fish community structure (diversity and abundance) that was expected at the Reef Ball site prior to Reef Ball deployment.

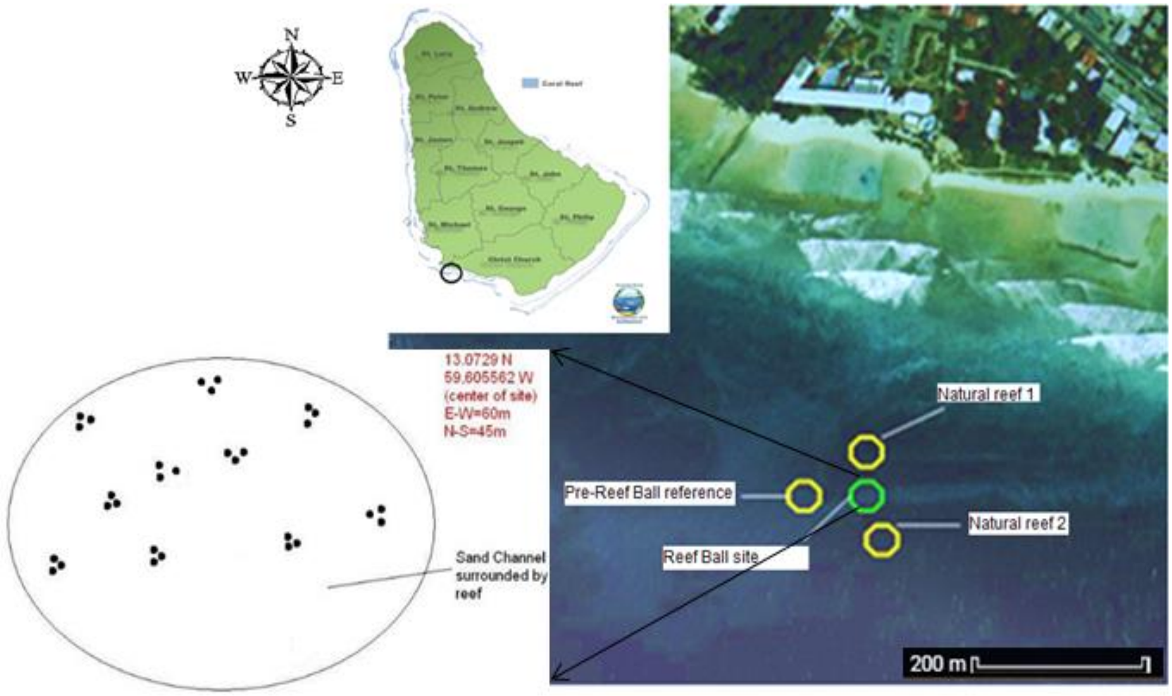

Figure 6.The locations of the Reef Balls; natural reefs; and Pre-Reef Ball Reference, with the overall site, Asta, highlighted by the black circle shown on the map of Barbados, and a magnification of the Reef Ball site. The dark patches in the sea show where the natural coral reef is situated.

DATA COLLECTION

Fish species richness and fish abundance before and after deployment of the Reef Balls (April 2004 to June 2004 and July 2004 to December 2005, respectively) for the four study sites in Asta, were sourced from the Barbados Marine Trust's (BMT) records. Fish species richness and fish abundance were estimated using SCUBA, and a reef-fish visual consensus (RVC) was conducted in order to obtain fishery-independent data (Ault et al., 2006). This is a standard, non-destructive, in situ visual monitoring method in which a stationary diver estimates fish diversity and fish abundance within a randomly selected circular plot of 15 m diameter and encompassing the entire water column from the seabed (containing a study site) to the surface, where possible (limited to visibility) (Figure 7). A five minute acclimation period was conducted to reduce the disturbance of the fish. All fish species were recorded and enumerated over a 10 minute observation period. Digital photographs were also taken at each study site for uncommon fish species observed, and of a Reef Ball for documentation. Surveys were conducted at each site once a month between April 2004 and December 2005. To determine if the fish community structure had changed over time these surveys were repeated eight years later (February to May 2014).

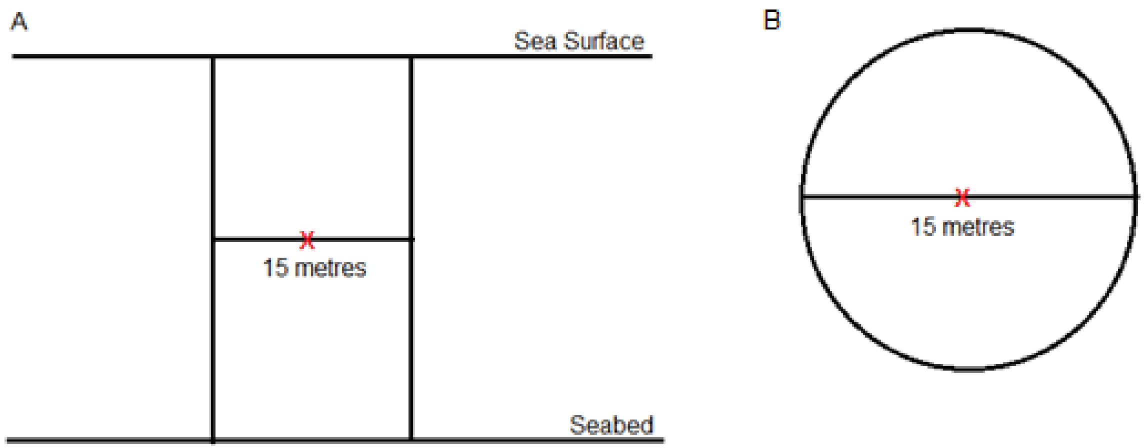

Figure 7. A) Side view of the reef-fish visual census method (Ault et al., 2006). B) Sectional view of the reef-fish visual census method. The red-cross depicts the position of the diver when estimating fish diversity and abundance.

DATA ANALYSIS

All the data was grouped together, and comparisons were done between each site in order to identify if Reef Balls can act as a proxy habitat for fish species in lieu of available suitable natural coral reef. T-tests were done to show the significance of these comparisons. The data was grouped into the different collection periods (April 2004 to December 2005 and February to May 2014) to show the comparisons between the Reef Ball; Natural Reef 1; Natural Reef 2; and the Pre-Reef Ball Reference, over the length of the study. ANOVA and t-tests were done to show the significance of these comparisons. Fish species diversity and fish abundance at the Reef Ball site were compared with Natural Reef 1; Natural Reef 2; and Pre-Reef Ball Reference sites, using multidimensional scaling (MDS) and analysis of similarity (ANOSIM) (PRIMER V5) to show how similar each dive's data was.

RESULTS

A total of 61 species were recorded over the of both whole study periods, with an average of 11.13 ± 0.77 species at each study site, and an average abundance of 83.05 ± 7.31 at each site.

There was no significant difference in the abundance of fish at Natural Reef 1 and the Reef Ball sites *(t-test, P-value = 0.1)*, with an average of 79.7 ± 6.6 and 65.5 ± 8.67 respectively (Figure 8). There were three times as many fish at the Natural Reef 2 than the Reef Ball site *(t-test, P-value = < 0.001)*, with an average of 173.3 ± 12.89 and 65.5 ± 8.67 respectively (absolute difference of 107.8) (Figure 8). There were five times as many fish at the Reef Ball site than at the Pre-Reef Ball Reference *(t-test, P-value = < 0.001)*, with an average of 65.5 ± 8.67 and 13.7 ± 2.63 respectively (Figure 8). There were double the number of fish at the Natural Reef 2 and Natural Reef 1 sites (*t-test, P-value = < 0.001)*, with an average of 173.3 ± 12.89 and 79.7 ± 6.6 respectively (absolute value of 93.6) (Figure 8).

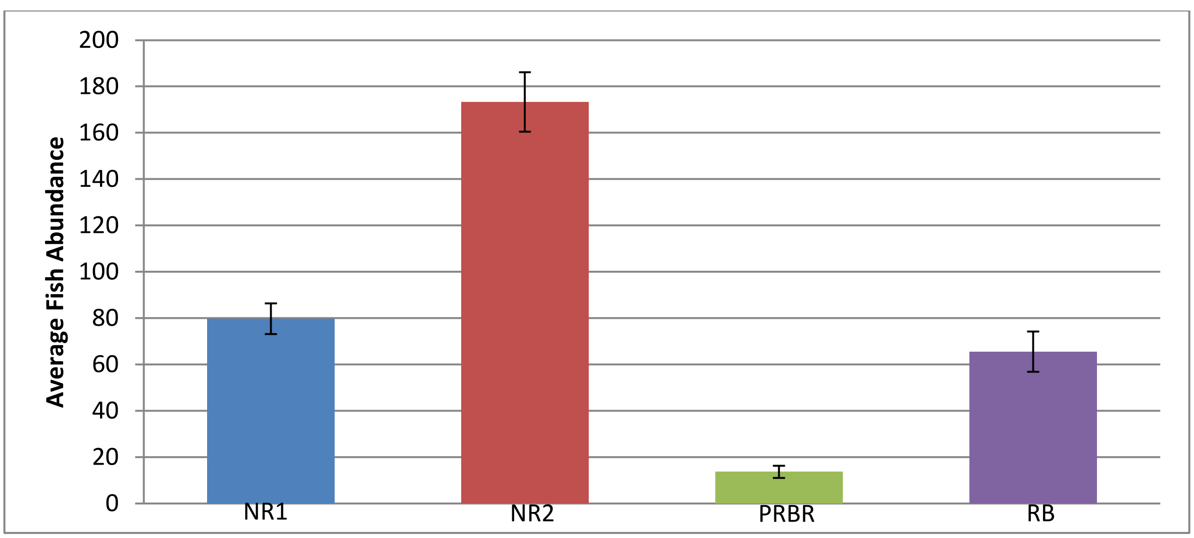

Figure 8. Average fish abundance (mean ± S.E.) at Natural Reef 1; Natural Reef 2; Pre-Reef Ball Reference; and the Reef Ball site.

There was a greater fish species richness at Natural Reef 1 than the Reef Ball site *(t-test, P-value = < 0.001)*, with an average of 13.0 ± 0.75 and 8.26 ± 0.71 respectively (absolute value of 4.74) (Figure 9). There were double the amount of fish species at Natural Reef 2 than the Reef Ball site *(t-test, P-value = < 0.001)*, with an average of 20.3 ± 1.3 and 8.3 ± 0.71 sites respectively (absolute value of 12.0) (Figure 9). There were three times as many fish species at the Reef Ball site than the Pre-Reef Ball Reference *(t-test, P-value = < 0.001)*, with an average of 8.3 ± 0.71 and 3.0 ± 0.31 respectively (Figure 9). There was a greater fish species richness at Natural Reef 2 than at the Natural Reef 1 site *(t-test, P-value = < 0.001)*, with an average of 20.3 ± 1.3 and 13.0 ± 0.75 respectively (absolute value of 7.3) (Figure 9).

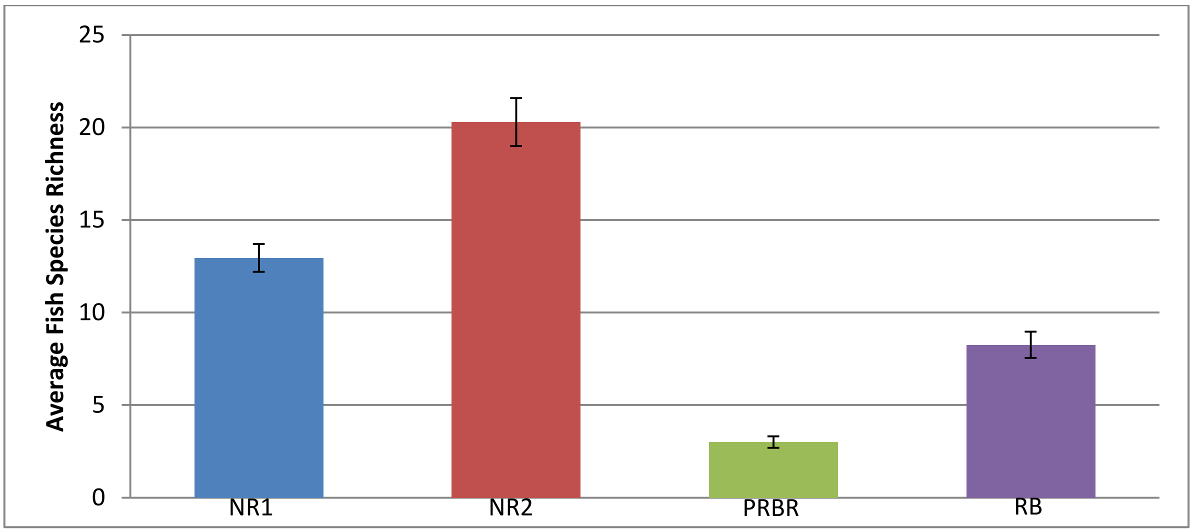

Figure 9. Average fish species richness (mean ± S.E.) at Natural Reef 1; Natural Reef 2; Pre-Reef Ball Reference; and the Reef Ball site.

There were highly significant differences in fish abundance between 2004/2005 (dive 1 - 20) and 2014 (dive 21 – 24) surveys *[F(3, 91) = 43419.89, P-value = < 0.001]*. At Natural Reef 1, Natural Reef 2, and Pre-Reef Ball Reference, there was a highly significant decrease in fish abundance *(t-test, P-values = < 0.001, < 0.01, < 0.001, respectively)*, whereas the Reef Ball site had an increase in abundance with an absolute value of 59.29 *(t-test, P-value = 0.1)*, (Figure 10).

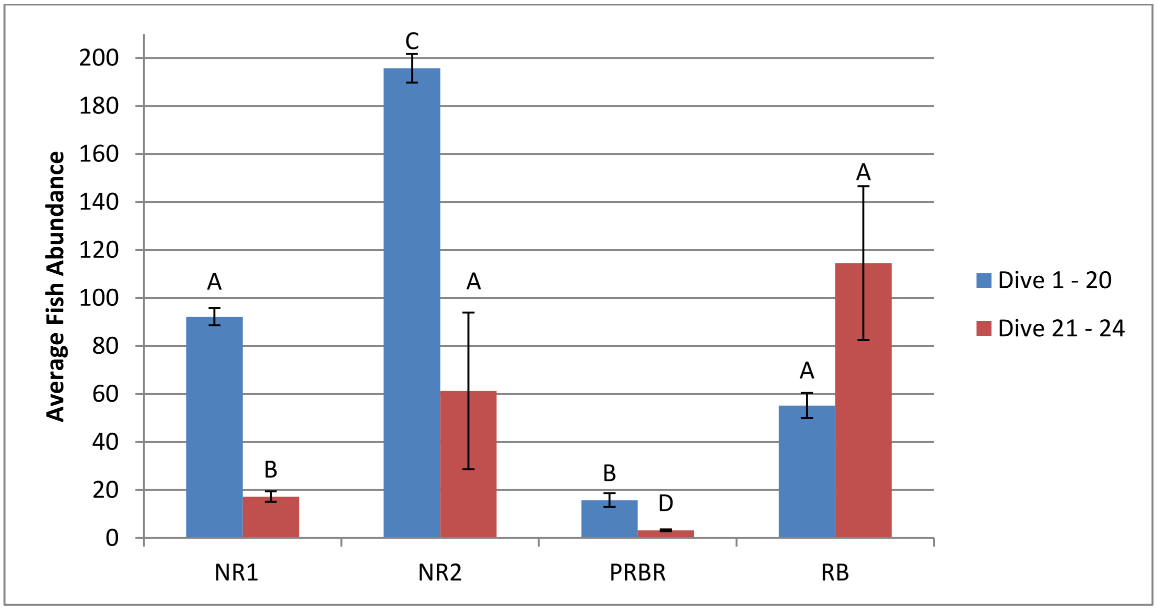

Figure 10. Comparison of the average fish abundance (mean ± S.E) between dive 1 – 20 (April 2004 to December 2005) and dive 21 – 24 (February to May 2014) at Natural Reef 1, Natural Reef 2, Pre-Reef Ball Reference and the Reef Ball site. Where letters differ indicates significant differences between zones ($P < 0.05$) within each time.

There were highly significant differences in fish species richness between 2004/2005 (dive 1 - 20) and 2014 (dive 21 – 24) surveys *[F(3, 91) = 3665.1, P-value = < 0.001]*. At Natural Reef 1, Natural Reef 2, and Pre-Reef Ball Reference, there was a highly significant decrease in fish species richness *(t-test, P-values both = < 0.001,< 0.001, < 0.05)*, whereas the Reef Ball site had an increase in fish species with an absolute value of 3.01 *(t-test, P-value = < 0.05)*, (Figure 11).

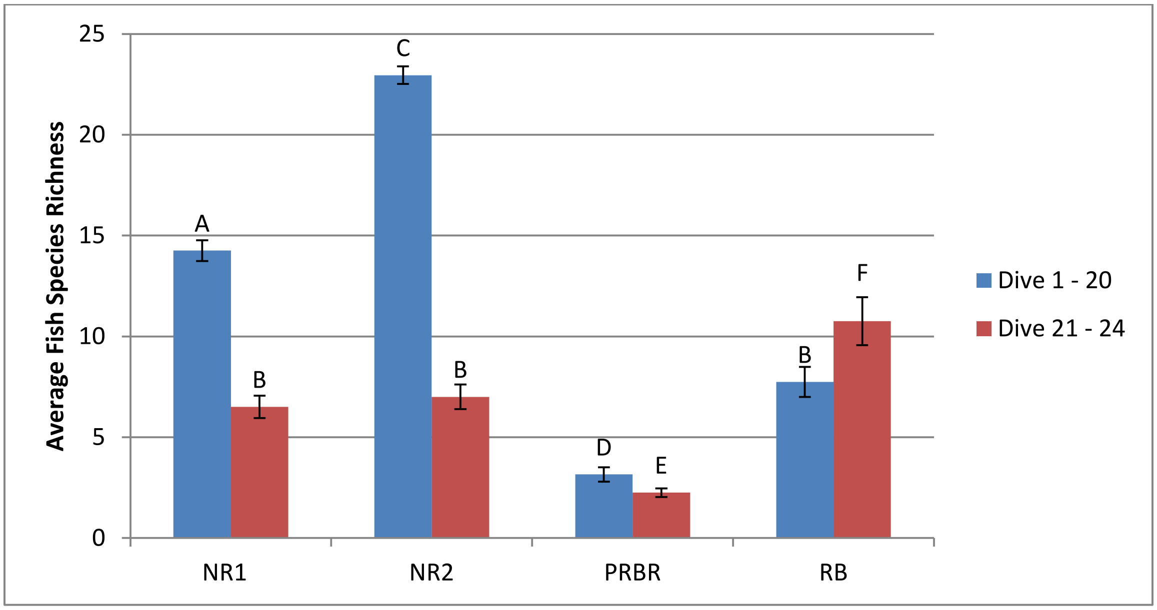

Figure 11. Comparison of the average fish species richness (mean ± S.E) between dive 1 – 20 (April 2004 to December 2005) and dive 21 – 24 (February to May 2014) at Natural Reef 1, Natural Reef 2, Pre-Reef Ball Reference and the Reef Ball site. Where letters differ indicates significant differences between zones ($P < 0.05$) within each time.

There was great dissimilarity of the fish abundance and species diversity observed between NR1, NR2, PRBR and RB site. There were clusters for each of the four sites therefore showing similarities within the sites (Figure 12). However, there are two outliers from PRBR (February 2005 and July 2005) which are not shown on the MDS plot as no fish were observed. Data points from the beginning of the study for April to August 2004 and October 2004, of the RB showed similarity with the PRBR cluster (green squares). The data points from 2014 RB were the furthest away from the RB cluster, therefore showing changes in fish abundance and species richness. Data points from 2014 for NR1 and NR2 overlapped in the PRBR cluster, therefore showing a change in fish abundance and species richness after eight years.

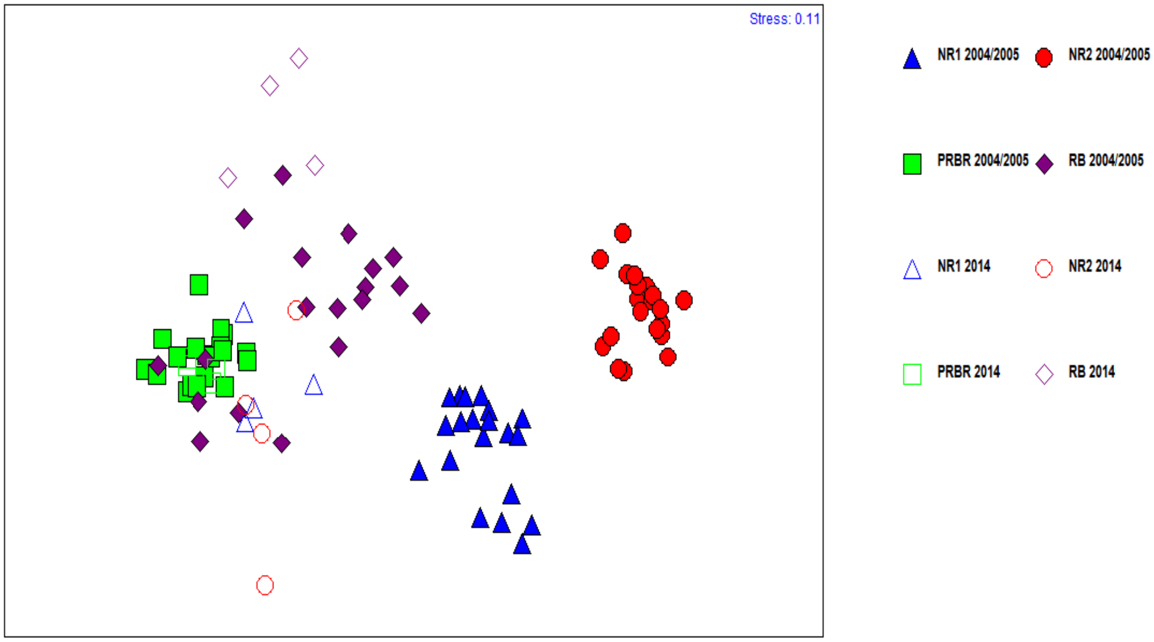

Figure 12. MDS plot of each dive (fish abundance and species richness) from Natural Reef 1 2004/2005 (blue triangle), Natural Reef 1 2014 (blue triangle outline), Natural Reef 2 2004/2005 (red circle), Natural Reef 2014 (red circle outline), Pre-Reef Ball Reference (green square), Pre-Reef Ball Reference 2014 (green square outline), Reef Ball 2004/2005 (purple diamond) and Reef Ball 2014 (purple diamond outline).

One-way ANOSIM analysis demonstrates that there was a highly significant variation in fish abundance and species richness between the four habitat sites (global R = 0.644, P-value = <0.001) (Figure 13). The pairwise comparisons showed great differences between NR1 and PRBR, NR2 and PRBR (R = 0.814, 0.906, respectively); overlapping between NR1 and NR2, NR1 and RB, NR2 and RB, PRBR and RB (R = 0.528, 0.541, 0.695, 0.344, respectively).

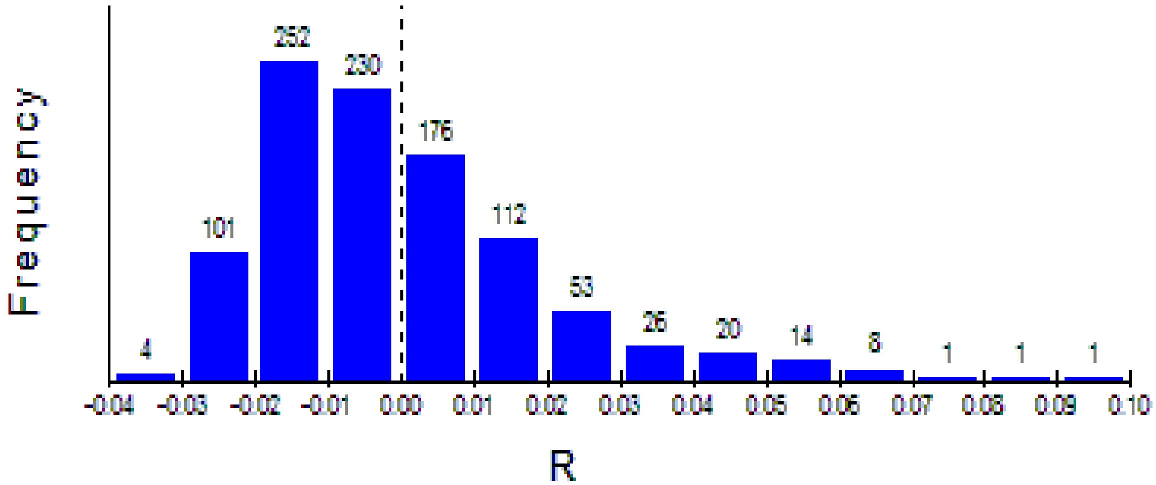

Figure 13. ANOSIM plot of each dive from Natural Reef 1, Natural Reef 2, Pre-Reef Ball Reference and the Reef Ball site.

DISCUSSION

ANALYSIS OF DATA

As mentioned previously understanding the habitat requirements for a variety of fish species with outstanding commercial and/or conservation value will become more important as managers develop an increasingly holistic approach to fisheries and nature conservation within the coastal zone (Jensen, 2002), due to the escalating issues such as overfishing, increase in sea surface temperature, pollution and many others. Therefore artificial reefs will be one of the most important research topics of the future. This study investigated if Reef Balls could act as a proxy habitat for fish species in lieu of available suitable natural reef. There have been contradictory findings from similar studies, such as Recasens et al., (2006), and Riloy and Benayahu (2000), which showed great similarities in species composition; however, fish abundance differed between artificial reefs and natural reefs. Whereas Hackradt et al., (2011), reported similar fish abundance and very different species diversity among the reef types.

The present study found that the Reef Balls (RB) had similar fish abundance to the patch reef (NR1), but were significantly less in abundance than the bank reef (NR2).

Despite sharing many species in common, NR2 had almost three times as many fish than the RB (173.3 ± 12.89 and 65.5 ± 8.67, respectively). This could be due to the Reef Balls occupying a relatively small area (similar to that of the patch reef) compared to the bank reef, which is continuous on the south-west of Barbados. This also holds true in that bank reefs have higher fish abundance than patch reefs, in this study being shown to be double, as was indicated by their averages 173.3 ± 12.89 and 79.7 ± 6.6, respectively. If the RB were isolated from natural reefs, there is a high chance that the abundance of the fish would have been much higher than what was observed, as was reported by Walsh (1985). The RB significantly increased the fish abundance for their area by five folds (65.5 ± 8.67 and 13.7 ± 2.63, respectively) when compared to a site similar to where the Reef Balls were placed initially (PRBR).

However, the Reef Balls were significantly different to the patch reef and also to the bank reef as regards to fish species richness, therefore this conincides with similar findings of Hackradt et al., (2011). Both natural reefs had a significantly greater fish species richness, NR1 had an average of 13.0 ± 0.75 and NR2 had 20.3 ± 1.3, whereas the RB had an average of 8.26 ± 0.71. The patch reef also had significantly less species richness than the bank reef, which reflects the size of the reefs (Logan and Sealy, 2013). There were 11 fish species that were only reported at the RB site out of the total 61 fish species observed for the whole study. Hence, Reef Balls do provide an essential niche for specific species such as the Dwarf Wrasse; Rainbow Wrasse; Sennet; and Lizard Fish, in this instance. This could be due to Dwarf Wrasse, Sennet, and Lizard Fish inhabiting sandy seabeds as well as coral reefs (Lieske and Myers, 1999), therefore the RB provide the perfect habitat as they are placed on sandy beds. The Rainbow Wrasse inhabits coral reefs; therefore they should be found in the neighbouring natural reefs as well not just RB. The RB significantly increased the fish species richness for their area by almost three folds (8.3 ± 0.71 and 3.0 ± 0.31, respectively) when compared to PRBR.

There were highly significant changes between the data from the two collection periods. Both the averages of the fish abundance and species richness were significantly greater from April 2004 to December 2005 for NR1, NR2 and PRBR compared to February to May 2014. However, the RB showed significant increases in fish abundance and species richness from the April 2004 to December 2005 time period, as compared with that of February to May 2014. Over all the fish abundance and species richness decreased significantly between the two data collection periods, with a sum of 358.86 fishes in the first period comprising of 48.1 species observed, compared to 196.25 fishes comprising of 26.5 species observed in the second period. This was shown by the ANOVA tests and MDS plot. Therefore the decrease in fish abundance and species richness for this study could be due to a combination of over-fishing; a rise in sea surface temperature; and pollution, as these directly and/or indirectly impact fish abundance and species. Fishing in Barbados has tradionally been an integral source of employment for the nation. However, in recent years the fishing industry has expanded their fleet size, landings, and species targeted (Mohammed et al., 2003). Mohammed et al., (2003) explains that as a result of the heavy reliance on fishing and the small size of the catchment area, many of the fisheries, including the shallow-shelf reef fisheries, which target species such as Parrotfish, Surgeonfish, Triggerfish and Grunts, are over-exploited. However, the sustainability of the Barbados fishing industry is linked to the wider Caribbean, as the Caribbean Sea is a common resource (Pena et al., 2012). Paddock et al., (2009) reported the overall reef fish density in the Caribbean has been declining significantly for more than a decade, at consistent rates throughout the region (2.7 % to 6 % loss per year). Over-fishing of key fish species, such as Parrotfish (as they graze primarily on algae-coated corals therefore their presence can be representative of a healthy reef system (Egeret al., 2014; Lokrantz et al., 2008) in addition to reducing their numbers, can lead to a physical breakdown of the coral reef system (McClanahan et al., 1996).

A rise in sea surface temperature (SST) can have multiple impacts on fish abundance and species richness within coral reefs, either directly or through coral bleaching and more intense hurricanes. Fish are ecotherms and temperature changes of a few degrees Celsius can influence their physiological condition, developmental rate, growth rate, swimming ability, reproductive performance and behaviour (Wood and McDonald, 1997; Munday et al., 2008). Green and Fisher (2004) reported larval duration of the red and black Anemonefish was 25 % shorter, growth rate was higher, and swimming ability enhanced at 28.0 °C compared with that of 25.0 °C. However, Gagliano et al., (2007) showed signs of increased mortality rates in Ambon Damselfish embryos at 31.0 °C compared with that at 29.0 °C, and larvae survived for a shorter period of time on their endogenous yolk-sac resources at the higher temperatures. All marine ecosystems depend on phytoplankton which are single celled, photosynthetic aquatic organisms that drift with the currents, therefore making their own energy which many other organisms such as zooplankton feed off of, and thus creating a link to this energy for larger organisms such as fish. Most marine organisms are dependent on temperature as a trigger for seasonal behaviour. Different plankton taxonomy have been found moving forward in their seasonal cycles due to the increase in SST (Edwards and Richardson, 2004). This affects many higher trophic levels as they are dependent on the synchronisation with pulsed plankton production (Edwards and Richardson, 2004). This can lead to spring blooms occurring after zooplankton have formed, such as fish larvae (Sommer and Lengfellner, 2008), which leads to a collapse of the food web. It can also affect the marine ecosystem by non-native species entering and taking the resident species niche, therefore causing competition for food and space.

Coral bleaching is a stress response that occurs when the local summer SST rises approximately 1 to 2 °C above the local mean summer temperature (Goreau and Hayes, 1994). Coral may recover from bleaching but if the stress is increased or prolonged they may die. During the collection of data for this study, there was a major bleaching event throughout the Caribbean in 2005, with many areas having over 90 % of the local coral reefs dead, and other areas having 20 – 50 % dead (Wilkinson and Souter., 2008). It was the most severe bleaching event recorded in Barbados, affecting all coral species at all depths; at the study site (Asta) there was an average of 86 % of coral colonies bleached (Bouchon et al., 2005). However, most of the coral died the following year around June 2006, with inshore coral reefs having 20.1 % mortality and offshore reefs 17.4 % (Bouchon et al., 2005). A large number of other organisms associated with coral such as, flatworms, copepods, shrimps, and crabs are likely to experience high mortality during bleaching events (Castro, 1988), this could then lead to a loss of fish abundance and species richness as it impacts the reef food web. The coral-eating fish tend to decrease in population while the herbivore fish increase due to the increase in algae cover on the dead coral (Lindahl et al., 2001). However, this is not as straightforward as many herbivore fish use the coral to hide from predators, therefore some species decline such as the parrotfish (Randall et al., 1990). A study in Sabang, in Indonesia concluded that the fish species richness was not affected by coral bleaching, however fish abundance decreased by approximately 50 % (Rudi et al., 2012). Pratchett et al., (2008) stated that coral loss may also have longer-term consequences for fishes that require live corals as settlement.

The SST needs to be a minimum of 26.5 °C for the development of a hurricane. This threshold is needed in order to provide energy to fuel the hurricane therefore if the SST increases, hurricanes will be more intense as more energy is provided (Arpe and Leroy, 2009). There has been an increase in hurricane activity over the last 20 years. The year 2005 had the most hurricanes on record with 15, followed by 2010 with 12, 2005 also had the most category 5 hurricanes, which are the strongest type of hurricane (Wunderground, 2013). Stronger frequent hurricanes will also have a negative impact on coral reefs, and thus the abundance and diversity of fish. There was no data collected in September 2004 for this study as this is when hurricane Ivan passed. However, it was documented by the BMT (2006) in the months after hurricane Ivan, that NR1 lost most of its soft corals and many of the residential reef fish. A similar but less pronounced pattern was detected at the deeper bank reef (NR2), which was only damaged close to the inner reef/sand interface. After hurricane Ivan, fish counts at both natural reefs declined to the lowest levels documented during the April 2004 to December 2005 period of data collecting. In contrast, there was no change in fish abundance or diversity at PRBR, as it is predominately sand and therefore a much less sensitive habitat. At the RB there was a decrease in fish abundance and diversity for the following month (October 2004), however, this then increased afterwards. BMT (2006) has documented that the Ferris Craig Wreck (a “materials of opportunity” artificial reef on the south-west coast Barbados) located 150 m seaward of the RB, experienced some damage from the hurricane, however, the RB had no structural damage. This could be linked to the RB having a porous design, and therefore allowed the fast moving water to pass through.

Between 2005 and 2014 the human population of Barbados increased by approximately 13,000 (CIA, 2014) which leads to an increase in discharged pollution into coastal ecosystems (Clausen and York, 2008). Additionally, occasional large storms and hurricanes can produce rainfall that can exceed the annual rainfall average in just a day or two, therefore creating runoff which then goes into the sea, taking pollutants with it such as sediments (Speed, 2012). In 2005 there were 66.34 inches of rainfall, this was linked to the passing of hurricane Ivan in September, and it was the highest annual rainfall on record since 1981, which had 68.47 inches (Nurse, 2011). 2001 to 2010 had the highest average decadal rainfall, with 2010 having the highest annual rainfall (72.2 inches) since 1942, therefore showing an increasing trend in rainfall in Barbados (Nurse, 2011). 2010's rainfall was also due to the passing of hurricane Tomas in October. An increase in pollutants, such as sediments, can cause smothering of marine communities with severe cases experiencing complete burial, leading to suffocation of corals; damage to fish by irritating or scouring their gills; reducing visibility which can lead to a decrease in the success of predators; decreases the amount of sunlight which will affect the production of algae and macrophytes which will then impact fishes and other organisms that feed or depend on them (Ongley, 1996; Boatman et al., 1999; Owens et al., 2005; UNEP and GEMS Water Programme, 2008). An increase in nutrients into coastal waters, such as nitrogen and phosphorous compounds (commonly found in fertilizers), can cause eutrophication which can lead to algal blooms, and the depletion in water oxygen content, and thus lead to the mortality in fish (CEP, 2001). Another major pollutant in the Caribbean is pesticides, which are highly toxic and tend to accumulate in the coastal and marine biota, they can cause fish deaths in areas of poor water circulation (CEP, 2001).

Any increase in SST and marine pollution at Asta would also impact the RB fish abundance and species richness, therefore the main reason for the increase at this site is most likely its ability to withstand storms and hurricanes. The RB abundance and species richness could have increased significantly due to their porous design, which as mentioned before helps allow fast moving water through it, as occurs during storms and hurricanes, which would normally damage and dislodge natural reefs. The porous design is also linked to a higher number and variety of refuges to hide from predators, light, or hydrodynamism (Hackradt et al., 2011). There is some evidence that shelter from predation may be more important than food for determining fish abundance (Buekers and Jones, 1997; Krohling et al., 2006). Shulman (1984), reported that the presence of holes, which RB have, enhance predation avoidance and can increase juvenile recruitment, species richness and fish density on small reefs. Many studies such as Bohnsack (1989), Carr and Hixon (1997), Svane and Peterson (2001) have stated that artificial reefs may not increase fish abundance or species richness, but that they attract fishes from the surrounding areas. This could possibly be the case for this study, as there was a documented decrease in fish abundance and species richness after hurricane Ivan at the natural reefs, but an increase was observed at the RB. Artificial purpose-design reefs can recruit coral polyps as they prefer to settle to alkaline substrates, and the leaching of calcium hydroxides from the cement in concretes should provide a more chemically attractive substrate for coral settlement (Anderson, 1996). An artificial reef therefore provides more space for coral polyps to settle on, and thus increases the coral population of an area, which in turn provides more habitats for reef fishes. Also, Perkol-Finkel and Benayahu (2007) found that artificial reefs tend to recruit soft corals, whereas natural reefs favour hard corals. This enhances artificial purpose-design reefs being able to withstand storms and hurricanes; thus a fish's habitat tends to remain undisturbed in comparison to natural reefs during severe storms and hurricanes (Speight and Henderson, 2010).

LIMITATIONS

This study was limited by the eight year gap between the two data collection periods. Continuous data over the entire period would have been able to show precisely when the increases in fish abundance and species richness occurred at the RB site and the natural reef's decreased, along with the possible causal factors. Therefore, with a larger data set the results would have been more significant, showing greater relationships. However, with a time constraint of eight months to complete the study, and with only one data resource for RB in Barbados, it was not possible. Within the data sets there were also some months missing due to bad weather and/or visibility issues, such as September 2004 when hurricane Ivan passed, and January 2014 as there was heavy rainfall which brought a lot of sediments into the coastal waters.

There are also a few limitations to the reef-fish visual census methodology used, such as, sources of error due to the diver/s and sources of error due to fish behaviour. The diver/s must be able to record information as quickly as possible such as species identification and quantity with a reasonable level of accuracy, the slightest hesitation will result in a loss of data. There is also the risk of counting the same individual fish multiple times as they swim around the study site. There were different divers used for each study time period, this could also provide further limitations as one of the divers could be less experienced in identifying fish than the other. Also only some of the scientific names of the fish were provided by the divers, therefore the diver/s could have given the same colloquial name for two different fish species. Interactions with fish can sometimes change their behaviour, for example some can be attracted to the divers such as coral trout, whereas some swim away from the divers such as spangled emperors (Labrosse et al., 2002). Yet other sources of error due can arise due to the behavioural distribution of fish species, for example some fish species are nocturnal and therefore will not be recorded in the data sets as they will not be seen during the day when the diver/s collect the data.

CONCLUSION

The total fish abundance and species richness decreased over the study periods, with a total sum of 358.86 fishes in the first period, which comprised of 48.1 species recorded, as compared to the second period, when only 196.25 fishes were recorded which comprised of 26.5 species. This proves that the Barbadian waters are still facing threats, the major ones being overfishing; rise in SST; and marine pollution. Nonetheless, the data shows that fish abundance and species richness improved at the Reef Ball site, however, due to the total decrease in abundance and species richness in the area, it is postulated that this observed improvement is possibly due to the attracting of fishes from the circumambient areas , rather than an actual increase. The fish attraction to the Reef Balls could be attributed to their porous design which has a higher number and variety of refuges to hide from predators, light, and hydrodynamism. The porous design also allows the Reef Balls to withstand hurricanes and severe storms better than natural reefs, as it helps fast moving water move through, as was observed with hurricane Ivan. Therefore a fish migration away from the damaged neighouring natural reefs to the Reef Balls would have caused a further ‘increase’ in fishes. The Reef Balls data produced similar fish abundance to that of the patch reef; however, the Reef Balls had significantly less species richness. When compared to the bank reef, the Reef Balls were significantly different, with the bank reef having three times as many fish and approximately two times as many fish species. This was linked to the Reef Balls occupying a relatively small area as compared to the bank reef, which is continuous on the south-west coast of Barbados. The Reef Balls did, however, provide an essential niche for specific species as 11 out of 61 species were only found at the Reef Ball site, such as Parrotfish, Surgeonfish, Triggerfish and Grunts.

There is a need to reduce or stop stressors on coral reefs (both natural and artificial), such as overfishing (destructive fishing) and marine pollution. This will improve overall coral health and also increase ecosystem resilience to coral bleaching. Stakeholders that rely on coral reefs will need to be engaged and educated, so that they will be able to better understand the benefits provided by the reefs and in turn help to protect them. This will lead to an increase in fish stocks and marine biodiversity in the wider Caribbean as well as the area.

Further research is required into the reasons as to why specific fish species are attracted to the Reef Balls but do not appear in the circumambient areas, as this could help improve the future design of Reef Balls. More research is needed appertaining to what species of fish are attracted to the Reef Balls from the surrounding areas and what fish species are actually increasing the total abundance and species richness of the area.

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