Spatial variation in coral abundance surrounding Boulder Island, Mergui archipelago.

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ABSTRACT

Percentage abundance of *Acropora* spp., *Heliopora coerulea, Montipora tuberculosa* and bleached coral was taken from five sites surrounding Boulder Island to determine if there was any geographic variability between sites, as well as inner and outer bay variability. Coral Point Count 4.1 (CPCe) was used to analyse photographs taken along transects at each site and comparison of sites was then conducted using IBM SPSS Statistics 24. *Acropora* spp. abundance appeared to be influenced by the southwest monsoon, *H. coerulea* abundance was best explained by its limited larval dispersal, *M. tuberculosa* abundance appeared to be influenced by neighbouring coral species and bleached coral abundance was most likely due to rising sea surface temperatures coupled with El Niño anomalies. This research provides useful information on the abundance of the three most dominant coral species surrounding Boulder Island, as well as providing some possible, initial explanations into their geographic variability using available literature.

INTRODUCTION

The Mergui (Myeik) archipelago is located in the NE Andaman Sea off the southern coastline of Myanmar, Tanintharyi Region (Howard, 2018). The archipelago consists of approximately 800 islands, constituting to an area of around 34,000km^2 (Novak *et al*., 2009; Obura et al., 2014). The region is recognised as a UNESCO site (WHC, 2014) and a Key Biodiversity Area (WCS, 2013), as it contains highly diverse coral reefs, mudflats, mangroves and seagrass meadows, that support rare and threatened species of rays, sharks, turtles, and cetaceans (Smith and Tun, 2008; Howard et al., 2015; Platt et al., 2016; Howard, 2017).

The Andaman Sea has the highest species diversity of corals in the Indian Ocean, because of its close proximity to the Coral Triangle (Obura, 2012). The reefs in the Andaman Sea are predominantly fringing reefs, with a tendency for faster development on the eastern side of islands (Phongsuwan & Chansang 1992; Spalding et al. 2001). Regarding community structure, intensive surveys found hard corals to be dominant overall (33%) with a predicted 309 species present (observed 287 sp.) (Obura et al., 2014). Extensive intertidal reefs flats are found throughout the region, dominated by *Acropora* spp., which is typical for the wave exposure occurring in the Indo- Pacific region (Rosen, 1975). The dominance of the highly diverse *Acropora* spp. results in higher species diversity in inner reefs, however, overall *Porites* spp. are dominant. In addition to fringing reefs, the reefs of some offshore islands develop mainly in bays as scattered isolated coral heads and clumps of coral which have a high percentage of living coral (Brown, 2007). Surveys suggest that the mean percentage coral in the southern Mergui is 20-50% (Wilkinson 2004; Howard et al., 2014). However overall, coral cover in the Mergui archipelago is low, primarily as a result of thermal stress, dynamite fishing and anchorage, evidenced through regular sightings of bleaching and coral rubble (Howard et al., 2014). Despite this, some individual reefs are recognised as being very healthy (Howard et al., 2014).

Coral reefs are important in promoting fish species diversity through increased habitat complexity providing a greater variety of habitats for different species to survive (Bell and Galzin, 1984), as well as impacting small-scale recruitment of reef fishes (Caselle & Warner, 1996); this enables support for the subsistence of local communities and commercial fisheries (Moberg & Folke, 1999). Despite the range of fishing activities in the Mergui archipelago being extensive (Saw et al., 2013), the quantity of marine fish that is taken directly from Myanmar reefs is unknown. However surveys in Ranong market, Thailand, where a significant number of Myanmar boats land their catch, state 24% of landed catch originate from coral reefs (Russell, 2016). With 2,996,740 metric tonnes of marine fish being landed in 2016-17, it is evident Myanmar's economy is heavily reliant on the fisheries, and therefore coral reefs (DoF, 2017).

As a result, reports of destructing fishing techniques (dynamite), pollution (Hughes et al., 2007), unregulated fishing (Anthony et al., 2011), rising coastal populations (Lubchenco et al., 2003; Fabricius, 2005), sedimentation (Fabricius, 2005) and climate change (Coles & Brown., 2003), have caused major concern for coral reefs in the archipelago (BANCA and Oikos, 2011; Rao et al., 2013). In particular, dynamite fishing and anchoring have long-lasting impacts on corals, specifically the reef foundation, with recovery from dynamite, even after 40 years, found to be minimal (Guard and Masaiganah, 1997). Overfishing and destructive fishing is clearly evident underwater (Tun, 2013; Cox et al., 2013), particularly in the inner islands of the seascape, where subsistence fishing is common. On the shallow platforms (40-70 metres deep), in the outer part of archipelago, trawling is the dominant fishing activity (Obura et al., 2014). Myanmar's under-resourced government cannot regulate the threat of illegal and unregulated fishing (Howard, 2017), which has caused a significant decline in marine resources in the past 30 years (Krakstad et al., 2014; BOBLME, 2015).

Coral reefs have clear social and ecological importance to Myanmar so it imperative that the reefs are monitored and protected to enable appropriate management and conservation of the Mergui archipelago for future generations (Howard, 2018). Despite this, little research on coral reefs has been conducted in the region (Obura et al., 2014), and in particular Boulder (Nga Khin Nyo Gyee) Island (Brown, 2007; Howard, 2018). Here, only a species survey and preliminary reef mapping has been produced which encourages continual research to further assess the reef (Marinelli et al., 2016; Cernohorsky et al., 2018).

The aim of this study was to investigate the amount of different coral species surrounding Boulder Island by creating a baseline for percentage abundance of each species. Photographs of the seabed were taken along line transects at 5 bays surrounding Boulder Island and were then visually analysed using a computer software. Specifically, this study set out to asses if there was: (1) a difference in percentage abundance of coral between bays, (2) a difference in percentage abundance of different coral species between inner and outer reef within each bay, (3) and a difference in coral abundance between inner and outer reef amongst bays.

MATERIALS AND METHODS

DATA COLLECTION

The study was conducted at five sites surrounding Boulder Island: Moken Bay (A), Sister's Bay (B), Bamboo Bay (C), Boulder Bay (D) and Eagle Bay (E) (Fig. 1), between the 30th January and 5th April 2019. Using a tape measure, ten, 30 metre (m) line transects were positioned on the sea floor, both inshore and offshore, at each site (20 total per site). Starting at 0m, a photograph of the sea floor was taken every two metres along each transect, using a GoPro HERO 7 mounted at the top of a 1.23m pole stand that was in contact with the transect. This was either done whilst SCUBA diving or snorkelling, dependant on the depth in the bay.

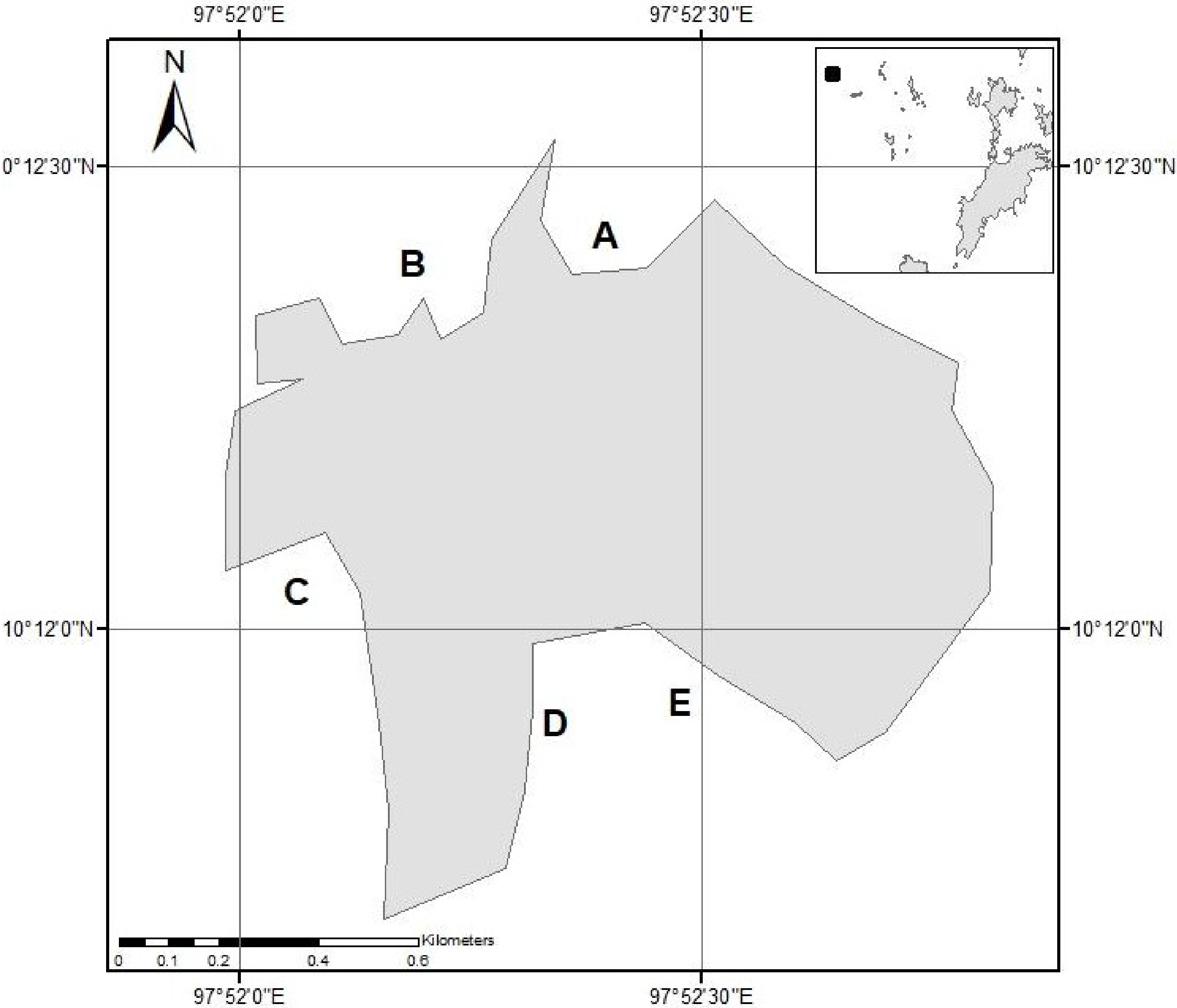

FIG. 1. The five sites surrounding Boulder Island where the transects were conducted (A-E).

The photographs were then analysed using Coral Point Count 4.1 (CPCe) (Kohler & Gill, 2006), which overlays a matrix of 100 randomly allocated points to each photo. The coral species, other organisms, substrate type or equipment underlying each point were visually identified and inputted into the software. This allowed percentage abundance of what each photo contained to be calculated by the software. This data was then separated into inshore and offshore for each bay and median percentage abundance was then calculated for each site using Microsoft Excel.

DATA ANALYSIS

Mean percentage abundance was analysed using IBM SPSS Statistics 24. Inner and Outer bay comparison, as well as comparing total bay composition amongst bays, was done using a Kruskal-Wallis test, followed by a series of Mann- Whitney *U*- tests if there was a significant difference between sites. Inner and Outer bay comparison within each bay was conducted using either a t-test, or Mann- Whitney *U*, depending on whether the data was normally distributed.

RESULTS

Coral Point Count 4.1 (CPCe) was used to analyse photographs taken along 20 transects in five different bays surrounding Boulder Island. In particular, the percentage abundance of the three most abundant coral species, *Acropora* spp., *Heliopora coerulea* and *Montipora tuberculosa,* were analysed, as well as the quantity of bleached coral. Total coral coverage was compared across the five sites surrounding boulder island to determine if there was a significant difference between bays.

INNER REEF COMPARISON

Mean % abundance of inner reef data from all bays were compared to test if there was any significant geographic variability in inner reef composition around Boulder Island. *Acropora* spp. at all sites did not conform to normal distribution (Kolmogorov Smirnov, $P < 0.05$). There was a statistically significant difference in mean % abundance of *Acropora* spp. in the inner bays at site A (median = 9.604 ± 32.379 range), site B (median = 0.72794 ± 2.089 range), site C (median = 1.906 ± 11.060 range), site D (median = 0.125 ± 20.471 range) and site E (median = 2.065 ± 6.500 range) (Kruskal-Wallis test, K = 14.647, df = 4, $P < 0.05$). Mean % abundance was significantly higher at Site A compared to site B, C and E, with significantly lower mean % abundance at site B compared to site E (Mann-Whitney *U*-test, $P < 0.05$).

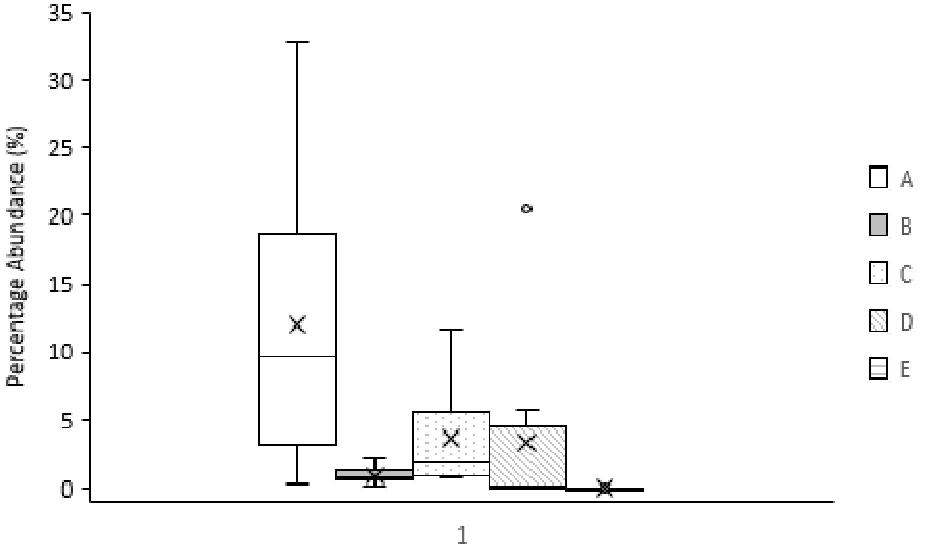

FIG. 2. Mean percentage abundance of *Acropora* spp. at inner bays at site A-E.

Mean % abundance of *H. coerulea* at all sites did not conform to normal distribution (Kolmogorov Smirnov, $P < 0.05$). There was a statistically significant difference in mean % abundance of *H. coerulea* in the inner bays at site A (median = 3.156 ± 28.933 range), site B (median = 0.313 ± 0.667 range), site C (median = 0.128 ± 0.625 range), site D (median = 0.094 ± 6.438 range) and site E (median = 5.045 ± 28.563 range) (Kruskal-Wallis test, K = 19.318, df = 4, $P < 0.05$). Mean % abundance was significantly higher at site A and E compared to site D and E, with significantly lower mean % abundance at site B compared to site E (Mann-Whitney *U*-test, $P < 0.05$).

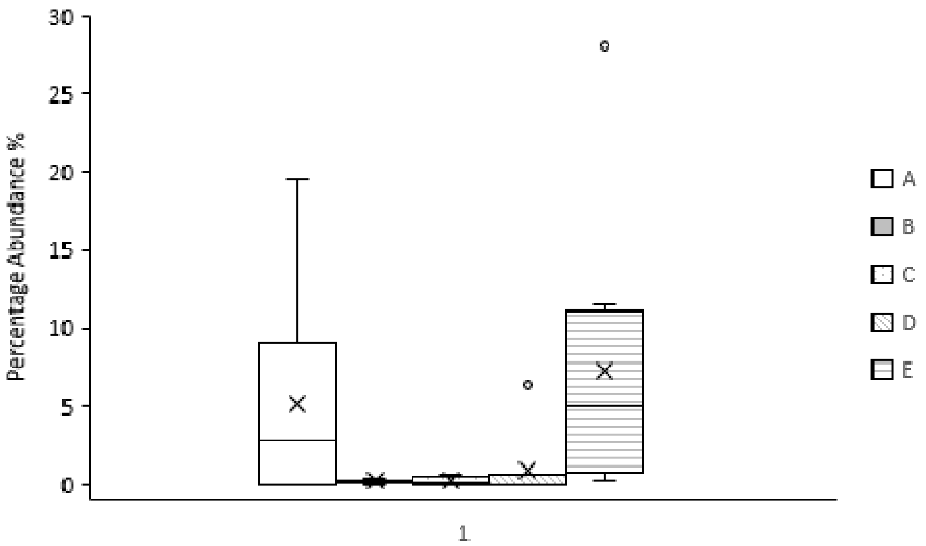

FIG. 3. Mean percentage abundance of *H. coerulea* at inner bays at site A-E.

Mean % abundance of *M. tuberculosa* at all sites did not conform to normal distribution (Kolmogorov Smirnov, $P < 0.05$). There was a statistically significant difference in mean % abundance of *M. tuberculosa* in the inner bays at site A (median = 0.000 ± 0.500 range), site B (median = 0.000 ± 0.500 range), site C (median = 0.68625 ± 5.50 range), site D (median = 0.000 ± 3.188 range) and site

E (median = 0.000 ± 2.688 range) (Kruskal-Wallis test, K = 17.870, df = 4, $P < 0.05$). Mean % abundance was significantly higher at site C compared to site A, B, D and E (Mann-Whitney *U*-test, $P < 0.05$).

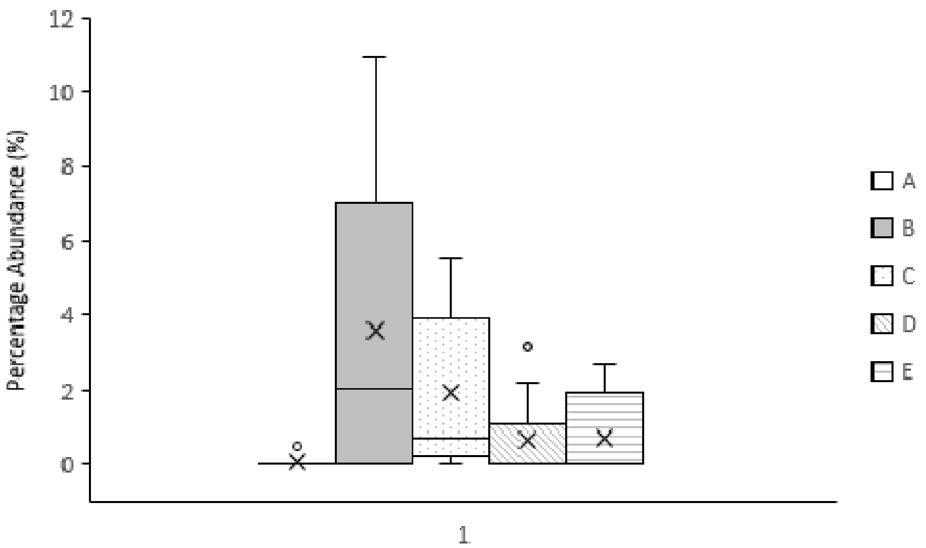

FIG. 4. Mean percentage abundance of *M*. *tuberculosa* at inner bays at site A-E.

Mean % abundance of bleached coral at all sites did not conform to normal distribution (Kolmogorov Smirnov, $P < 0.05$). There was a statistically significant difference in mean % abundance of bleached coral in the inner bays at site A (median = 5.127 ± 20.900 range), site B (median = 9.679 ± 27.838 range), site C (median = 1.688 ± 7.688 range), site D (median = 0.000 ± 0.938 range) and site E (median = 5.332 ± 17.313 range) (Kruskal-Wallis test, K = 23.625, df = 4, $P < 0.05$). Mean % abundance was significantly higher at site A and B compared to site C, D and E, with site D being significantly lower than C but significantly more than E (Mann-Whitney *U*-test, $P < 0.05$).

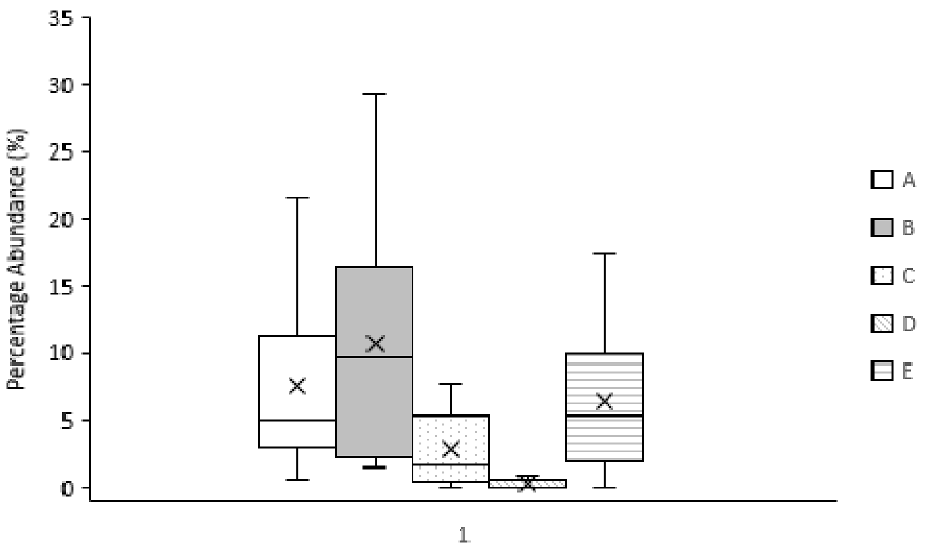

FIG. 5. Mean percentage abundance of bleached coral at inner bays at site A-E.

OUTER REEF COMPARISON

Mean % abundance of outer reef data from all bays were compared to test if there was any significant geographic variability in inner reef composition around Boulder Island. Mean % abundance of *Acropora* spp. did not conform normal distribution (Kolmogorov Smirnov, $P < 0.05$). No statistical significant difference in mean % abundance of *Acropora* spp. was found at sites A, (median = 5.371 ± 8.380 range), B (median = 1.125 ± 6.550 range) C, (median = 4.190 ± 12.370 range) D, (median = 1.602 ± 15.940 range) and site E (median = 1.281 ± 4.630 range) (Kruskal Wallis test, K = 8.630, df = 4, P > 0.05).

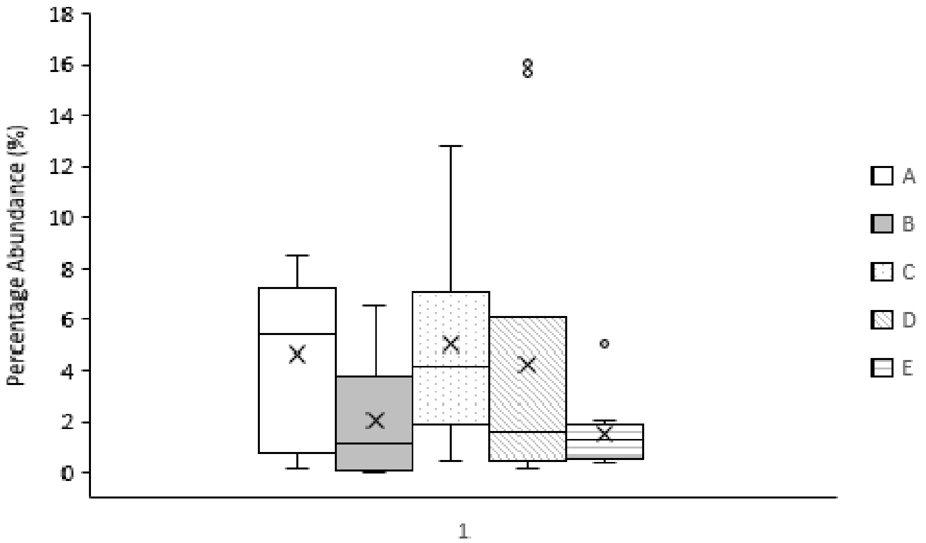

FIG.7. Mean percentage abundance of *Acropora* spp. at outer bays at site A-E.

Mean % abundance of *H. coerulea* did not conform normal distribution (Kolmogorov Smirnov, P > 0.05). There was a statistically significant difference in mean % abundance of *H. coerulea* at sites A, (median = 59.378 ± 50.32 range) and B, (median = 0.000 ± 0.380 range) C, (median = 0.300 ± 1.810 range) D, (median = 1.344 ± 11.250 range) and site E (median = 10.938 ± 65.31 range) (Kruskal Wallis test, K = 37.953, df = 4, P < 0.05). Mean % abundance of *H. coerulea* was significantly higher at site A than all other sites with Sites B and C being significantly lower than sites D and E (Mann-Whitney *U*-test, $P < 0.05$).

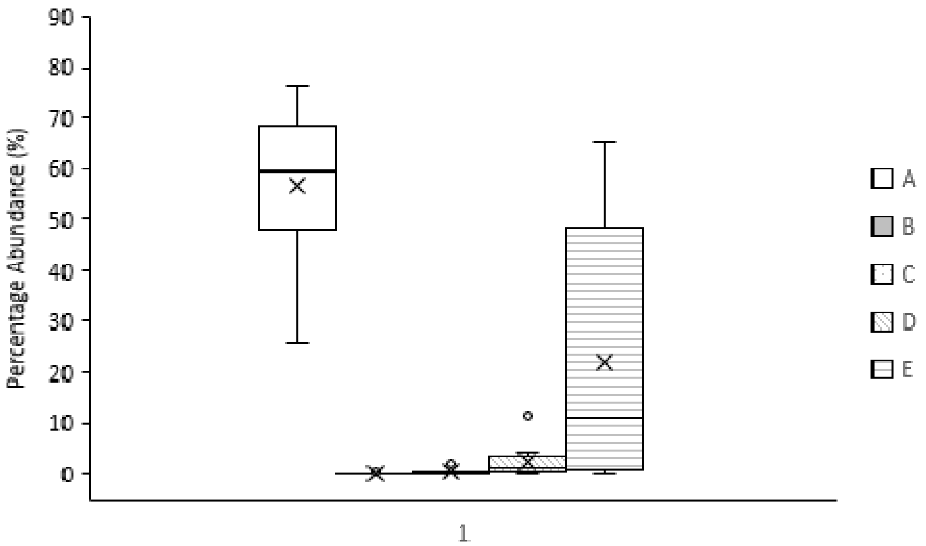

FIG.8. Mean percentage abundance of *H. coerulea* at outer bays at site A-E.

Mean % abundance of *M. tuberculosa* did not conform normal distribution (Kolmogorov Smirnov, P > 0.05). There was a statistically significant difference in mean % abundance of *M. tuberculosa* at sites A, (median = 0.000 ± 1.310 range) and B, (median = 1.7710 ± 20.690 range) C, (median = 0.530 ± 2.440 range) D, (median = 0.094 ± 43.190 range) and site E (median = 0.0938 ± 1.190 range) (Kruskal Wallis test, K = 11.308, df = 4, P < 0.05). Mean % abundance was significantly higher at sites B and C than site A (Mann-Whitney *U*-test, *P* < 0.05).

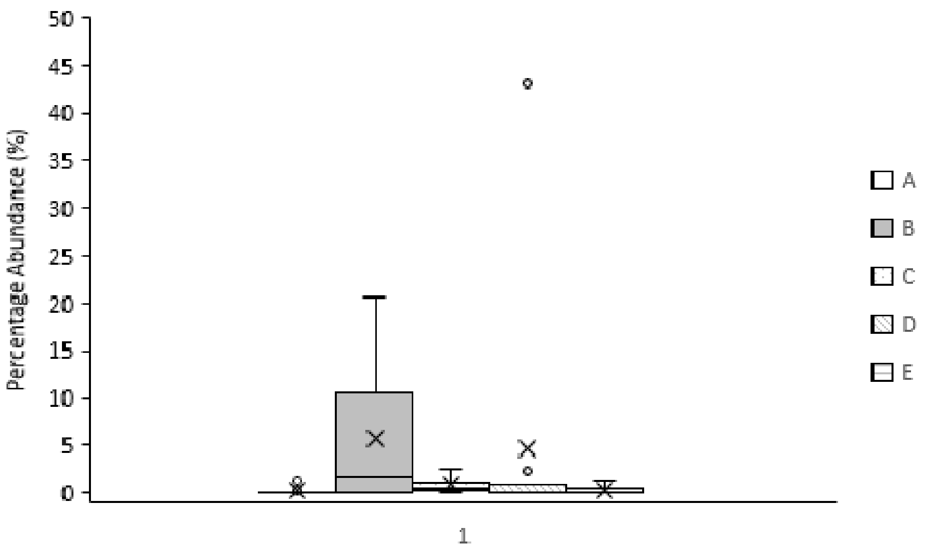

FIG.9. Mean percentage abundance of *M. tuberculosa* at outer bays at site A-E.

Mean % abundance of bleached coral did not conform normal distribution (Kolmogorov Smirnov, P > 0.05). There was a statistically significant difference in mean % abundance of bleached coral at sites A, (median 0.656 = ± 1.670 range) B, (median = 0.000 ± 0.380 range) C, (median = 0.440 ± 2.060 range) D, (median = 0.281 ± 2.440 range) and site E (median = 10.936 ± 65.310 range) (Kruskal Wallis test, K = 21.864, df = 4, P < 0.05). Mean % abundance of bleached coral was significantly higher at site E than all other sites with sites A, C and D all showed significantly higher abundance than site B (Mann-Whitney *U*-test, $P < 0.05$).

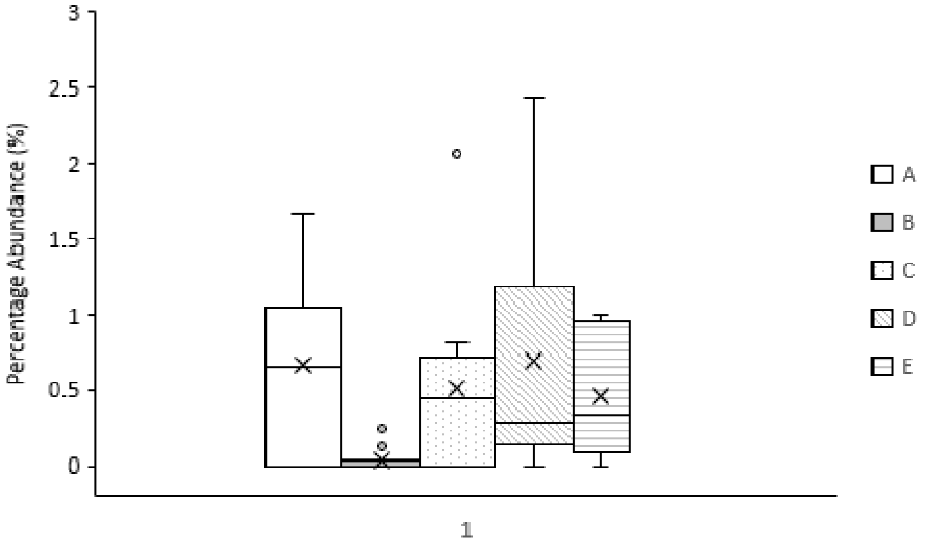

FIG.10. Mean percentage abundance of bleached coral at outer bays at site A-E.

INNER AND OUTER REEF VARIABILITY

Comparative analysis between inner and outer reef was conducted to determine if there was a difference in coral composition within each bay. Mean % abundance of *Acropora* spp. for sites A, C and E conformed to normal distribution (Kolmogorov Smirnov, $P > 0.05$) however, sites B and D did not (Kolmogorov Smirnov, $P < 0.05$). For sites C (Levene's test, F = 0.03, P > 0.05) and E (F = 1.445, P > 0.05), the variances could be considered equal, however site A did not (Levene's test, F = 7.02, P < 0.05). No statistically significant difference in mean % abundance of *Acropora* spp. between inner and outer reef was found at site A (inner mean = 11.94708 ± 10.971 % S.D.; outer mean = 4.6225 ± 3.196 % S.D.) (t-test, t = -2.207, df = 18, $P > 0.05$), site C (inner mean = 3.164 ± 3.628 % S.D.; outer mean = 5.034 ± 3.909 % S.D.) (t-test, t = -0.842, df = 18, $P > 0.05$) and site E (inner mean = 2.510 ± 1.953 % S.D.; outer mean = 1.521 ± 1.397 % S.D.) (t-test, t = 1.302, df = 18, $P > 0.05$). No statistically significant difference in median % abundance of *Acropora* spp. was found between inner and outer reef at site D (inner median = 0.125 ± 20.471 % range; outer median = 1.602 ± 15.938 % range) (Mann-Whitney *U*-test, $U = 35$, $n_{1,2} = 10$, $P > 0.05$) and site B (inner median = 0.728 ± 2.089 % range; outer median = 1.125 ± 6.553 % range) (Mann-Whitney *U*-test, $U = 44$, $n_{1,2} = 10$, $P > 0.05$). This suggested there was no variability in *Acropora* spp. cover in all bays, and that there was no inner and outer reef variability for these species.

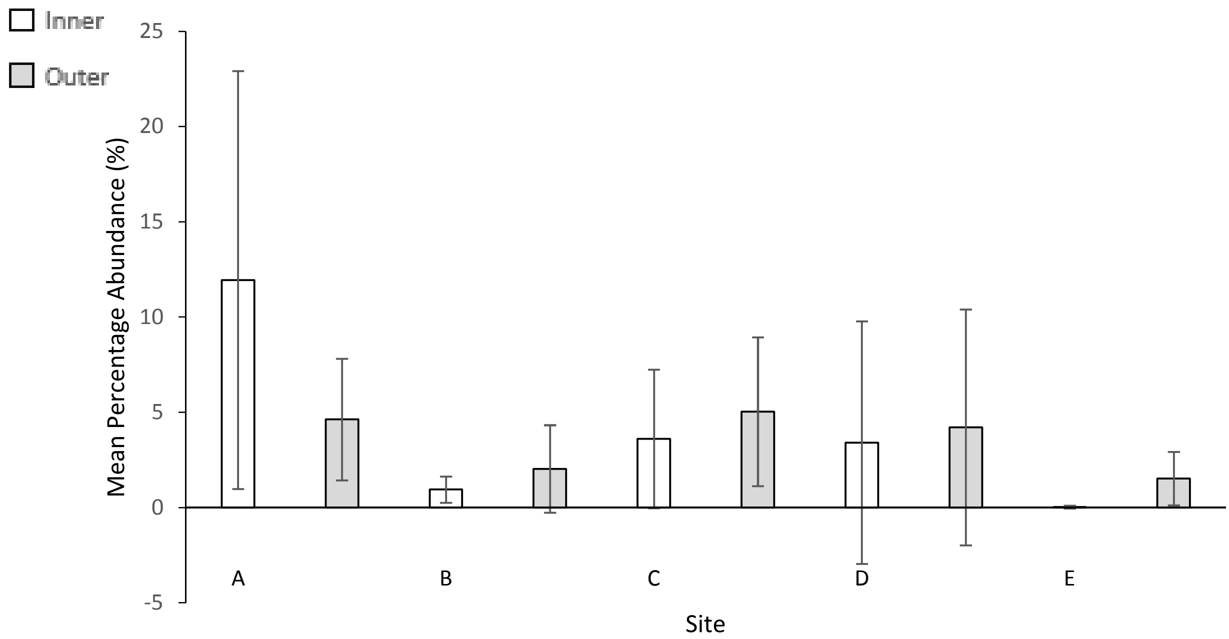

FIG.12. Comparison of mean percentage abundance of *Acropora* spp. between inner and outer bay at site A-E.

Mean % abundance of *H. coerulea* for sites B and E conformed to normal distribution (Kolmogorov Smirnov, $P > 0.05$), whereas C and D did not (Kolmogorov Smirnov, $P < 0.05$). The variance of that site B (Levene's test, F = 1.264, P > 0.05) could be considered equal, whereas site E (F = 10.223, P < 0.05) could not. No statistically significant difference in mean % abundance of *H. coerulea* between inner and outer reef was found at site B (inner mean = 0.282 ± 0.378 % S.D.; outer mean = 0.190 ± 0.119 % S.D.) (t-test, t = 3.450, df = 18, $P > 0.05$) and site E (inner mean = 9.390 ± 21.917 % S.D.; outer mean = 10.788 ± 25.274 % S.D.) (t-test, t = -1.442, df = 12.174, $P > 0.05$). A statistically significant difference in median % abundance of *H. coerulea* was found between inner and outer reef at site A (inner median = 3.156 ± 28.933 % range; outer median = 59.478 ± 50.321 % range) (Mann-Whitney *U*-test, $U = 1$, $n_{1, 2} = 10$, $P < 0.05$), however no significant difference was found at site C (inner median = 0.128 ± 0.625 % range; outer median = 0.03 ± 1.81 % range) (Mann-Whitney *U*-test, $U = 40.5$, $n_{1, 2} = 10$, $P > 0.05$) and site D (inner median = 0.936 ± 6.438 % range; outer median = 1.344 ± 11.250 % range) (Mann-Whitney *U*-test, $U = 20.5$, $n_{1, 2} = 10$, $P > 0.05$). This suggested there was significantly more *H. coerulea* in the outer bay at site A. It also suggests no variability in *H. coerulea* cover in the other bays, and that there was no inner and outer reef variability for these species.

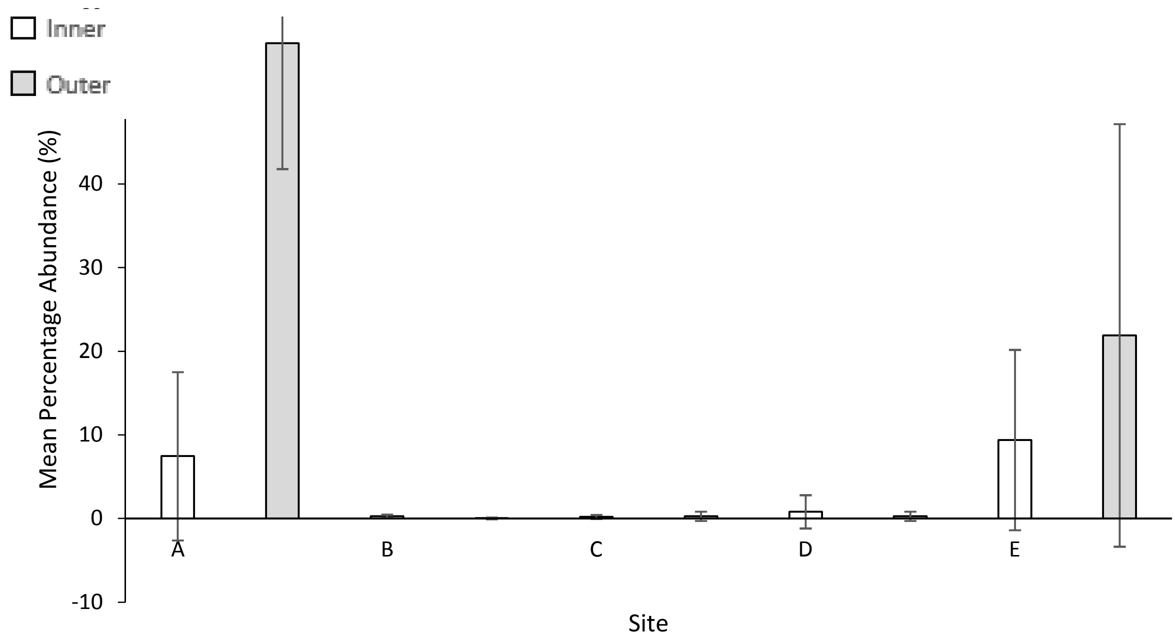

FIG.13. Comparison of mean percentage abundance of *H. coerulea* between inner and outer bay at site A-E.

Mean % abundance of *M. tuberculosa* did not conform to normal distribution at all sites (Kolmogorov Smirnov, $P < 0.05$). No statistically significant difference in median % abundance of *H. coerulea* was found between inner and outer reef at site A (inner median = 0.000 ± 0.500 % range; outer median = 0.000 ± 1.313 % range), site B (inner median = 0.000 ± 0.500 % range; outer median = 8.246 ± 20.688 % range), site C (inner median = 0.686 ± 5.500 % range; outer median = 0.530 ± 2.440 % range), site D (inner median = 0.000 ± 3.188 % range; outer median = 0.938 ± 43.188 % range) and site E (inner median = 0.000 ± 2.688 % range; outer median = 0.094 ± 1.188 % range) (Mann-Whitney *U*-test, $P > 0.05$). This suggested there was no variability in *M. tuberculosa* cover in all bays, and that there was no inner and outer reef variability for these species.

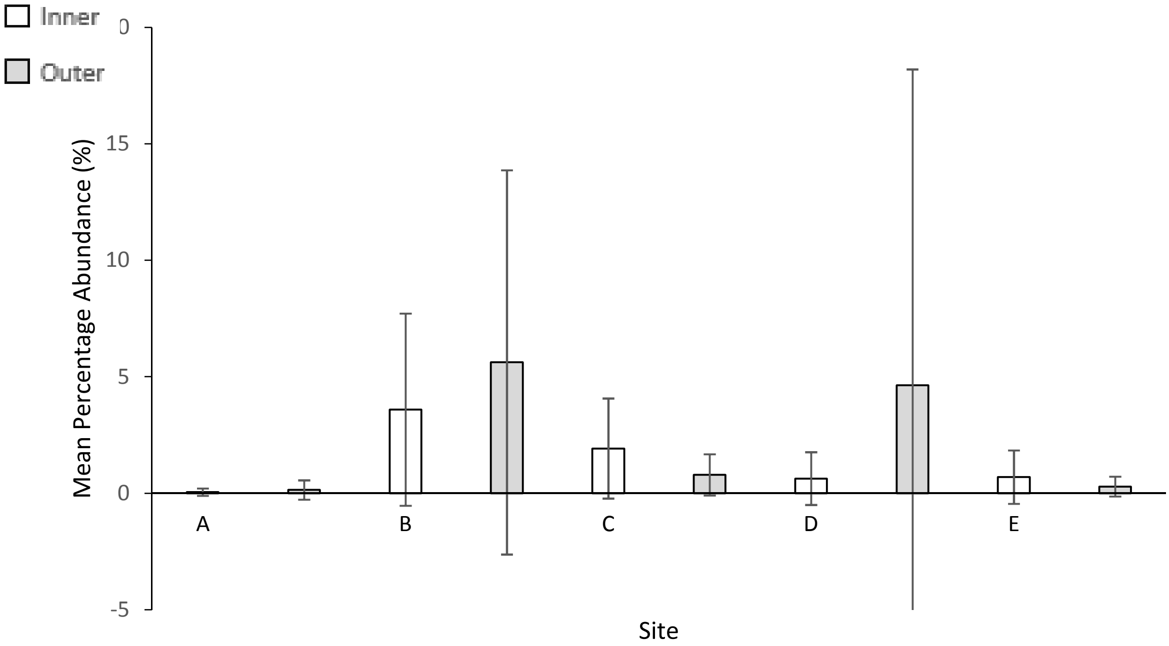

FIG.14. Comparison of mean percentage abundance of *M. tuberculosa* between inner and outer bay at site A-E.

Mean % abundance of bleached coral for sites A, C and E conformed to normal distribution (Kolmogorov Smirnov, $P > 0.05$) however, sites B and D did not (Kolmogorov Smirnov, $P < 0.05$). For sites A (Levene's test, F = 12.733, P < 0.05), C (Levene's test, F = 26.638, P < 0.05) and E (F = 14.728, P < 0.05), the variances could not be considered equal. There was a statistically significant difference in mean % abundance of bleached coral between inner and outer reef at site A (inner mean = 7.550 ± 6.734 % S.D.; outer mean = 0.662 ± 0.599 % S.D.) (t-test, t = 3.222, df = 18, $P < 0.05$) , B (inner median = 9.679 ± 27.838 % range; outer median = 0.000 ± 0.250 % range) (Mann-Whitney *U*-test, $P > 0.05$), site C (inner mean = 2.838 ± 2.840 % S.D.; outer mean = 0.507 ± 0.621 % S.D.) (t-test, t = 2.536, df = 9.858, $P < 0.05$) and site E (inner mean = 6.461 ± 5.681 % S.D.; outer mean = 0.546 ± 0.416 % S.D.) (t-test, t = 3.333, df = 9.096, $P < 0.05$), whereas site D displayed no statistical significance (inner median = 0.000 ± 0.938 range; outer median = 0.281 ± 2.438 range) (Mann-Whitney *U*-test, $U = 33.5$, $n_{1,2} = 10$, $P > 0.05$). This suggests that there is significantly more bleached coral inshore at sites A, B, C and E compared to offshore.

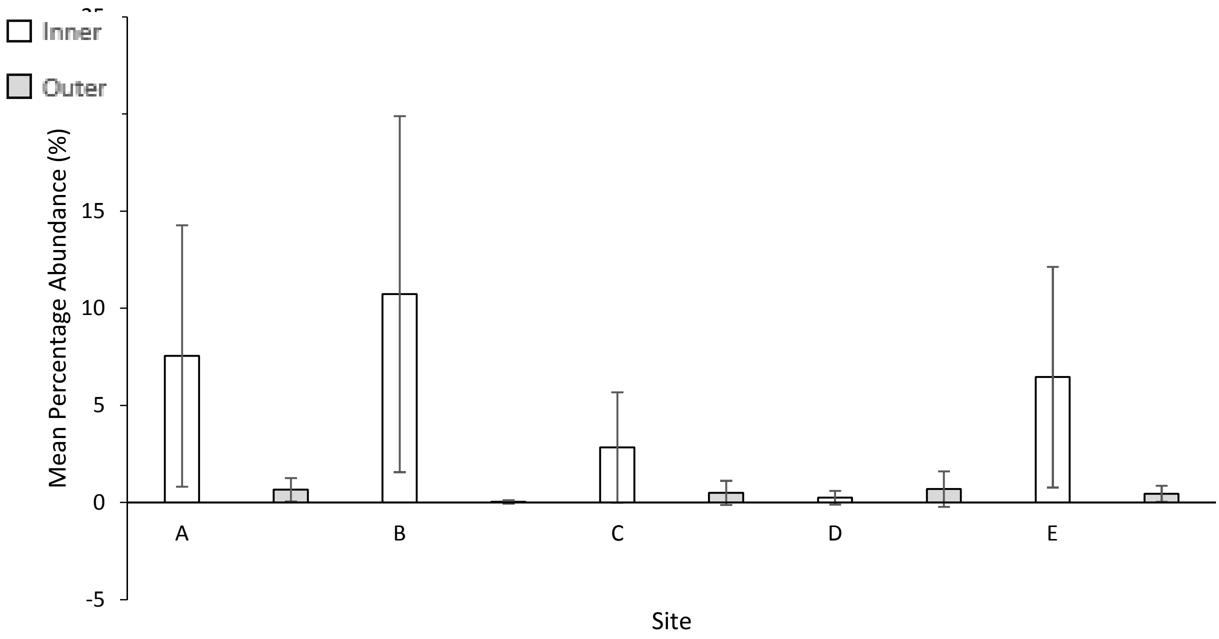

FIG.15. Comparison of mean percentage abundance of bleached coral between inner and outer bay at site A-E.

TOTAL REEF COMPARISON

Mean % abundance of *Acropora* spp. for all sites did not conform normal distribution ($P < 0.05$). There was a statistically significant difference in mean % abundance of *Acropora* spp. at sites A, (median = 6.375 ± 32.630 range) and B, (median = 0.750 ± 6.550 range) C, (median = 3.755 ± 12.370 range) D, (median = 1.259 ± 20.47 range) and E (median = 1.844 ± 6.500 range) (Kruskal Wallis test, K = 19.855, df = 4, P < 0.05). Mean % abundance was significantly higher at site A compered to site B, D and E, with significantly lower mean % abundance at site B and E compared to C (Mann-Whitney *U*-test, $P < 0.05$).

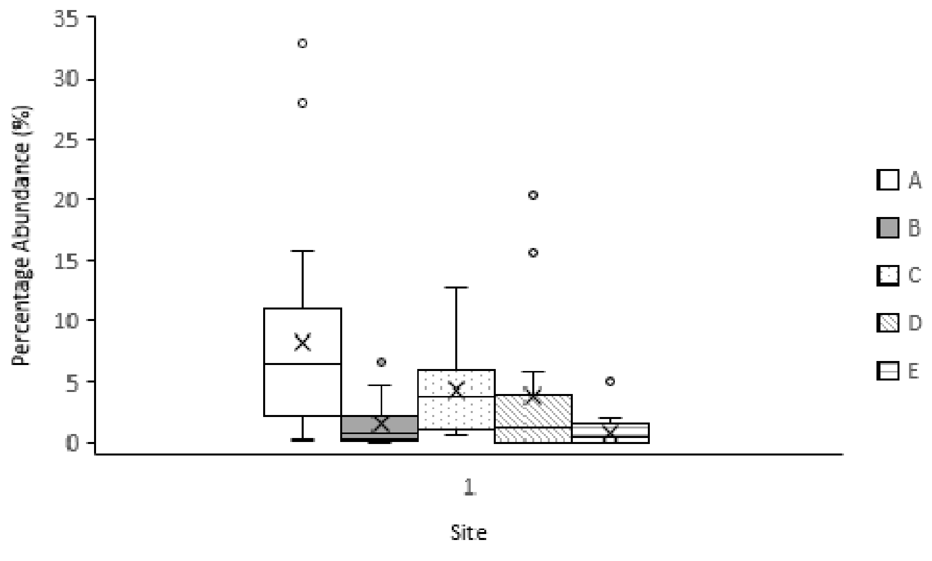

FIG.17. Mean percentage abundance of *Acropora* spp. at sites A-E.

Mean % abundance of *H. coerulea* for all sites did not conform normal distribution ($P < 0.05$). There was a statistically significant difference in mean % abundance of *H. coerulea* at sites A (median = 27.400 ± 76.190 range) and B, (median = 0.000 ± 0.670 range) C, (median = 0.094 ± 1.810 range) D, (median = 0.563 ± 11.25 range) and E (median = 7.686 ± 65.310 range) (Kruskal Wallis test, K = 49.918, df = 4, P < 0.05). Mean % abundance was significantly higher at sites A and E compered to sites B, C and D however, there was no significant difference between sites A and E. There was also significantly lower mean % abundance at sites B and C compared to site D (Mann-Whitney *U*-test, *P* < 0.05).

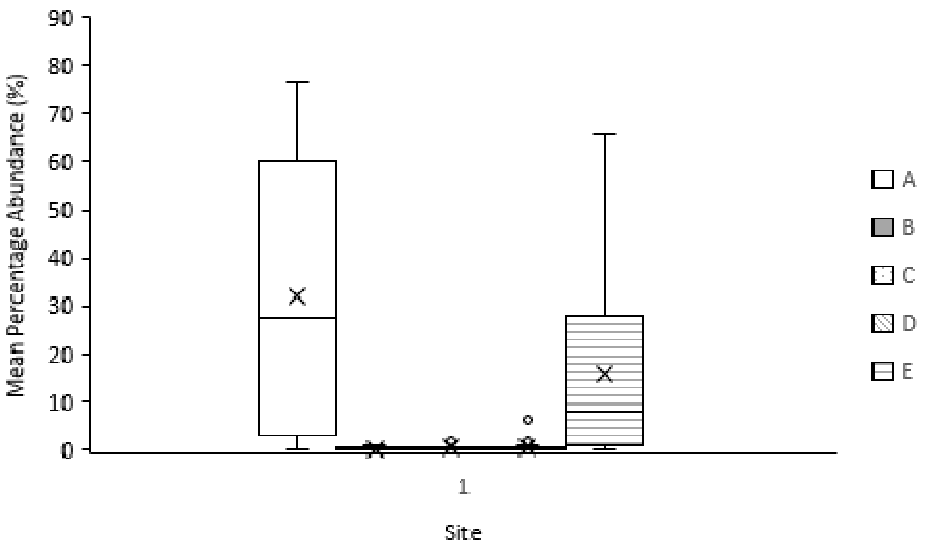

FIG.18. Mean percentage abundance of *H. coerulea* at sites A-E.

Mean % abundance of *M. tuberculosa* for all sites did not conform normal distribution ($P < 0.05$). There was a statistically significant difference in mean % abundance of *M. tuberculosa* at sites A (median = 0.000 ± 1.31 range) and B, (median = 1.771 ± 20.69 range) C, (median = 0.530 ± 5.500 range) D, (median = 0.000 ± 43.19 range) and site E (median = 0.000 ± 2.690 range) (Kruskal Wallis test, K = 22.892, df = 4, P < 0.05). Mean % abundance was significantly higher at site C compared to site A, D and E. Sites A and E also showed significantly lower mean % abundance than site B (Mann-Whitney *U*-test, *P* < 0.05).

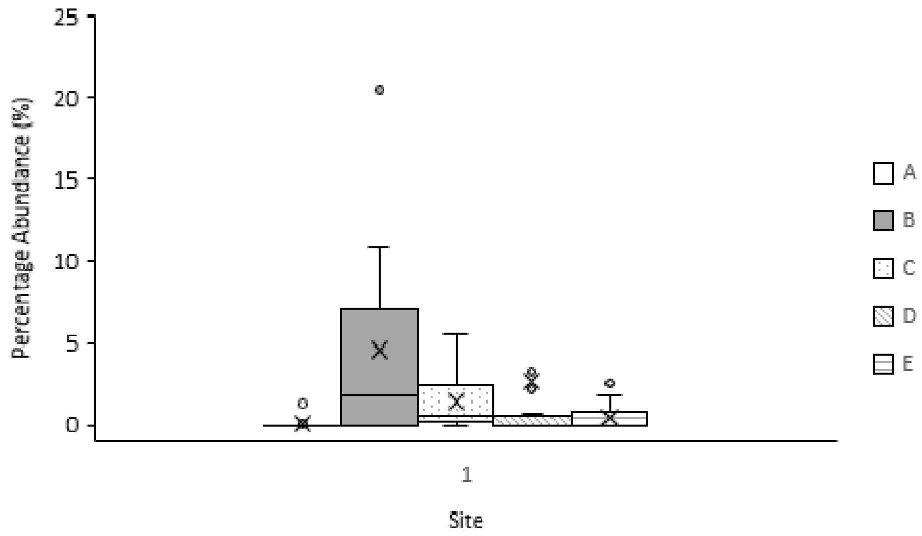

FIG.19. Mean percentage abundance of *M*. *tuberculosa* at sites A-E.

Mean % abundance for bleached coral for all sites did not conform normal distribution ($P < 0.05$). There was a statistically significant difference in mean % abundance of bleached coral at sites A (median = 1.615 ± 21.500 range) and B, (median = 0.902 ± 29.270 range) C, (median = 0.595 ± 7.750 range) D, (median = 0.219 ± 2.44 range) and site E (median = 1.000 ± 17.310 range) (Kruskal Wallis test, K = 10.615 df = 4, $P < 0.05$). Sites A, C and E showed significantly higher mean % abundance of bleached coral than site D (Mann-Whitney *U*-test, $P < 0.05$).

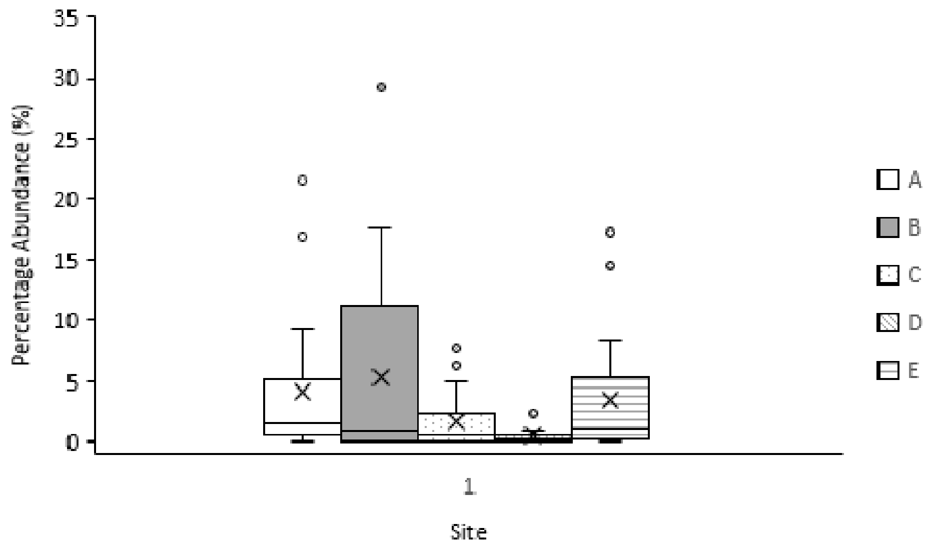

FIG.20. Mean percentage abundance of bleached coral at sites A-E.

DISCUSSION

Acropora spp.

Acropora spp. abundance in the inner bays was significantly higher at site A than all other sites, except site D (Fig. 2). Site B also had a larger abundance than site E. This could be a result of reefs on the eastern side of Andaman islands having a tendency to be better developed due to less wave exposure from the southwest monsoon (Phongsuwan & Chansang, 1992; Spalding et al., 2001). However, *Acropora* spp. are resilient to wave exposure, and tend to dominate reefs under higher exposure which contradicts the results found in this study (Rosen, 1975), as site A and B are the least exposed sites surrounding Boulder Island. This could suggest that the monsoon influence is greater than the resilience of *Acropora* app. explaining the dominance of the species on the eastern side of the island.

There was no significant geographic variability for *Acropora* spp. abundance between the outer bays (Fig. 7). This may also be explained by the resilience to wave exposure (Phongsuwan & Chansang, 1992; Spalding et al., 2001). The species may be greater influenced by the monsoon due to having less protection from the bays, resulting in a uniform abundance surrounding the island.. No inner-outer bay variability in *Acropora* spp. abundance was found at all sites suggesting that distance from the bay was not a significant determiner of abundance of this species (Fig. 12). This is surprising as previously research in the Myiek archipelago found that the species tends to be more dominant in the inner reef, due to its fast growing nature and being more sheltered (Howard, 2018). However these were only visual observations, and lack empirical and methodological rigour.

Total reef comparison of *Acropora* spp. found site A had significantly higher abundance than site B, D and E but not C (Fig. 17). Site A may have the higher than B, D and E as a result of being the most eastern site surrounding the island, and so is most protected from the monsoon influence (Phongsuwan & Chansang, 1992; Spalding et al., 2001). Other research on *Acropora* spp. may explain why site C has higher abundance than B and E due to this site being the most western and therefore exposed site, under which this species dominates (Rosen, 1975). Additionally, site C is very long and narrow which magnifies the velocity of the waves (Bernoulli Effect), increasing the impact of wave exposure, which could further explain the high abundance at this site (Cernohorsky et al., 2018). Overall, it is difficult to assume what is exactly causing dominance in these two sites surrounding the island, and that there may be numerous variables causing the results found.

H. coerulea

Currently, no research exists on the *H. coerulea* regarding geographic variability over small spatial-scales for adult populations. Instead, most research focuses on reproduction, larval development, and dispersal. Larval dispersal, death of post-recruitment and/or adult colonies is a key determiner of adult population distribution (Hughes & Jackson, 1985; Smith, 1992; Babcock & Mundy, 1996). However, due to the species limited potential dispersal, it is not an accurate method of determining geographic variability over the small, spatial- scales used in this study (Zann and Bolton 1985; Babcock 1990).

Its limited dispersal is a result to *H. coerulea* being an unusual octocoral in that it hermatypic (forms a skeleton). Its planulae larvae develop into female polyps and attach to the female colony prior to release (Babcock, 1990). This enables prolonged development, and in turn faster settlement, causing a narrow dispersal range, which is advantageous as the habitat has previously proven to be a suitable for the species (Harii & Kayanne, 2003). This may explain why the species is prominent at all sites, and particularly A, B and D (Marinelli, 2016) (Fig. 3; Fig. 7; Fig. 18), due to this narrow dispersal range causing dense aggregations of *H. coerulea* surrounding Boulder Island. Narrow dispersal ranges could also explain why there was no inner-outer bay variability found at all sites apart from site A (Fig. 13), as the population is densely aggregated in one uniform, sheltered area where there is suitable habitat for development into adult populations already occurring (Harii & Kayanne, 2003).

Currently, the species is listed as vulnerable by the IUCN (Marinelli, 2016), due its shallow distribution causing it to be susceptible to bleaching and is therefore at risk of disappearing within one generation (Obura et al. 2008; Burke et al. 2012). *H. coerulea* is also under threat by various anthropogenic stressors, including coastal development and overharvesting for the aquarium trade (Green & Shirley 1999; Obura et al. 2008; Burke et al. 2012). The vulnerability of *H. coerulea* encourages future research into its larval development and recruitment mechanisms, and reinforces protection of the healthy, dense population surrounding Boulder Island.

M. Tuberculosa

Percentage abundance of *M. tuberculosa* in the inner bay was significantly higher at site C than all other sites (Fig. 4). No research focusing specifically on this species and causes of distribution has been conducted previously, apart from effects of SCUBA diving and other anthropogenic damage (Hall, 2001; Barker & Roberts, 2004). As a result, it is difficult to determine what has caused significantly higher abundance at site C than all other sites for the inner bays.

Site C, although not quantified, appeared to have a higher frequency of boats anchoring for shelter compared to other bays, so it is unusual to find that the fragile *M. tuberculosa* was most abundant here (Hall, 2001). This would suggest that there is something with a strong influence causing the significantly higher abundance of this species at site C. However, future research should include count data of boats in bays correlated against coral abundance to determine whether there is a relationship between these two variables.

Outer bay comparison found percentage abundance of *M. tuberculosa* to be significantly higher at sites B and C than site A (Fig. 9). This may be explained by the dominance of *H. coerulea* in the outer bay at site A (56.85%). This species is well-established and densely aggregated over the majority of this outer site, preventing suitable space for *M. tuberculosa* growth into a sized population. This could also explain why total reef comparison is significantly higher for sites B and C than sites A and E (*H. coerulea* % abundance: site B 0.17%; C 0.24%; A 32.16%; E 15.66%) (Fig. 19); evidentially at sites A and E, *H. coerulea* dominates the bays. However, a previous survey of site A surrounding Boulder Island found that over 50% of coral cover was *M. tuberculosa* which contradicts the results found in this study (Marinelli, 2016). The two surveys were conducted three years apart which might explain the difference in abundance of this species; however this is highly unlikely due to the drastic differences in percentage abundance. Additionally, the slow growing *H. coerulea* is dominant throughout the outer bay, and so appears to have been well established as the dominant species for a period of well over three years. Despite currently being not under threat by the IUCN, *M. tuberculosa* should be closely monitored, particularly at site A, due to the bays increasing use by snorkelers and SCUBA divers, as both can have a clear detrimental impact on the species if damaged by either (Hall, 2001; Barker & Roberts, 2004).

Bleached Coral

Rising SST (Sea Surface Temperature), tsunami's and El Niño years are the biggest causes of coral bleaching in the Andaman Sea (Ravindran et al., 1999; Arthur, 2000; Turner et al., 2009). In this study, average temperature for all bays was practically the same and so it was difficult to accurately determine the cause of geographic variability in bleached coral abundance over the small distances between the sites. Any differences are therefore likely due to interspecific variation in coral species' susceptibility to coral bleaching, which has been documented in the Andaman Sea (Marimuthu et al., 2013). Future research on bleached coral should be a temporal study that accumulates average temperatures surrounding the island correlated against the abundance of bleached coral present, over a period of ten years. This could produce data on the susceptibility of coral to bleaching from external environmental pressures to be used for governmental purposes, such as management for ecological services of coral reefs.

Despite not discussing most of the data for bleached coral due to lack of continual temperature records, inner and outer bay comparison within each bay could be analysed. Mean percentage abundance of bleached coral was significantly higher in the inner bay compared to the outer for all sites except for site D, which showed no difference (Fig. 15). Previous research in relatively close proximity to Boulder Island found that greatest coral loss and community disruption occurred in shallower reef flats, whereas deeper reefs were: less susceptible to aerial exposure, flushing and had longer submergence in more turbid waters, resulting in less bleaching at greater depths (Brown et al., 2019). In addition, Andaman reefs further offshore are more resistant to bleaching due to experiencing a greater amplitude of waves (Wall et al., 2014; Schmidt et al., 2016), greater frequency of temperature variability and pulses of cool, nutrient rich water (Safaie et al., 2018). This could explain why offshore reefs had significantly less bleached coral than inshore in all bays except site D. However, it cannot be ignored that shallow- reefs also benefit from increased turbidity, temperature variability and greater physiological tolerances of corals, regarding reduced coral bleaching (Brown, 2007). As a result, offshore reefs may have greater tolerances to coral bleaching and mortality than inshore reefs. However, further research should be conducted to evaluate the individual variables causing resistance to bleaching to for monitoring and conservational purposes.

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