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ADAM K. SMITH[1], NATHAN COOK[1], AL SONGCUAN[1,2], GRETA SARTORI[1], DANIEL CASSIDY[1], MATTHEW DEANE[3], TUKABU TERORОKO[4], and BETARIM RIMON[4]

ABSTRACT

The remote Kanton (Abariringa) Atoll, in the South Pacific Phoenix Islands Protected Area, was assessed using rapid techniques to describe the infrastructure, fish, coral, birds, vegetation, sharks, turtles, and marine mammals. Median live coral cover was 28% (8%–93%) with 11 coral genera, the most abundant being tabular *Acropora* spp. A total of 130 species of fish (9365 individuals) showed highest abundance in the fore reef habitat. The most abundant bird was the Brown noddy (*Anous stolidus*) with 3600 individuals counted. Nine species of plants were identified, with Beach saltbush (*Scaevola sericea*) being the most abundant. The human subsistence catch was 345 fish and invertebrates with a weight of 103.5kg over a five-day period. Assessment of the aesthetics of dive sites identified two excellent sites: the shipwreck of *President Taylor* and the Cascades, with very high abundances of coral and reef fish. The condition of infrastructure on the island, including the Kanton port, airfield, and road network, were rated as “Poor” for Port (above water), Jetty, Road, Water, and Waste management; followed by “Fair” for Road and Energy and “Good” for Port (below water).

Key words: Coral reefs, *Acropora*, Snapper, *Lutjanu*s, subsistence fishery, shark, turtle, bird, vegetation, aesthetics, infrastructure, port, airport, road

INTRODUCTION

The Republic of Kiribati is a nation of 33 atolls (Goldberg, 2016) and islands scattered over 5 million km^2 of the equatorial Pacific Ocean. As one of 40 Small Island Developing States (SIDS), it faces distinct developmental and environmental challenges (Watson et al., 2016). Common characteristics of remote islands include limited and expensive transport for people and commodities between islands, high dependence on tourism for economic growth, and natural resources for sustenance (Watson et al., 2016; Almeida-Santana and Moreno-Gil, 2018).

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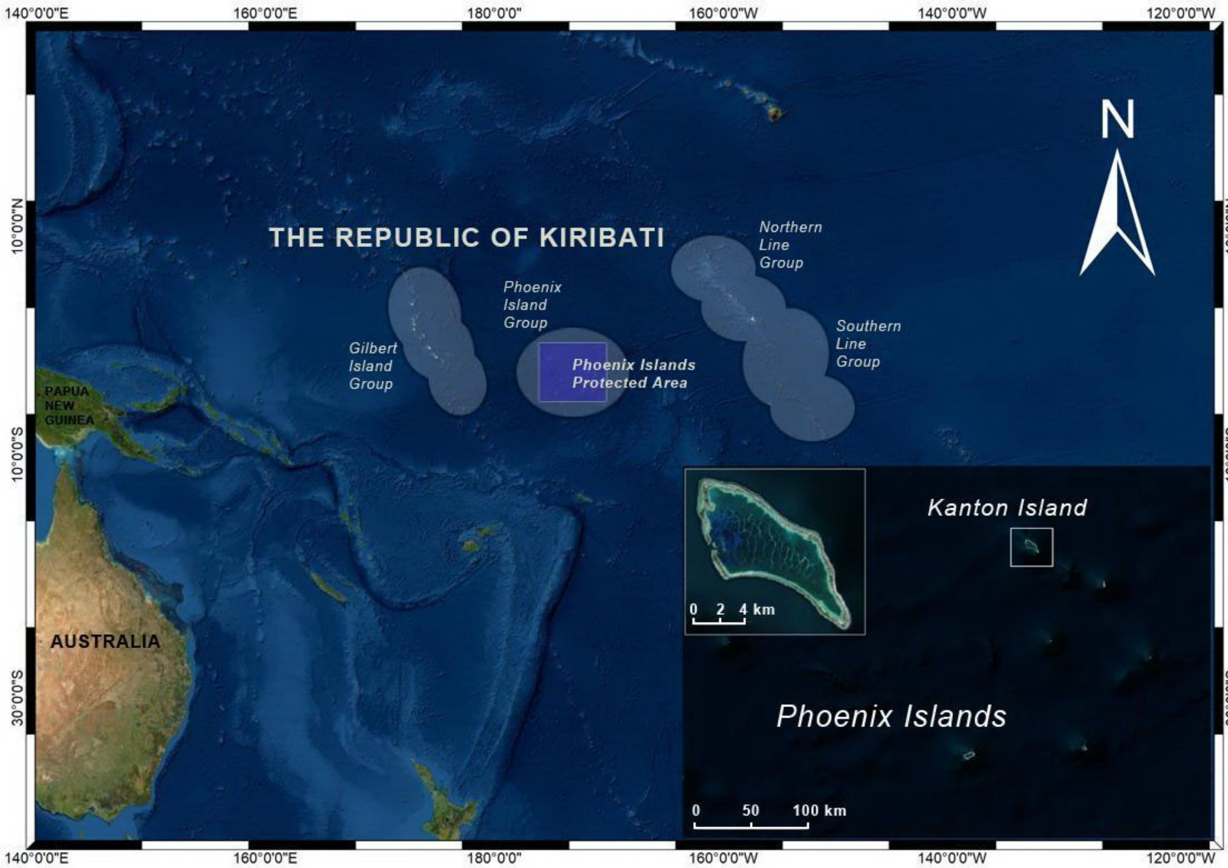

Figure 1. Location of Kanton Island, within the Phoenix Island Protected Area in the Republic of Kiribati, Pacific Ocean.

Kanton Island (2°52’04.11” S; 17°39’26.38” W) is an extremely remote atoll located in the South Pacific Ocean roughly halfway between Hawaii and Fiji. The capital of Kiribati, South Tarawa, lies 1,765 km to the west (Figure 1). Kanton Island is the largest and northernmost atoll of the Phoenix Islands Group (Figure 1, inset), with a total land area of 9.2 km^2. The atoll extends 14.5 km from its northwest to southeast points, has land rim widths varying from 50 to 600 m, and elevations ranging from 1.5 to 7 m. The increasing popularity of island tourism in the last decades can create economic opportunities for remote communities like Kanton Island, but also has the potential for negative impacts on the ecosystem (Moore, 2014). This highlights the importance of collecting baseline information and developing a sustainability plan to manage environmental, social, and economic well-being concurrently (Sarrasin, 2013; Moore, 2014). In developing an effective sustainability management plan, a detailed assessment and inventory of existing natural and man-made resources is important to understand the values and the potential effects of future changes. To inform a government-based sustainability planning initiative, we conducted an infrastructure and ecological assessment of the marine and terrestrial ecosystems of Kanton Island in 2017.

Kanton Island (also currently known as Canton Island or Abariringa Island) has historically been alternatively known as “Mary Island,” “Mary Ballcout’s Island,” or “Swallow Island” and is the only inhabited island within the Phoenix Islands Protected Area (PIPA) (Uwate and Teroroko, 2007). The human population of the island declined from more than 1000 in the 1940s to less than 100 in the last five decades. The island has been used for mining, fishing, transport, strategic war bases, space tracking, and tourism (Degener and Gillaspy, 1955; Maragos and Jokiel, 1975; Uwate and Teroroko, 2007; Turner et al., 2009; Mangubhai et al., 2014).

The infrastructure on Kanton Island is understood to have been originally constructed by Pan American Airways between 1938 and 1939, and was used by the airline as a stopover on its route from Hawaii to New Zealand. In 1941–1942, during World War II, the United States Navy upgraded and extended the airfield, road infrastructure, and port to accommodate heavy bombers and larger cargo vessels. Dredge spoil from the channel is understood to have been placed on the inside of the lagoon, forming islands (now known as the Spam Islands and Bird Island), providing bird nesting habitats. After the war, Pan American Airways continued to use Kanton Island as the main refuelling station for trans-Pacific flights until 1965. It is understood that little to no maintenance to the island infrastructure has occurred post 1965.

Kiribati declared the Phoenix Islands Protected Area in 2006 (Witkin et al., 2016), with the marine reserve being expanded in 2008 to cover 425,300 km^2, containing eight coral atolls including Kanton (Rotjan et al., 2014) and designated as a UNESCO World Heritage Area in 2010 (UNESCO, 2020). There have been more than 130 years of research and literature on the fish, fisheries, coral, birds, introduced species, and human use of Kanton Island (Longley, 1940 [1888]; Schultz, 1943; Maragos and Jokiel, 1975; Jokiel and Maragos, 1978; Smith and Henderson, 1978; Stone et al., 2000, 2001; Obura and Stone, 2002; Stone et al., 2009; Obura et al., 2011a, 2011b; Mangubhai et al., 2012, 2014; Rotjan et al., 2014; Obura et al., 2016). However, research on the social, cultural, and heritage values of Kanton Island has been limited (Longley, 1940 [1888]; Di Piazza and Pearthree, 2001, 2004; Chen, 2012).

Detailed fish surveys have reported that snappers, parrotfishes, and surgeonfishes were the most abundant groups (Stone et al., 2000; Obura et al., 2011b; Reef Ecologic, 2017a). Seventy-three coral species were recorded from the Phoenix Islands between 2000 and 2002, and coral cover averaged between 45.1% and 58.1% (Obura, 2011). Between 2002 and 2005, a thermal stress event induced above average water temperatures, which caused extensive bleaching and coral mortality in Kanton, particularly in the lagoon area (Obura and Mangubhai, 2011). However, the coral community appears to have recovered (Mangubhai and Rotjan, 2015; Mangubhai et al., 2019).

METHODS

Study Site

Kanton Island (Figure 1) shows different topography and oceanographic conditions as well as a variety of exposures to winds and waves between the western flank (leeward) and the other flanks (windward) (Obura, 2011), which are likely to influence coral and fish presence. The island environment hosts a shallow lagoon that is linked to the open ocean by a small channel. The open ocean shows a steep drop-off starting uniformly at 15–20 m, broken only by the deep entrance to the channel (Obura, 2011). The channel linking the lagoon to the ocean is subjected to strong tide currents. For these reasons, in the data analysis, sites have been categorised into reef zones: inner reef (lagoon), transition zone (channel), fore reef (oceanic sites).

Surveys and Assessments

In June 2017, Reef Ecologic, Arup, and the Phoenix Island Protected Area (PIPA) Implementation Office conducted assessments of the natural resources and human infrastructure in Kanton Island (Arup, 2017; Reef Ecologic, 2017a). The assessment involved coral reef, fish, and bird surveys as well as an inventory of existing infrastructure including port, airport, and roads. In-water sites were selected to be consistent with previous studies by Obura et al. (2011b) where possible. In-water field observations were made by experienced marine biologists while snorkelling on shallow reefs between 0 and 10 metres. Several species of fish were collected. Most species of fish, coral, birds, and vegetation were photographed, and video taken to assist accurate identification and quality assurance. Coral cover data and fish surveys had three replicates per each site: n=9 in the inner reef, n=12 in the transition zone and n=15 in the fore reef.

Coral Assessment

To provide a synoptic view of the composition and general health condition of the coral community, we surveyed three 50m transects at each of the 12 sites at Kanton Island (Figure 2, Appendix A), using point intercept transects (PIT) adapted from methods used by the Australian Institute of Marine Science (AIMS) (Jonker et al., 2008), and similar to that utilised in other regions of Kiribati (Obura and Mangubhai, 2011; Obura et al., 2011b; Mangubhai and Rotjan, 2015; Mangubhai, Lovell, et al., 2019). Assessed benthos was categorised into biotic (live coral cover (LCC) and macroalgae), and abiotic components (rock, rubble, sand, and recently dead coral). All hard (scleractinian) corals were recorded to genus (and species, where possible). Additional assessments were made of the coral growth forms and observed health of coral.

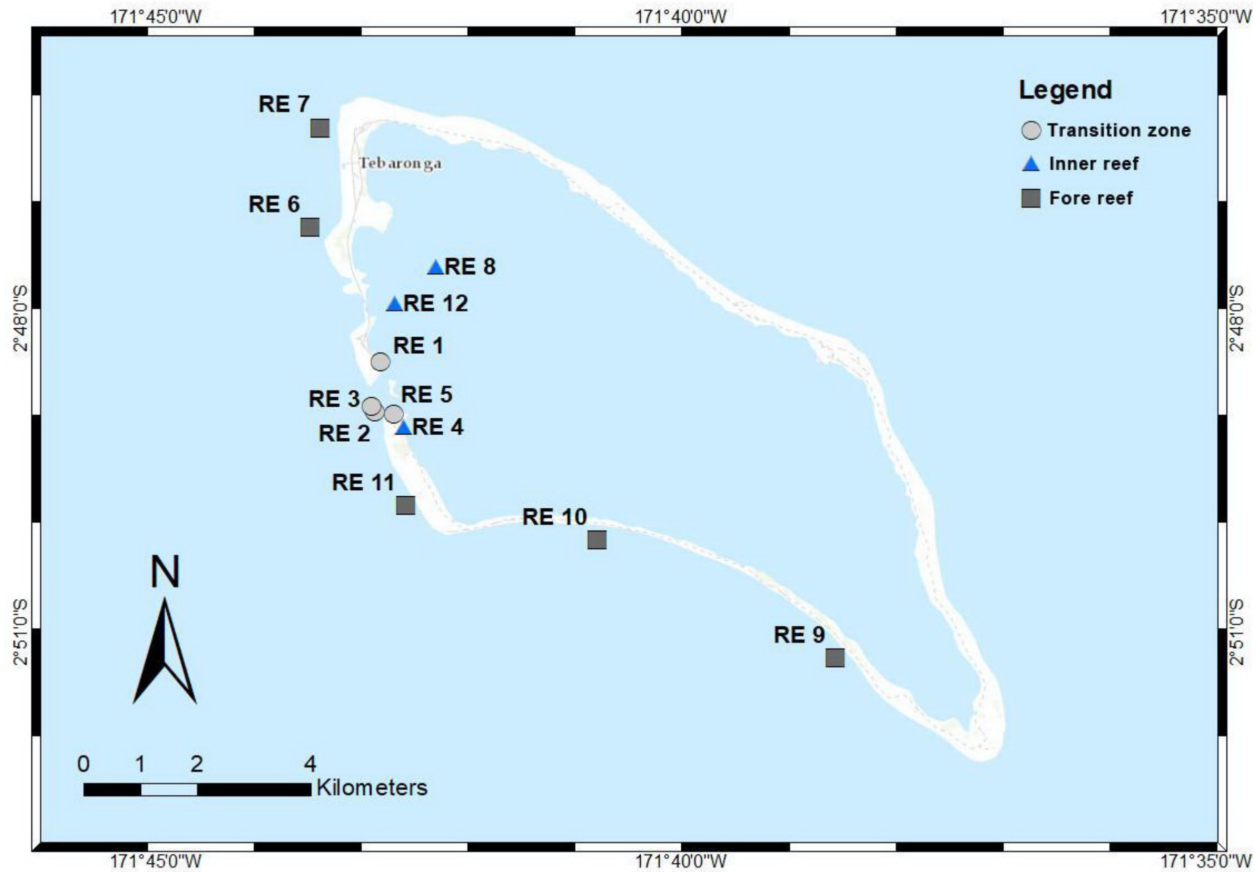

Figure 2. Locations of fish and coral assessment surveys in three habitats: inner reef (RE4, 8, 12), transition zone (RE1, 2, 3, 5), and fore reef (RE6, 7, 9, 10, 11).

Fish and Fisheries Assessment

Fish visual censuses were performed on three 50m × 4m transects for each of the 12 sites (Figure 2). Transect surveys followed the protocol developed by Halford and Thompson (1994). Surveys were performed by a very experienced free diver for 30–45 minutes along the transect at depths <10 m. Due to lack of facilities, conventional surveys using SCUBA could not be performed. This poses some limitations, as benthic species are likely to be under-represented. Fish species were identified, and abundance was recorded on underwater slates. Nomenclature followed Fishbase.org (Froese and Pauly, 2019), an online catalogue of fishes.

Species were later categorised into either target or non-target species, referring to species commonly targeted by fisheries in the Pacific (Obura et al., 2011b). This was done to assess value for subsistence fishing (Dalzell et al., 1996). Fish and invertebrates were caught throughout the island either by hand, line, trolling, dip net, or spear. We opportunistically recorded and estimated the species, number, and the weight of daily catch of fish and invertebrates that were collected and eaten, or used as bait, by the local community during the assessment period.

Shark, Ray, Turtle, and Marine Mammal Assessment

Sharks, rays, turtles, and dolphins were recorded during underwater visual surveys by both observers. Additionally, opportunistic sightings during boat travel between sites were also recorded. Species were identified and the number for each species on each site was recorded.

Bird and Vegetation Assessment

Seabird assessments were conducted at five locations at Kanton Island (Figure 3, Appendix A). We used a combination of fly-on monitoring, involving counting a sample of the most sensitive and threatened bird species, and ground surveys, consistent with the methods of Pierce et al. (2006, 2008) and Pierce (2013) to determine more accurate population sizes. Two surveys counted roosting bird populations in situ at the two locations (Channel and Spam Islands), consistent with the methods of Pierce (2013). Additional observations were made opportunistically during boat travel between sites or during landings on the island.

Random transects were surveyed at four locations at Kanton Island (Figure 3) to assess the diversity of existing vegetation and the relative abundance of each species in each location. Three replicate transects, each 100m in length, were laid and all vegetation types within the transect were identified to genus (and species, where possible). Photographs and video were taken and cross-referenced to validate identification and quality assurance.

Aesthetics Assessment

Aesthetics assessments of 12 sites in Figure 2 were conducted using a 5-star rating system: 1 star (poor), 2 star (below average), 3 star (average), 4 star (above average), and 5 star (excellent). The aesthetics rating was based on methodology developed by Marshall et al. (2019) using five factors including coral cover (1<10% cover, 2<20% cover, 3=30% cover, 4>40% cover, 5>50% cover), fish diversity and abundance (1<10 species, 2<20 species, 3=30 species, 4>40 species, 5>50 species), seascape diversity (1=flat, 2=low relief, 3=small caves, 4=diverse shapes and holes, 5=complex 3 dimensional shapes), water quality (1<5m visibility, 2<10m visibility, 3=15m visibility, 4>20m visibility, 5>25m visibility), and rubbish (1>5 pieces rubbish, 2=4 pieces rubbish, 3=3 pieces rubbish, 4=1 piece rubbish, 5=no rubbish). Equal weight for each of the five factors was assigned for the survey.

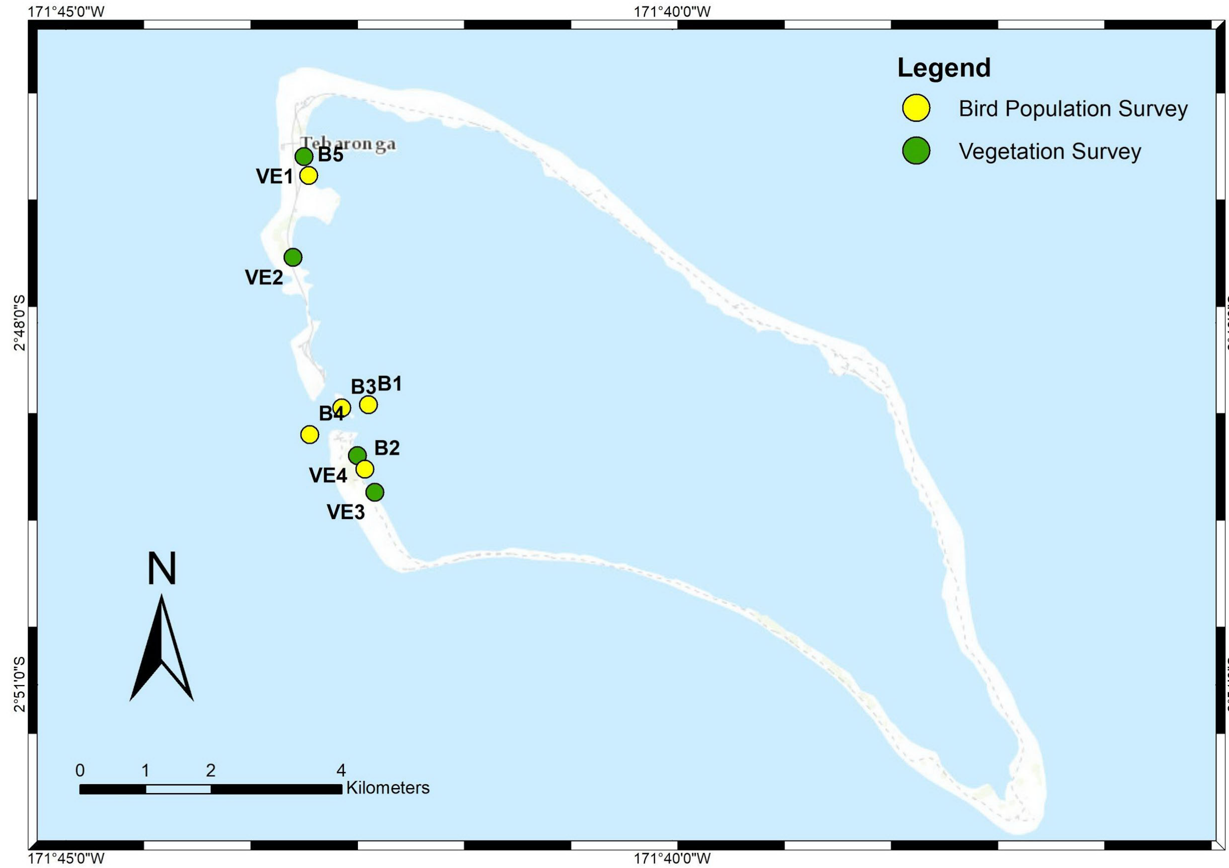

Figure 3. Location of vegetation (VE1, 2, 3, 4) and bird assessment (B1, 2, 3, 4, 5) surveys at Kanton Island.

Infrastructure Assessment

Visual inspection was conducted between 19 and 23 June 2017 to identify and assess the condition of the key existing civil, marine, and aviation infrastructure on the island (Figure 4). Each observation was rated in accordance with the Queensland Department of Transport and Main Roads (DTMR) Structures Inspection Manual condition rating guidelines to standardise and rationalise the observations (Table 1).

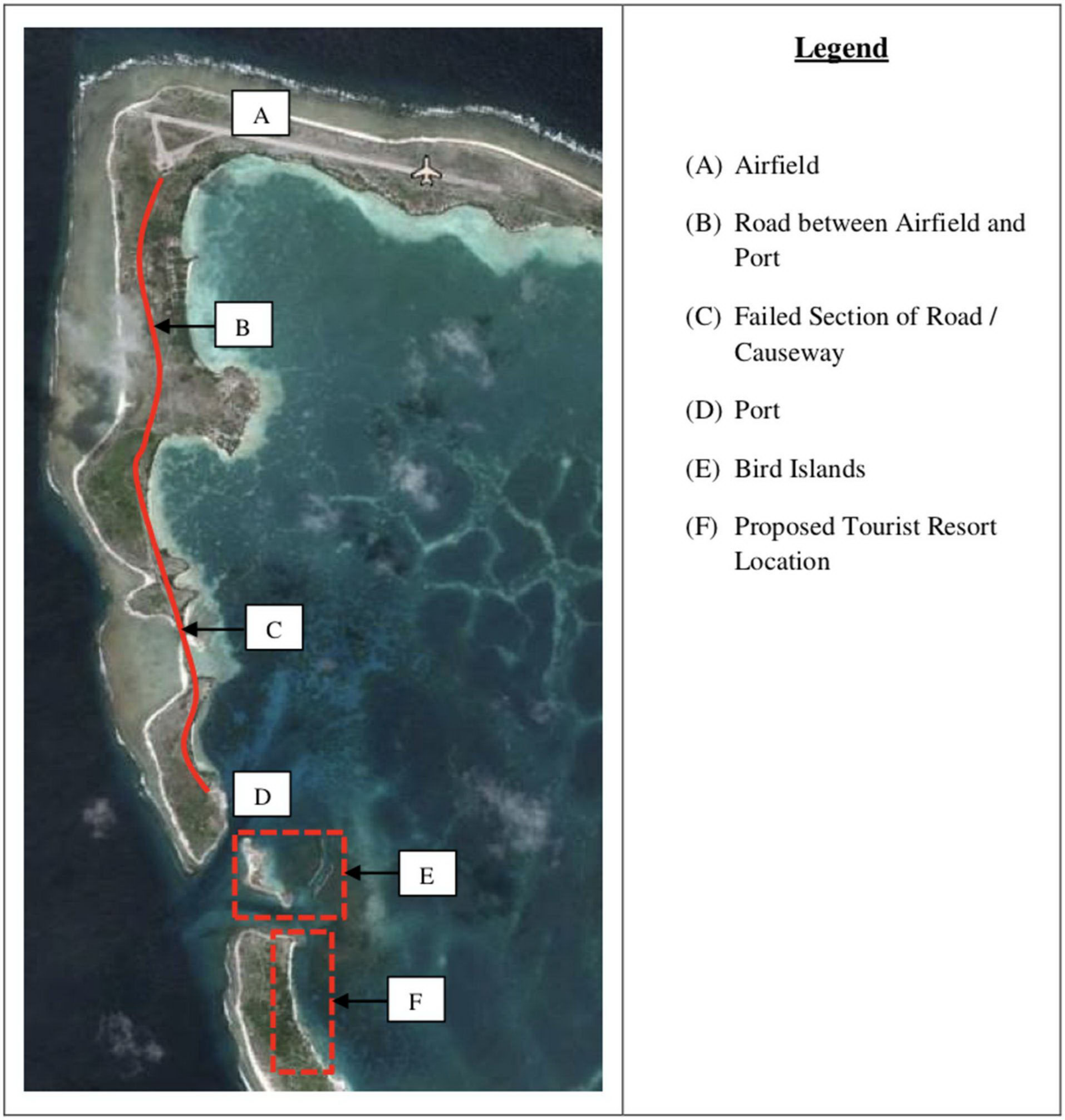

Figure 4. Existing and proposed infrastructure at Kanton Island. (Source: Google Earth satellite timeline imagery)

Statistical Analysis

All statistical analysis was performed with the R "Vegan" package (Oksanen et al., 2010). One-way ANOVAs were performed to assess differences in total Live Coral Cover (LCC) between "reef zones." Log transformation of the observed coral cover data allowed parametric testing. Kruskal-Wallis one-way analysis of variance was used to compare cover of coral morphologies and genus diversity between reef zones, followed by the non-parametric Dunn-Bonferroni post-hoc test to further investigate difference

Table 1. Assessment criteria for condition rating of infrastructure at Kanton Island.

State	Subjective Rating	Description
1	GOOD ("as new")	Free of defects with little or no deterioration evident
2	FAIR (monitoring required)	Free of defects affecting structural performance, integrity and durability. Deterioration of a minor nature in the protective coating and/or parent material is evident.
3	POOR (monitoring required)	Defects affecting the durability/serviceability, which may require monitoring and/or remedial action or inspection by a structural engineer. Component or element shows marked and advancing deterioration including loss of protective coating and minor loss of section from the parent material is evident. Intervention is normally required.
4	VERY POOR (remedial action required)	Defects affecting the performance and structural integrity, which require immediate intervention including an inspection by a structural engineer, if principal components are affected. Component or element show advanced deterioration, loss of section from the parent material, signs of overstressing or evidence that it is acting differently to its intended design mode or function.
5	UNSAFE (immediate remedial Action required)	This state is only intended to apply to the "whole structure" rating. Structural integrity is severely compromised and the structure must be taken out of service until a structural engineer has inspected the structure.

patterns. Post-hoc analysis using Tukey's HSD test (TukeyC R package; De Caceres et al*.,* 2016) was performed on significant relationships to explore distribution patterns.

Alpha diversity of fish communities at each site was explored using fish abundance, species richness, and Shannon-Weiner diversity. Replicates were assigned by grouping sites in reef zones. Data distribution was visualised and checked for normality. Differences in alpha diversity indices were tested between categories using independent one-way ANOVA. Post-hoc analyses using Tukey's HSD test were run to observe where significance lay within the data. Beta diversity of these communities across three reef zones were calculated using the Bray-Curtis dissimilarity index. Differences in community composition among categories were evaluated using PERMANOVA. The R "Vegan" package (Oksanen et al*.,* 2010) was used to calculate Shannon-Weiner diversity and Bray-Curtis dissimilarity and to perform the PERMANOVA. Species and family-level differences in community composition were explored using indicator analysis. Multipattern indicator analysis was performed to identify both fish families and species whose abundance was statistically associated with reef zones using the indicspecies package in R (De Caceres et al*.,* 2016).

Total abundance, species richness, and diversity of fishery-targeted species were compared between reef zones with one-way ANOVA and Tukey-HSD post-hoc. Differences in abundance of each targeted fish family were tested with Kruskal-Wallis non-parametric test, as a transformation to parametric distribution was not possible. Dunn-Bonferroni post-hoc was used to assess where significance lay within the data.

As a consequence of the time constraints and logistical difficulties associated with the remoteness of the atoll, we were only able to collect limited samples and observations for vegetation, birds, turtles, and elasmobranchs. Therefore, we did not utilise statistical tests for these categories.

RESULTS

Coral Assessment

Coral health surveys revealed healthy corals at all sampling locations with no records of disease, bleaching, or predation. Fore reef sites were dominated by rock, predominantly covered by coralline crustose algae (CCA), however, CCA was not individually quantified.

Significant differences in log transformed LCC were detected between study sites ($F_{11,24} = 31.23$, $P < 0.001$). LCC was not significantly different between reef zones ($F_{2,33} = 2.57$, $P = 0.09$), but median LCC was higher for inner reef and transition zone, compared to fore reef (Table 2, Figure 5).

Differences in coral morphologies were found between survey sites. Tabular coral was the dominant morphology, followed by bushy and encrusting (Table 2, Figure 5). Tabular morphology cover differed significantly between inner reef and transition zone (Chi-squared = 24.5, df = 2, $P < 0.001$) and fore reef ($P < 0.001$). The inner reef was characterised by the highest percentage cover of tabular coral (Table 2, Figure 5). Bushy cover differed between inner and fore reef ($P = 0.004$) with highest percentage cover in the latter (Table 2, Figure 5). Encrusting and massive corals showed higher cover in the fore reef (Table 2, Figure 5), differing from the other reef zones ($P < 0.001$). No difference was detected for percentage cover of other morphologies ($P > 0.05$).

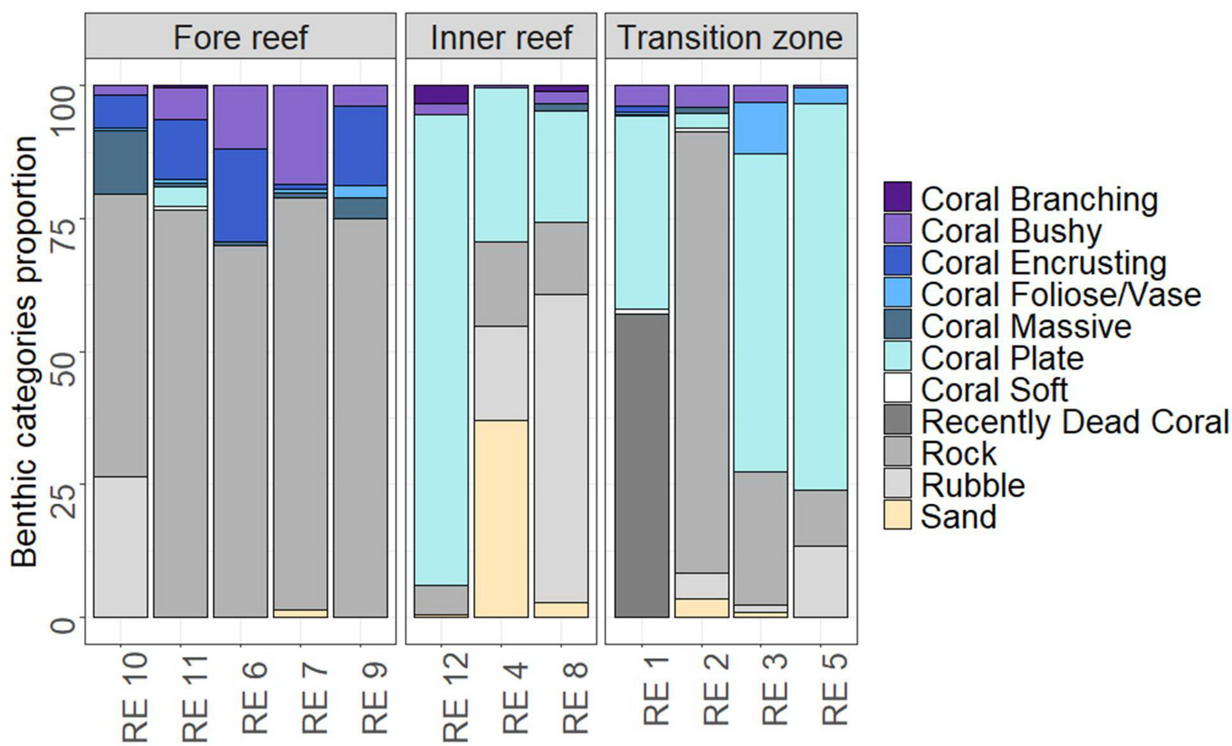

Figure 5. Benthic cover of different coral morphologies and benthic categories across sampling sites and between reef zones.

Table 2. Percentage cover of live coral cover, coral morphologies, and coral genera, overall and between reef zones. Coral morphology is calculated based on overall benthic cover, whereas percentage cover of coral genus is calculated based on live coral cover. IQR = Inter Quartile Range

	Overall	**Inner Reef**	**Transition Zone**	**Fore Reef**
Live Coral Cover	27.5% (IQR 27.8)	29.3% (IQR 34.2)	57.8% (IQR 16.0)	23.3% (IQR 4.3)
Morphologies (% in overall benthic cover)				
Tabular/Plate	23.3% (IQR 4.3)	48.1% (IQR 30.9)	28.9% (IQR 33.8)	0
Bushy	3.5% (IQR 1.5)	2.0% (IQR 1.0)	3.5% (IQR 1.50)	6.0 (IQR 5.8)
Massive	0.7% (IQR 1.3)	0	0.1% (IQR 0.5)	0.9% (IQR 3.3)
Encrusting	0.4% (IQR 7.4)	0	0	11.3% (IQR 8.8)
Genus (% in the coral community)				
Acropora	59.0% (IQR 74.8)	94.5% (IQR 3.9)	85.1% (IQR 18.1)	16.3% (IQR 13.7)
Pocillopora	8.7% (IQR 20.2)	1.5% (IQR 1.4)	6.0% (IQR 17.4)	22.3% (IQR 9.3)
Porites	3.3% (IQR 53.6)	0	1.0% (IQR 5.9)	60.6% (IQR 9.3)

Eleven coral genera were identified during the surveys (Figure 6). Cover of *Acropora* (Chi-squared = 27.4, df = 2 1, P < 0.001), *Porites* (Chi-squared = 21.55 , df = 2 1, P < 0.001), and *Pocillopora* (Chi-squared = 14.4 , df = 2 1, P < 0.001) were significantly different between reef zones. *Acropora* cover was higher in the inner reef and transition zone (P < 0.001), whereas *Porites* (P < 0.001) and *Pocillopora* (P < 0.001) cover was higher in fore reef sites (Table 2, Figure 6). No difference was detected for cover of other genera (P > 0.05). Coral genus diversity was significantly different between reef zones (Chi-squared = 24.4 , df = 2 1, P < 0.001). Fore reef sites showed highest diversity (P < 0.002).

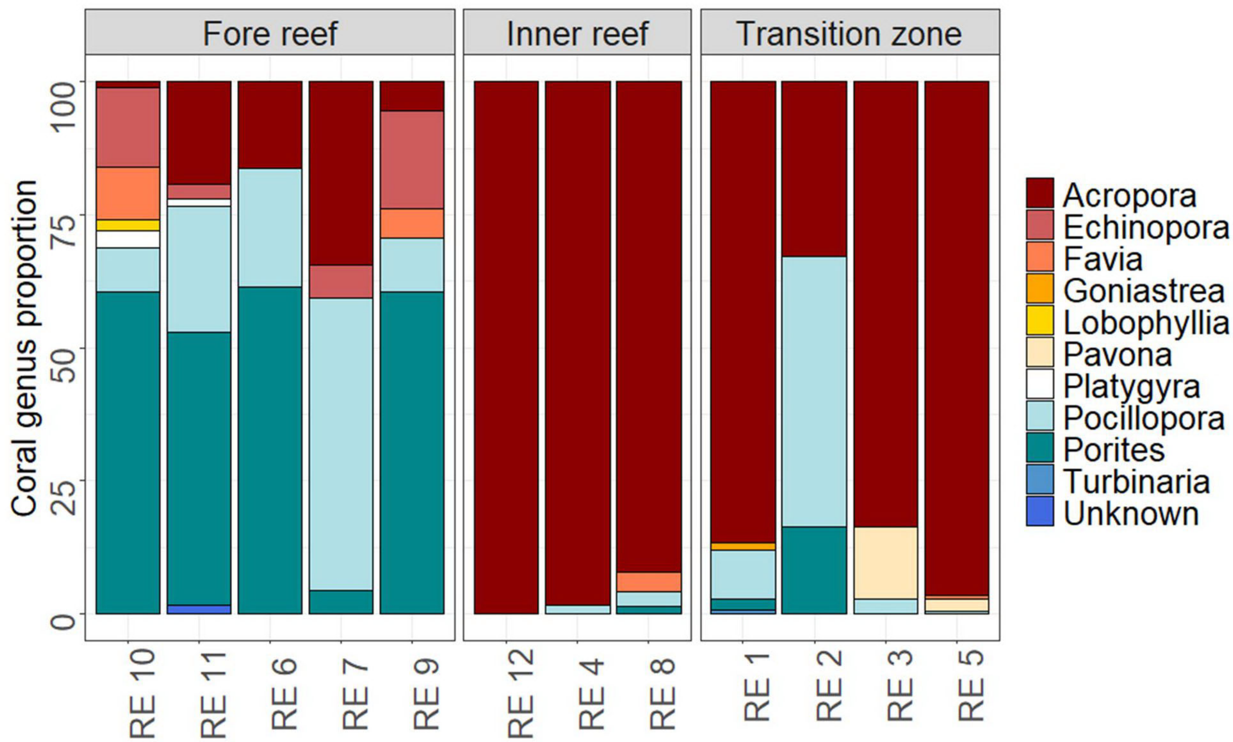

Figure 6. Distribution of coral genera across sampling sites and between reef zones.

Fish Assessment

A total of 130 species of fish were recorded, belonging to 23 families and comprising 9577 individuals. The fish community was dominated by reef fish (97% of all individuals) and occasionally included pelagic fish species such as tuna, queenfish, and trevally (3%). Fish assessment revealed that 47.7% of all fish surveyed were target species dominated by surgeonfish (Acanthuridae), snappers (Lutjanidae), and parrotfish (Scaridae) (Table 3). Non-target fishes (52.3%) were mostly anthias (Serranidae), damselfish (Pomacentridae), and wrasse (Labridae) (Table 3). Large reef macro-predators such as Maori Wrasse and cod (also called groupers) were relatively abundant (0.46% and 1.58% of total fish, respectively).

Fish family indicator analysis showed that sea chubs (Kyphosidae, S = 99.7%, p = 0.004) and fusiliers (Caesionidae, S = 86.6%, p = 0.002) were representative of sampling sites within the channel (Table 4). Snappers (Lutjanidae) were distributed throughout transition and fore reef sites (S = 99.7%, p = 0.004), with only 0.6% of all snappers sighted in inner reef sites. Snappers were the dominant predatory reef fish recorded; most abundant of which was the Humpback Red Snapper (*Lutjanus gibbus*) with 580 individuals (6.1%) cumulatively, followed by the Red Snapper (*Lutjanus bohar*) with 258 individuals (2.7%) (Reef Ecologic, 2017a).

Across the entire atoll, planktivorous fish species were the most abundant (3190 individuals), comprising 33.3% of all species. This was followed by herbivorous fish (2318 individuals), which accounted for 24.2% of all fish sighted. Similarly, fish with omnivorous feeding patterns encompassed 21.5% of all species (2059 individuals). Piscivorous species represented a small (15%) portion of overall fish abundance (1437 individuals). The remaining fish observed were corallivorous (2.05%, 196 individuals) or other carnivorous species (e.g., Cleaner Wrasse) that did not suitably fall into other categories (3.94%, 377 individuals).

Table 3. Abundance of fish families per 150m^2 snorkel transect. Sites (n=3) are categorised into respective "reef zones." * represents families that are targeted by fisheries. Annotated letters represent where significant differences lie, using independent one-way ANOVA and Tukey's HSD post-hoc tests, respectively.

Family \ Site	Inner Reef [a]				Transition Zone [b]					Fore Reef [b]					
	RE4	RE8	RE12	Avg	RE1	RE2	RE3	RE5	Avg	RE6	RE7	RE9	RE10	RE11	Avg
Acanthuridae	9 ±2.2	13 ±2.9	19.7 ±9	**13.9 ±4.4**	17.3 ±21	2 ±1.6	25 ±7	25.7 ±13.6	**17.5 ±9.5**	50.7 ±14.5	57.7 ±18.4	25.3 ±6.8	51 ±6.2	45 ±6.4	**45.9 ±11.1**
Balistidae	4 ±5.7	10 ±4.1	0 ±0	**4.7 ±4.1** [b]	3.3 ±4.7	0 ±0	16.7 ±12.5	7.3 ±9.7	**6.8 ±6.3** [a]	10 ±4.1	0 ±0	15 ±2.9	0.7 ±0.9	0 ±0	**5.1 ±6.2**
Blenniidae	0 ±0	0 ±0	0.3 ±0.5	**0.1 ±0.1**	0 ±0	7.3 ±9	0 ±0	0 ±0	**1.8 ±3.2**	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**
Caesionidae	0 ±0	0.3 ±0.5	0 ±0	**0.1 ±0.1** [c]	4.3 ±1.7	5.3 ±4.1	0.7 ±0.5	0.3 ±0.5	**2.7 ±2.2** [c]	1 ±0.8	2 ±0.8	14.3 ±9	0.3 ±0.5	7.3 ±7.1	**5 ±5.3** [a, b]
Carangidae*	3.7 ±5.2	6.3 ±1.7	25.7 ±6.6	**11.9 ±9.8**	0 ±0	0 ±0	1 ±1.4	16.7 ±5	**4.4 ±7.1**	4.3 ±2.5	21 ±5.1	5.3 ±4.1	5 ±1.6	0.7 ±0.9	**7.3 ±7.1**
Chaetodontidae	3.3 ±2.1	0 ±0	7 ±5.9	**3.4 ±2.9**	0 ±0	0 ±0	34.7 ±48.3	2.7 ±1.2	**9.4 ±14.7**	1.7 ±0.5	0.7 ±0.5	0.3 ±0.5	0 ±0	1.3 ±1.2	**0.8 ±0.6**
Cirrhitidae	0 ±0	0 ±0	7 ±7.8	**2.3 ±3.3**	0 ±0	0 ±0	0 ±0	2 ±2.8	**0.5 ±0.9**	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**

Table 3. *Continued*

Ephippidae*	0 ±0	0 ±0	0 ±0	**0 ±0**	2.3 ±2.6	80 ±53.5	8.3 ±2.4	18.3 ±5.9	**27.2 ±31**	0.7 ±0.5	0 ±0	0 ±0	0 ±0	0 ±0	**0.1 ±0.3**
Gobidae	10.7 ±15.1	3.7 ±2.5	1.7 ±1.7	**5.4 ±3.9**	0 ±0	0 ±0	0 ±0	1 ±1.4	**0.3 ±0.4**	0 ±0	0 ±0	0 ±0	0 ±0	0.3 ±0.5	**0.1 ±0.1**
Hemiramphidae	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	0 ±0	0.3 ±0.5	0 ±0	**0.1 ±0.1**	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**
Holocentridae	0 ±0	0.3 ±0.5	0 ±0	**0.1 ±0.1**	0 ±0	0 ±0	1.3 ±1.2	0 ±0	**0.3 ±0.6**	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**
Kyphosidae	1.7 ±1.7	2.7 ±0.9	5.3 ±3.4	**3.2 ±1.5** [c]	0 ±0	0.3 ±0.5	14.7 ±3.1	4 ±0.8	**4.8 ±6** [a, c]	11.7 ±5	1.3 ±0.9	1.3 ±0.9	0.7 ±0.5	2.3 ±2.1	**3.5 ±4.2** [a, b]
Labridae*	6 ±2.9	1.7 ±1.2	0 ±0	**2.6 ±2.5**	42.3 ±0.9	38.3 ±1.2	37 ±0	37 ±0	**38.7 ±2.2**	36 ±0.8	35 ±0	31.3 ±2.9	24 ±1.4	16.7 ±2.1	**28.6 ±7.3**
Labridae	2.3 ±1.2	3.3 ±1.9	6.3 ±4.2	**4 ±1.7**	3 ±1.4	47.3 ±42	60 ±10.8	4.7 ±1.2	**28.8 ±25.3**	35 ±25.4	8.7 ±10.9	1.3 ±0.9	2.7 ±2.4	6 ±6.4	**10.7 ±12.4**
Lethrinidae*	0.3 ±0.5	0.3 ±0.5	1.7 ±1.2	**0.8 ±0.7** [c]	0 ±0	1.3 ±0.9	0.7 ±0.5	0 ±0	**0.5 ±0.5** [c]	1.3 ±0.5	5 ±2.9	8.7 ±2.1	6.3 ±1.2	4.3 ±1.7	**5.1 ±2.4**
Lutjanidae*	0.3 ±0.5	0.3 ±0.5	3.7 ±2.6	**1.4 ±1.6** [c]	11.3 ±10.4	101.3 ±49.4	4.3 ±2.1	6.7 ±3.3	**30.9 ±40.7** [c]	37.3 ±34.6	18.3 ±6.8	51.7 ±38.5	46.7 ±33.5	81.7 ±53.1	**47.1 ±20.7**
Mullidae	2.3 ±0.5	1.7 ±1.7	0 ±0	**1.3 ±1**	0.7 ±0.5	0 ±0	0 ±0	0 ±0	**0.2 ±0.3**	0 ±0	0.7 ±0.9	0 ±0	0 ±0	0 ±0	**0.1 ±0.3**
Pomacentridae	56 ±12.1	49.7 ±12.3	38 ±8.5	**47.9 ±7.5**	110.3 ±42.2	10 ±8.2	106 ±17.1	14.7 ±7.7	**60.3 ±48**	14.3 ±2.5	7.3 ±8.3	4.3 ±1.7	34 ±28.6	22.3 ±14.3	**16.4 ±10.8**

Table 3. *Continued*

Family \ Site	Inner Reef [a]				Transition Zone [b]					Fore Reef [b]					
	RE4	RE8	RE12	Avg	RE1	RE2	RE3	RE5	Avg	RE6	RE7	RE9	RE10	RE11	Avg
Scaridae*	65.7 ±20.3	44.3 ±28.5	1.7 ±0.5	**37.2 ±26.6**	9.7 ±6.8	17.7 ±13.9	14.3 ±9.1	14 ±8.3	**13.9 ±2.8**	1.3 ±0.5	9.7 ±2.4	27 ±24	5.7 ±1.7	5.3 ±2.5	**9.8 ±9**
Scombridae*	0 ±0	0 ±0	0 ±0	**0 ±0**	0.3 ±0.5	0 ±0	0 ±0	0 ±0	**0.1 ±0.1**	0 ±0	0 ±0	0.3 ±0.5	0 ±0	0 ±0	**0.1 ±0.1**
Serranidae*	0.3 ±0.5	0.3 ±0.5	0.7 ±0.5	**0.4 ±0.2**	3.3 ±3.3	0.7 ±0.5	4 ±1.4	0.3 ±0.5	**2.1 ±1.6**	4.3 ±0.9	12.7 ±4.6	1.3 ±1.2	0.3 ±0.5	0.7 ±0.9	**3.9 ±4.6**
Serranidae	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**	146.7 ±179.9	203.3 ±68.5	163.3 ±102.1	93.3 ±73.6	243.3 ±9.4	**170 ±50.9**
Sphyraenidae*	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	0.3 ±0.5	0 ±0	0 ±0	**0.1 ±0.1**	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**
Tetradontidae	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	0 ±0	0 ±0	0 ±0	0.3 ±0.5	**0.1 ±0.1**
Zanclidae	0 ±0	0 ±0	0 ±0	**0 ±0**	0 ±0	1 ±0.8	0 ±0	0.3 ±0.5	**0.3 ±0.4**	0.7 ±0.9	0 ±0	0.3 ±0.5	0 ±0	2.3 ±0.5	**0.7 ±0.9**
Total	**118.8 ±39.3**	**137.9 ±35.8**	**118.8 ±9.2**	**125.2 ±13.4** [c]	**208.3 ±42.2**	**313 ±71.9**	**329 ±52**	**155.7 ±22.5**	**251.5 ±72.2**	**383.4 ±206.2**	**351 ±79.7**	**270.7 ±107.9**	**439.8 ±64.8**	**165.6 ±65.8**	**322.1 ±95.5** [a]

Table 4. Results from indicator analysis, grouping fish by family. Grouping factor refers to habitat groups: inner reef, transition zone, and fore reef. S refers to the indicator value, which is a product of relative frequency and relative abundance used to measure the "exclusiveness" of a family in each reef zone. p refers to the significance as a result of 999 permutations.

Grouping Factor	Fish Family	Indicator Value and Significance
Transition zone	Kyphosidae	S = 99.7%, p = 0.0038
	Caesionidae	S = 86.6%, p = 0.0023
Transition zone + fore reef	Lutjanidae	S = 99.7%, p = 0.0036

Subsistence Fishery Assessment

A total of 4565 individuals from 71 fisheries-targeted species were observed in all transects and comprised of families surgeonfish (Acanthuridae), triggerfish (Balistidae), fusiliers (Caesionidae), trevallies (Carangidae), halfbeaks (Hemiramphidae), soldierfish (Holocentridae), drummers (Kyphosidae), wrasse (Labridae), emperors (Lethrinidae), snappers (Lutjanidae), goatfish (Mullidae), parrotfish (Scaridae), groupers (Serranidae), and tunas (Scombridae). For this analysis, individual counts for Anthias sp. (Serranidae) were not considered since they are not fisheries targets. Similarly, target fish from Labridae and Scombridae are only represented by Maori Wrasse and Dogtooth Tuna, respectively. Relatively large numbers (43) of the iconic, rare, protected fish species Maori Wrasse were recorded across all surveys.

For the fish and invertebrates that were collected and eaten, we recorded a total of 345 individuals with an estimated weight of 103.5kg over a five-day period (Table 5).

Shark, Ray, and Turtle Assessment

We counted 54 sharks from four species; Blacktip Reef Shark (*Carcharhinus melanopterus*), Grey Reef Shark (*Carcharhinus amblyrhynchos*), Whitetip Reef Shark (*Triaenodon obesus*), and Tawny Nurse Shark (*Nebrius ferrugineus*) at 10 locations (Figure 7). A total of 19 individuals were observed at fore reef sites. Of the remaining 35 sharks sighted, 19 were observed at sites close to the channel (Figure 7) and 16 inside the lagoon. The most abundant shark species recorded was the Blacktip Reef Shark with 25 sightings, and the second most abundant shark species was the Grey Reef Shark with 14 individuals recorded. Whitetip Reef Shark sightings accounted for 11 individuals, and only 1 Tawny Nurse Shark was identified. Four Reef Manta Rays (*Mobula alfredi*) were observed inside the lagoon near the channel mouth at two locations (Figure 7).

We observed 25 turtles during underwater visual surveys and travelling between sites (Figure 7). All turtles observed were Green turtles (*Chelonia mydas*). 14 of the 25 turtles were observed during surveys at fore reef sites, 11 were observed inside the lagoon. Nesting locations identified by Balazs (1975) are reported in Figure 7. We did not observe any turtles nesting during our surveys.

Table 5. Observations of date, number, estimated total weight, and species of fish and invertebrates caught for bait and consumption at Kanton Island. NA indicates no bait species.

Date	Bait Species	Bait #	Catch	Catch #	Weight (kg)	Comments
19 June 2017	Hermit Crabs (*Coenobita perlatus*)	50	Brown Marbled Grouper (*Epinephelus fuscoguttatus*)	10	50	Line (Jetty)
19 June 2017	Hermit Crabs (*Coenobita perlatus*)	50	Land Crab (*Cardisoma carnifex*)	10	5	Hand
20 June 2017	NA	NA	Emperors (*Lethrinidae*)	15	5	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
20 June 2017	NA	NA	Humpback Red Snapper (*Lutjanus bohar*)	3	1.5	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
20 June 2017	NA	NA	Needlefish (*Belonidae*)	2	0.2	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
20 June 2017	NA	NA	Crayfish (*Panulirus* sp.)	8	8	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
20 June 2017	NA	NA	Slipper Lobster (*Scyllarides* sp.)	2	0.2	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
20 June 2017	NA	NA	Mantis Shrimp (*Lysiosquillina maculata*)	1	0.8	Line (Causeway). Spotlight at night and hand/dip net. Approx. 10 female crayfish with eggs were released.
21 June 2017	Yellowfin Surgeonfish (*Acanthurus xanthopterus*)	1	Humpnose Bigeye Bream (*Monotaxis grandoculis*)	1	2	Bycatch of shark released
21 June 2017	Yellowfin Surgeonfish (*Acanthurus xanthopterus*)	1	Bluefin Trevally (*Caranx melampygus*)	1	5	Bycatch of shark released
21 June 2017	Yellowfin Surgeonfish (*Acanthurus xanthopterus*)	1	White Bivalve (*Asaphis violascens*)	30	4	Hand
22 June 2017	NA	NA	Great Barracuda (*Sphyraena barracuda*)	1	3	Trolling lure (channel)
22 June 2017	NA	NA	Green Jobfish (*Aprion virescens*)	1	5	Trolling lure (channel)

Table 5. *Continued*

Date	Bait Species	Bait #	Catch	Catch #	Weight (kg)	Comments
23 June 2017	NA	NA	Red Snapper (*Lutjanus bohar*)	1	6	Spearfishing (Spam Island)
			Steephead Parrotfish (*Chlorurus microrhinos*)	1	3	
			Crabs	10	5	Hand
Total catch				**97**	**103.7**	
Fish				36	80.7	
Invertebrates				61	23	

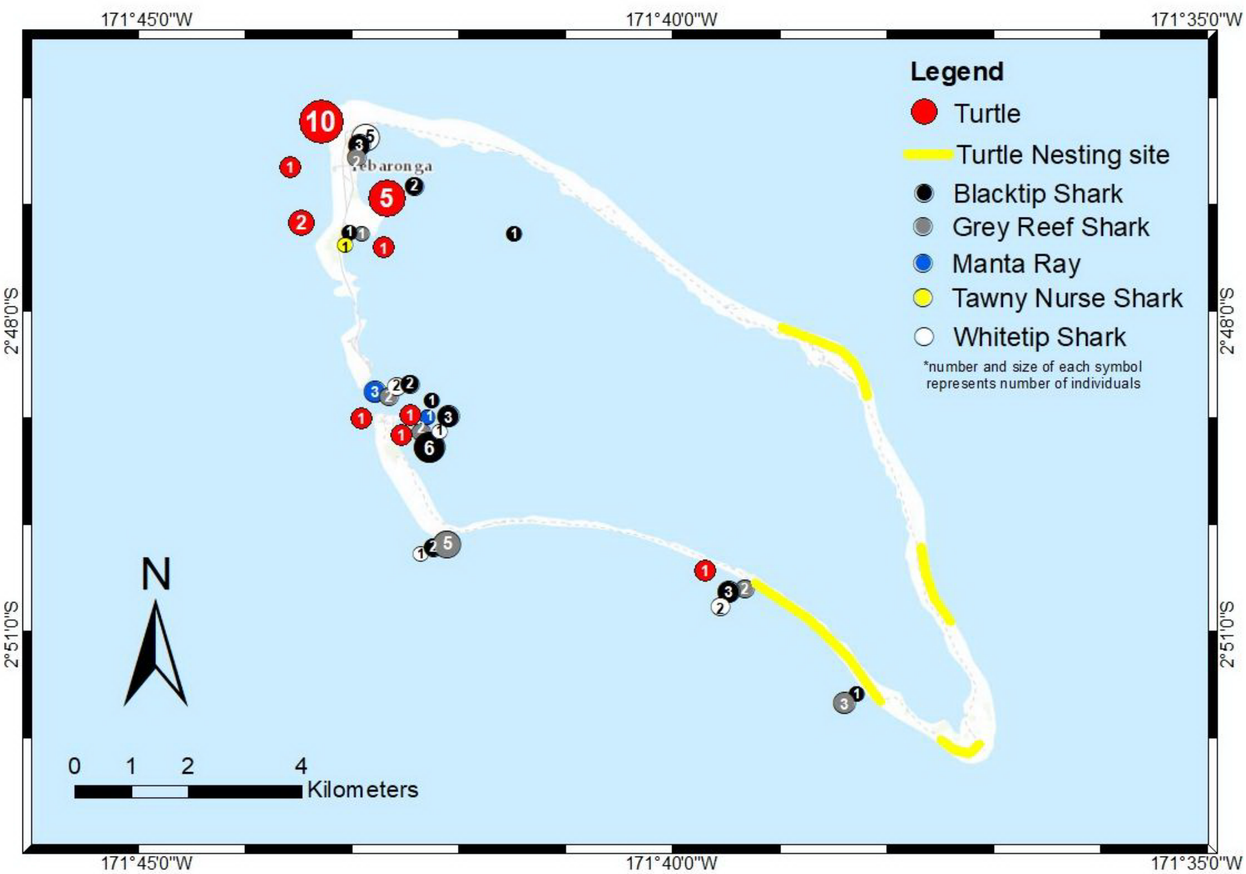

Figure 7. Map showing locations of turtles, sharks, and manta rays observed on Kanton Island, 19–24 June 2017.

Bird and Vegetation Assessment

A total of four species of bird were identified at the surveyed sites (Figure 3, Table 6): the most abundant was Brown noddy with 3600 individuals counted. Grey-backed tern was the second most abundant species with the presence of 400 individuals. Brown booby was another common species with 230 individuals, and Lesser frigatebird was the less abundant species with only 6 individuals identified during the surveys.

In survey B1 (Figure 3; Channel island) 1600 Brown noddy and 400 Grey-backed terns were sighted. Another 2000 Brown noddy were counted in B2 (Spam Islands) with 5 Lesser frigatebirds. At site B3 (*President Taylor* shipwreck), 10 Brown booby were identified. One Lesser frigatebird and 20 individuals of Brown booby were sighted in site B4 (western side of the island). In B5 (British Settlement), 200 Brown boobies were counted.

Table 6. Estimate of maximum number of pairs or individual seabirds present at Kanton Island in 2006–2013 (Pierce, 2013) and observed in 2017. i = individuals

Common Name	**Scientific Name**	**Pierce, 2013**	**Reef Ecologic, 2017a**
Phoenix petrel	*Pterodroma alba*	<10	0
Red-tailed tropicbird	*Phaethon rubricauda*	<50	0
Masked booby	*Sula dactylatra*	<10	0
Brown booby	*S. leucogaster*	50 i	230 i
Red-footed booby	*S. sula*	500	0
Great frigatebird	*Fregata minor*	<10	0
Lesser frigatebird	*F. ariel*	50+	6 i
Sooty tern	*Sterna fuscata*	50+	0
Grey-backed tern	*S. lunata*	2000+	400 i
Black noddy	*Anous minutus*	50+	0
Brown noddy	*A. stolidus*	2000+	3600 i
Blue noddy	*Procelsterna caerulea*	0	0
White tern	*Gygis alba*	10+	0
Approximate total pairs		**4000+**	**4236 i**
Total species		**13**	**4**

Nine different species of plants were identified during vegetation surveys (Table 7), Beach saltbush was the most abundant species covering 65.3% (±SD 37.32), followed by Buttonwood with cover of 24.0% (±SD 38.13). Other species identified: Coconut palm, Casuarinas, Seagrape, Tropical almond, Beach heliotrope, Pandanus palm, and White leadtree. Each individually accounted for less than 2.8% of vegetative cover (Table 7).

Table 7. Results from vegetation surveys at Kanton Island in 2017.

Location	**Kanton Settlement**	**Road to Wharf**	**British Settlement #1**	**British Settlement #2**
Survey #	**VE1**	**VE2**	**VE3**	**VE4**
Beach saltbush (*Scaevola sericea*)	1%	90%	90%	80%
Buttonwood (*Conocarpus erectus*)	90%	4%	0%	2%
Coconut palm (*Cocos nucifera*)	5%	4%	2%	0%
Casuarinas (*Casuarina equisetifolia*)	4%	1%	4%	2%
Seagrape (*Coccoloba uvifera*)	0%	0%	2%	7%
Tropical almond (*Terminalia catappa*)	0%	0%	0%	8%
Beach heliotrope (*Heliotropium foertherianum*)	0%	1%	0%	0%
Pandanus palm (*Pandanus tectorius*)	0%	0%	1%	1%
White leadtree (*Leucaena leucocephala*)	0%	0%	1%	0%

Aesthetics Rating of Dive Sites for Tourism

Two dive sites were rated as aesthetically excellent sites: (1) shipwreck of the U.S. troop transport vessel *President Taylor* (RE2), which ran aground in 1942 at the entrance to the channel (Turner et al., 2009), with a complex infrastructure containing a diversity and abundance of schooling fish; and (2) the Cascades (RE12), which is located inside the lagoon and contains a very high abundance of coral and butterflyfish (Figure 8).

Three sites were rated as “above average”: The Nursery (RE4), Snapper Reef (RE6), and Pelagic Point (RE9), and they contained diverse fish, coral, sharks, and turtles. Three sites were rated as “average”: Trigger Reef (RE10), Unicorn Reef (RE11), and Spam Island Channel (RE5). Only one of the 12 sites we surveyed, House of Cards (RE8) was assessed as below average (Figure 8) because of relatively poor water visibility, low coral cover and fish abundance.

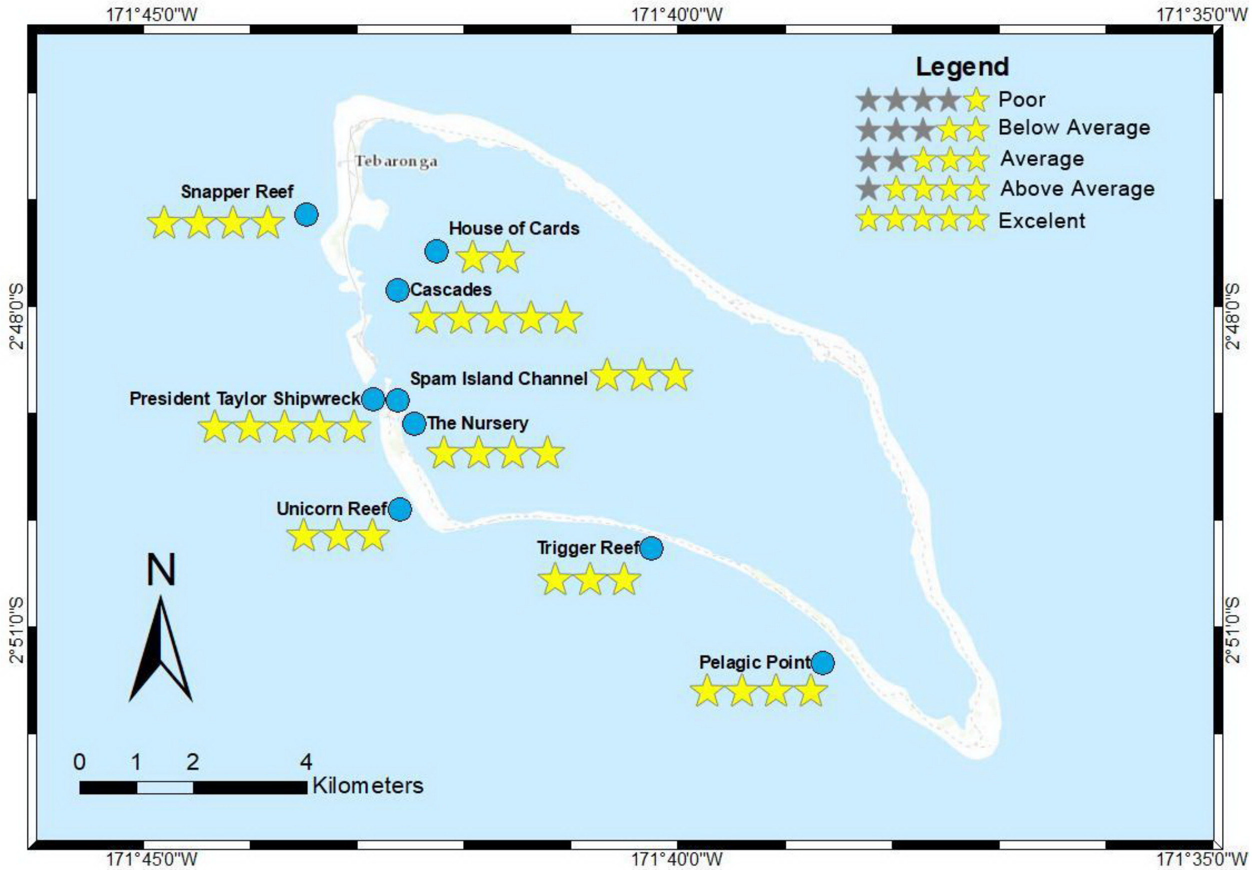

Figure 8. Dive site aesthetic rating of Kanton Island.

Infrastructure Assessment

The infrastructure inspection scope included visual assessment and reporting of:

- The port infrastructure including approximately 150m of sheet piled quay line wall, 75m of reinforced concrete seawall, a 12m long steel piled jetty, and concrete vessel slipway (Figure 4);
- Airfield comprising taxiways, 2.4-km airstrip, and two remaining buildings, one of which is currently used for aviation fuel storage (Figure 4);
- Approximately 4.3 km of road between the port and airfield including a ~100 m section of road/causeway that is understood to have failed at some point between November 2014 and June 2016 (Figure 4).

A summary of the existing infrastructure, condition rating, key issue and criticality/risk is in Table 6. One component of infrastructure, the below-water section of the port, was assessed as "Good." The most common condition rating was "Poor" for Port, Jetty, Road, Water, and Waste management; followed by "Fair" for Road and Energy (Table 8). The causeway was assessed as "Damaged." The risk was assessed as "High" for the Port, Airport, Road, Causeway, Energy, Water, and Waste management (Table 8). The risk was assessed as "Medium" for Jetty and Moorings (Table 8).

Table 8. Summary of infrastructure at Kanton Island, key issue, condition, and criticality/risk.

Infrastructure	Key Issue	Condition	Criticality/Risk
Port	Transport, food, fuel, tourism	Poor (above water) Good (below water)	High
Jetty	Transport, food, fuel, tourism	Poor	Medium
Airport	Transport, food, fuel, tourism	Fair	High
Road	Transport	Fair to poor	High
Causeway	Transport	Damaged	High
Moorings	Tourism, environmental protection	None	Medium
Energy	Diesel, solar	Fair	High
Water	Wells, rainwater tanks	Poor	High
Waste management	Burning, toilet, recycling, WWII	Poor	High

DISCUSSION

This study was broad in scope to meet the requirements of the PIPA Implementation Office, Ministry of Environment, Land & Agricultural Development, Kiribati to establish a contemporary ecological and infrastructure baseline for Kanton Atoll, in preparation for development of a Kanton Resource Use Sustainability Plan (KRUSP). The ecosystem assessment identified a high abundance of coral and fish. Coral cover was higher inside the inner reef (lagoon) and in the transition zone (channel) than in fore reefs, in particular at site RE12 (the Cascades), which showed 93% cover of tabular *Acropora*. Fish species diversity and abundance was similar to surveys conducted 20 years previously by Obura et al. (2011b) and Stone et al. (2000, 2001), which reported an average of 109 species in the Phoenix Archipelago compared to the 130 species identified in Kanton in the present study. The bird assessment identified large numbers of roosting and nesting birds at Channel and Spam Islands. The vegetation assessments indicated an abundant (and, in places, virtually impenetrable) cover of trees and shrubs.

Limitations with the Survey Method

Marine ecosystem assessment surveys were limited to one survey period (June 2017) and areas we could access from the shore or by small boat, which were primarily the leeward side of the island and close to the channel. Research was limited to a depth of approximately 10m by snorkelling compared to previous vessel-based research expeditions involving research divers using SCUBA (Allen and Bailey, 2011; Obura et al., 2011b; Mangubhai et al., 2012; Mangubhai and Rotjan, 2015). Visual assessments are an easy and effective way to rapidly assess and record common fish and coral species, but pelagic and deep-water species of fish are rarely sighted, and small cryptic species are often overlooked. A limitation is that the fish surveys did not include estimates of fish sizes, so biomass could not be assessed.

There is a range of recognized methods for the survey and census of birds. We counted individual birds on the ground and in the air and compared our results to Pierce (2013; Table 6), who counted pairs of birds.

A limitation of our observations of turtles is that they were based on in-water surveys. Surveys of marine turtle numbers are typically undertaken during peak nesting season of October–November (Balazs, 1975; Maison et al., 2010; Obura et al., 2011a).

Coral Community Assessment and Variation

The highest coral cover was observed at survey location RE12 (93%) compared to RE4 and RE8, where we recorded less than 30% live cover (Figure 5). Sites more distant from the channel (RE8), or outside of the tidal water flow path (RE4) are potentially subjected to higher sedimentation as illustrated by higher percentages of sand and rubble. The channel is a wave-sheltered environment with strong water flows, offering ideal conditions for coral growth and, for this reason, hosts higher coral and more genera than the inner reef (Figure 6). As reported by Obura et al. (2011a), areas further than 2 km from the channel mouth inside the lagoon do not experience water recycling from the tide cycle, allowing sediment accumulation, which is known to have negative effects on coral growth and recruitment (Crabbe and Smith, 2005). The coral community of the fore reef was more varied in terms of genera and of morphologies hosting coral genera not present in other reef zones (Figure 6). The lower coral diversity of sheltered habitat compared to exposed habitats has been previously reported by Williams et al. (2013).

The most common coral genera in Kanton Atoll were *Acropora, Pocillopora*, and *Porites*, which were also reported by Obura et al. (2011a) as most common species, as well as Fungiidae, Faviidae, Agariciidae, and Milleporidae, which were present in small proportions in this study (Figure 6). The change between dominant morphologies could be an effect of the thermal stress event registered between 2002 and 2005. Lasting for nearly five years, with a peak at 21 Degree Heating Weeks, this event caused extensive bleaching, estimated at between 63% and 100% coral mortality (Alling et al., 2007; Obura and Mangubhai, 2011). Mean total live coral cover in this study accounted for 42.33% (± 27.73%), showing that the coral community was able to recover despite the global bleaching event in 2015–2016 (Herring et al., 2018).

Fish Community Assessment and Variation

We recorded a total of 130 species of fish from twelve sites. This is similar to the 143 species that were identified at Nukunonu Atoll, Tokelau (Fergusson, 2015) but is less than the 166 species recorded at the *President Taylor* shipwreck, Kanton Island by Allen and Bailey (2011).

Comparison of Indicator Fish and Fish Families

Recent studies of fish in the Phoenix Islands by Mangubhai et al. (2014) recorded selected fish families, and previous surveys (Obura et al., 2011b) recorded indicator groups, families, and species. We were unable to compare our results with Mangubhai et al. (2014), because the fish family data were not provided in tabular form or in appendices. We compared four groups: tuna and pelagics, jacks, reef predators, and sharks and rays, and five families (groupers, snappers, parrotfishes, surgeonfish, triggerfish), and provide general comments on the trend (higher, lower) between the two studies (Table 9). Three species, Rainbow Runner, Black Trevally, and Chevron Barracuda, were reported by Obura et al. (2011b) but not reported by Reef Ecologic (2017a) (Table 9). Six species, Yellow-Spotted Trevally, Great Barracuda, Smalltooth Jobfish, Paddletail, Blacktip Reef Shark, and Tawny Nurse Shark were reported by Reef Ecologic (2017a) but not reported by Obura et al. (2011b) (Table 9).

Table 9. Comparison of total numbers of large indicator fish species and average numbers of fish families at Kanton Island from 2000 (4 sites, Obura et al., 2011b, 27) and 2017 (12 sites, Reef Ecologic, 2017a). Lower part of the table tabulates fish family level data. — indicates no trend determined. [1] = not recorded by Obura et al. (2011b)

Scientific Name	Common Name	Obura et al. (2011)	Reef Ecologic (2017a)	Trend
TUNA AND PELAGICS				
Gymnosarda unicolor	Dogtooth Tuna	17	2	Decrease
Euthynnus affinis	Mackerel Tuna	0	0	—
Scomberoides lysan	Double-Spotted Queenfish	12	105	Increase
Elagatis bipinnulata	Rainbow Runner	60	0	Decrease
JACKS				
Caranx sexfasciatus	Bigeye Trevally	1700	20	Decrease
Caranx melampygus	Bluefin Trevally	126	108	—
Caranx lugubris	Black Trevally	84	0	Decrease
Carangoides orthogrammus[1]	Yellow-Spotted Trevally	NA	49	Increase
REEF PREDATORS				
Sphyraena barracuda[1]	Great Barracuda	NA	1	—
Sphyraena qenie	Chevron Barracuda	127	0	Decrease
Cheilinus undulatus	Maori Wrasse	27	43	Increase
Epinephelus fuscoguttatus	Flowery Cod	13	19	—
Plectropomus laevis	Footballer Trout	0	1	—
Aprion virescens	Green Jobfish	3	0	—
Aphareus furca[1]	Smalltooth Jobfish	NA	19	Increase
Lutjanus bohar	Red Bass	112	258	Increase
Lutjanus gibbus	Paddletail	NA	580	Increase
Macolor macularis	Midnight Seaperch	0	0	—
Macolor niger[1]	Black Snapper	NA	1	—
SHARKS AND RAYS				
Carcharhinus melanopterus	Blacktip Reef Shark	0	23	Increase
Carcharhinus amblyrhynchos	Grey Reef Shark	25	17	Decrease
Triaenodon obesus	Whitetip Reef Shark	9	11	—
Nebrius ferrugineus[1]	Tawny Nurse Shark	NA	1	—
Manta birostris	Manta Ray	4	4	—
FISH FAMILY	Groupers	4.2	2.4	—
	Snappers	296	205	Decrease
	Parrotfishes	208	18	Decrease
	Surgeonfishes	17	44	Increase
	Triggerfishes	7	5.7	—

The trends from a comparison of the two data sets (Obura et al., 2011b; Reef Ecologic, 2017a) indicate trends of a comparative decrease between 2000 and 2017 for Dogtooth Tuna, Bigeye Trevally, Black Trevally, Chevron Barracuda, Rainbow Runner, and parrotfishes, and comparative increases in Double-Spotted Queenfish, Yellow-Spotted Trevally, Maori Wrasse, Red Bass, Paddletail, Smalltooth Jobfish, Blacktip Reef Shark, and surgeonfishes. Snappers were the most abundant category of fish, followed by surgeonfishes and parrotfishes (Table 9). The comparison indicates that Obura et al. (2011b) reported very large schools of parrotfish with up to 800 individuals compared to a maximum of 82 parrotfish in our assessment (50m × 4m) (Table 9). There were several families of fish that were NOT observed including sweetlips, flutemouth, and trumpetfish (Reef Ecologic, 2017a).

Comparison of Fish between Habitats

Fish populations in inner reef habitat were characterised by similar diversity indices as fore reef and transition zone, whilst containing significantly lower numbers of individuals (Table 3), highlighting a small but heterogeneous community. In this study, fish showed an ecological preference for inner reef habitats included Whitetail Dascyllus, Sailfin Tang, Steephead Parrotfish, Orange Striped Emperor, and Peacock Damselfish (Appendix B).

Inner reef included a high (295) abundance of juvenile parrotfish (Scaridae). Juveniles were almost exclusively (96.7%) found in the inner reef sites except for 10 individuals observed in transition zone (3.3%). This is consistent with Russ (1984), who showed that scarids generally have higher numbers of species and individuals on reef crests and in lagoons than on reef flats or reef slopes. Conversely, fore reef sites housed the greatest number of adult parrotfish (97 individuals) throughout all surveys in fore reef sites, comprising 86.6% of all observed parrotfish species. From this observation it could be assumed that parrotfish use the lagoon environment as a nursery (Gratwicke et al., 2006).

The Flowery Rockcod (*Epinephelus fuscoguttatus*) was an indicator of transition zone sites (Appendix B). Only 14 individuals were observed throughout all surveys, 13 of which appearing in the channel. At site RE1, 10 individuals were observed; this site hosted the most diverse coral community of all *transition zone* sites (Figure 5) and was also the location of the jetty. It could be assumed that these factors provide a topologically complex environment whilst maintaining access to the ocean to suit large mobile Serranidae, such as *E. fuscoguttatus,* which utilize both roving and cryptic predation (Pears et al., 2005). Fusiliers (Caesionidae) was found exclusively in *transition zone* sites (Table 3). The distribution of this planktivorous family of fish (Froese and Pauly, 2019) is likely reflective of lagoon-ocean water exchanges, in which lagoonal water containing a relatively higher biomass of zooplankton is mixed with oceanic waters (Pagano et al., 2017). Drummers (Kyphosidae) were also observed almost exclusively (99.4% of all observations) in these channel systems despite an omnivorous diet (Silvano and Güth, 2006), suggesting a preference for planktivorous feeding. Allen and Bailey (2011) also described a high proportion of plankton feeders in channel-lagoon systems, supporting this pattern of distribution. Conversely, fore reef sites hosted a higher abundance of planktivorous fish species (Appendix C).

Multipattern indicator analysis identified four fish species whose abundance was statistically associated with reef zones. The indicator species analysis revealed the prevalence of carnivorous Bluespotted Hind (*Cephalopholis cyanostigma*), Yellowfin Emperor (*Lethrinus xanthochilus*), and omnivorous species such as Black Triggerfish (*Melichthys niger*) and the Red Spot Wrasse in fore reef sites. The lower trophic diversity of species from fore reef sites suggests that these environments host less ecological niches than inner reef sites. Fore reef coral communities were less diverse, and most of the substrate was characterised by rock with coralline crustose algae. Despite the low overall abundance of piscivorous fish species (15% of all fish observed), they were consistently observed in *fore reef* and *transition zone* sites (Table 4, Appendix C).

Subsistence Fisheries

Fish and other marine species are the principal food for Kiribati people (Johannes and Yeeting, 2000; Rouatu et al., 2017; Thomas, 2020). A 1988 survey of five households (18 people) in Kanton indicated consumption of 2.89 kg per person per day and total landings of 364.4 kg (51% from lagoon and 49% from reef) with bonefish (31%), emperors (16%), and mullets, trevallies, soldierfish, groupers, snappers, drummers, surgeonfish, and crayfish (Uwate and Teroroko, 2007). Our survey indicated a similar 50:50 split of catch from the inner reef and fore reef, and subsistence catch of approximately 20 kg per day for 50 people, which averages as approximately 0.4 kg of fish and invertebrates per person per day. This is similar to the estimated whole fish consumption in Kiribati of 62–150 kg per capita per year (Bell et al., 2009; Mangubhai et al., 2019).

There is very limited data on subsistence fisheries of Kanton Island (Uwate and Teroroko, 2007). A comparison of the 1988 survey with this study indicated differences with the dominant catch from 1988 being bonefish and the 2017 survey recorded no bonefish, mullets, soldierfish, or drummers. Although the 1988 survey included crayfish, it did not report any crabs, Slipper Lobsters, Mantis Shrimp, or bivalves. Recording the wide abundance of shellfish (bivalves, crabs) caught during 2017 subsistence fisheries assessment, we speculate that Kanton inhabitants have shifted their diet to include more invertebrates. Ciguatera, a type of fish poisoning that occurs throughout the tropics, was historically reported at Kanton Island between 1998 and 2008 (Skinner et al., 2011). Several of the fish species collected and eaten at Kanton Island during our survey, such as the snappers (*Lutjanus gibbus*, *L. bohar*) and the larger groupers, are well known for ciguatera fish poisoning in other areas of the Pacific. However, no ciguatera symptoms were noted during our visit.

In a 2000 visual census of Kanton Island, Dogtooth Tuna (*Gymnosarda unicolor*) were observed in 75% of indicator species surveys in fore reef and transition zones (Obura et al., 2011b). A year after the legalisation of tuna fishing in 2001 (Rotjan et al., 2014) fish censuses showed Dogtooth Tuna present in 0% of all surveys in the Phoenix Islands (Obura and Stone, 2002). Three years following the introduction of the PIPA no-take area (stating full closure to commercial fishing) in January 2015 (Witkin et al., 2016), fish censuses by Reef Ecologic in 2017 observed Dogtooth Tuna in 22.2% of surveys of fore reef and transition sites. Reef Ecologic (2017a) recorded the presence and abundance of target fish families and species common in the Pacific (Table 3), including 43 individuals of Maori Wrasse (*Cheilinus undulatus*) across all transects. Maori Wrasse is a high value target for fisheries in the Indo-Pacific region, which caused its population decline resulting in its listing as endangered species by the IUCN (Barott et al., 2010). The presence of these target fish families and abundant shark populations are indicative of low fishing pressure (McClanahan et al., 2007; Wilkin et al., 2016). The abundance of certain families in different areas of the island may provide valuable input in future fisheries management to support subsistence fisheries in the island (Rotjan et al., 2014).

Sightings of Sharks, Rays, and Turtles

Shark presence was higher in the transition zone, with 35 individuals from 4 species identified in this environment. Most individuals of Blacktip reef shark were found in the shallow sand flats of the transition zone (lagoon). Papastamatiou et al. (2009, 2015) reported that Blacktip Reef Sharks have a relatively small home range (0.55 ± 0.24 km^2) and show high site fidelity within lagoon atolls. Grey Reef Sharks were observed in the fore reef habitat (Figure 7). The sighting of a Tawny Nurse Shark (*Nebrius ferrugineus*) is rare in the Phoenix Islands, and only 1 individual has previously been recorded, by Allen and Bailey (2011).

Four Reef Manta Rays were sighted during the surveys, and all of them were in the transition zone (lagoon) in proximity of the channel. High productivity of lagoon environments and planktonic tide transport within the channel (Pagano et al., 2017) are likely the cause for Reef Manta Ray presence in atoll lagoons.

The 25 Green turtles sighted during the surveys were mostly in fore reef sites. Nesting of this species goes on all year long, with a peak in October and November (Balazs, 1975; Maison et al., 2010; Obura et al., 2011a). Additionally, 15 Bottlenose dolphins (*Tursiops* sp.) were sighted while riding the bow wave of our vessel as we transited between sites.

Bird and Vegetation Surveys

The Phoenix Islands are an internationally important seabird haven supporting 19 species of breeding seabirds. These include two endangered species, the Phoenix petrel and the White-throated storm-petrel, and several globally important breeding colonies of boobies, frigatebirds, tropic birds, and terns. All PIPA islands have a unique assemblage of seabirds reflecting each island's habitat and invasive species history.

Recent assessments (Pierce, 2013) indicate that populations of many of these species declined in the late twentieth century and became confined to fewer islands in the PIPA. Surveys between 2006 and 2013 found Kanton to be home to 13 species of seabirds and an estimate of more than 4000 pairs or individuals (Pierce, 2013; Table 6). Bird population declines in the Pacific have come about mainly through the arrival of invasive species, with a few arriving during the Austronesian settlement period 1000 years ago (Steadman, 1995), but as with most islands impacts, these have escalated during the period of European colonization over the last 30 years (Croxall et al., 2012).

The total number of seabirds observed during surveys in 2017 were consistent with estimates reported by Pierce (2013) (Table 6). In identifying only four species of seabirds in 2017, our results represent a reduction in the diversity of species represented. However, it is important to note that bird surveys were coarse estimates that may have resulted in few sightings of less obvious species. For example, night surveys are recommended for the Phoenix petrel (*Pterodroma alba*).

PIPA provides protection for terrestrial habitats on each of its islands, safeguarding traditional plants that have cultural and medicinal values in Kiribati but are now depleted on more populated islands. This includes the Pandanus palm, observed at two of the four locations surveyed. Several invasive species are present in Kanton including Lantana and Pluchea (Pierce, 2013), however neither were recorded during our surveys but were noted during casual observations on the island. Management of terrestrial native plant species requires a two-step process of eradication of predators (both floral and mammalian) and improvement in biosecurity. Kanton's remoteness, limited number of visitors, and small, supportive community provide favourable logistics for undertaking terrestrial restoration in coming years.

Values for Future Tourism

Coral reefs are one of the main assets of remote tropical island tourism. Aside from pristine wildlife, rich culture, history, and sense of privacy, much of the value of remote island tourism is directly related to coral reef in-water activities such as snorkelling, SCUBA diving, and fishing (Spalding et al., 2017). Many studies and aesthetic surveys have shown that clear water, fine sand, fish abundance, diversity, and coral complexity greatly influence tourist preferences (Uyarra et al., 2009; Navrátil et al., 2012; Marshall et al., 2019).

Sites located in the inner reef and transition zone show high value for tourism due to high mean live coral cover (>30% and up to 93%). The high percentage of *Acropora* spp. also contribute to increased tourism value of transition and inner reef sites due to higher reef structural complexity. Live coral cover and topographic complexity provided by branching and bushy corals (in the lagoon they are all tabular) are important indicators of snorkelers and diver experience due to the aesthetic value they add to photo compositions (Uyarra et al., 2005, 2009; Marshall et al., 2019). More complex and colourful reefs give tourists a perception of higher chances to encounter rare organisms (Uyarra et al., 2009).

Another indicator of coral reef value for tourism is fish abundance and diversity. Although overall fish abundance is significantly higher in fore reef sites, colourful fishes that attract tourists, such as butterflyfish, parrotfish, damselfish, and wrasse, have high abundance in sites located in lagoon and channel (Giglio et al., 2015). On the other hand, more experienced divers prefer cryptic fauna and small invertebrates or rare species such as turtles, manta rays, and sharks, which were also observed inside the lagoon and in the channel. The results of our aesthetic survey correlates with this finding such that two of the "excellent" dive sites (i.e., RE2, *President Taylor* shipwreck, and RE12, Cascades) and one "above average" dive site (i.e., RE4, The Nursery) are located in the lagoon and the channel. The dive site aesthetic rating is a subjective but readily understood tool for the community, industry, and marine park managers to prioritise sites, as it summarises complex information into simple values.

Tourists that participate in fishing value catching sports fish such as Bonefish (*Albula glossodynia*) and Giant Trevally (*Caranx ignobilis*) (Aardvark McLeod, 2018; Kiribati Tourism, 2020). There is a new, exclusive, limited tourism market for catch and release fishing at Kanton Island with groups of up to five fishers paying US$10,000 per person for 7–10 day expeditions (Aardvark McLeod, 2018; Kiribati Tourism, 2020).

State of Infrastructure

Infrastructure is necessary for transport, food, fuel, tourism, and implementing environmental protections for the island's ecosystems. In stark contrast to the ecosystem assessment, the condition of the island's infrastructure was generally poor, as would be expected given little to no maintenance has been undertaken since 1965 when Pan American Airways abandoned the island. Potential re-use and upgrade options were presented for the island's critical port, airfield, and road network infrastructure at an estimated total capital expenditure of US$31.2 million (Arup, 2017). This strategy included provision for necessary repair and upgrade works to the port, airfield, road network, and buildings. In addition, further studies and investigations were recommended for repair and upgrade of the island's power generation and associated distribution network, communication services, water supply, and reticulation services and waste treatment/sewerage services.

CONCLUSION

The atoll of Kanton Island is of scientific, conservation, and potentially tourism interest because of its geographical location, extreme isolation, small size, human history, and ecological value. Whilst limited in intensity, the rapid ecosystem assessment provides a comprehensive snapshot recording fish, coral, birds, vegetation, sharks, turtles, and marine mammals at Kanton Island. Our research identified very high coral cover in transitional and inner reef environments and demonstrated recovery of corals following past bleaching events. The atoll hosted a moderate diversity of fish communities compared to global hotspots (Allen, 2008), with high abundance of fisheries-targeted species, particularly on the outer reef. The Kanton Island transitional environment is likely to have important ecological functions in sustaining a wide range of terrestrial and marine species with economic and ecosystem value. The research indicates that the local community relies on subsistence fishing of fish and invertebrates (crabs, lobster, shellfish) for food.

The infrastructure inventory demonstrates the diversity of existing man-made facilities including port, airport, road, and causeway. Our assessment indicates most infrastructures are in poor condition, which is not surprising as they were primarily constructed during WWII, and there has been little ongoing maintenance or repair over the past 80 years.

The ecological and infrastructure assessments (Arup, 2017; Reef Ecologic, 2017a), together with extensive consultation of more than 200 people, were used to inform a Kanton Resource Use Sustainability Plan (KRUSP) (Reef Ecologic, 2017b) to comply with the requirements of the PIPA Management Plan 2015–2020.

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APPENDIX A: GEOGRAPHIC COORDINATES OF EACH STUDY SITE

Site ID	Site	Latitude	Longitude
RE1	Transition zone	-2.80678300	-171.71423300
RE2	Transition zone	-2.81488300	-171.71515000
RE3	Transition zone	-2.81388300	-171.71575000
RE4	Inner reef	-2.81728300	-171.71051700
RE5	Transition zone	-2.81526700	-171.71218300
RE6	Fore reef	-2.78543300	-171.72543300
RE7	Fore reef	-2.76958300	-171.72386700
RE8	Inner reef	-2.79185000	-171.70543300
RE9	Fore reef	-2.85408300	-171.64215000
RE10	Fore reef	-2.83531700	-171.67981700
RE11	Fore reef	-2.82981700	-171.71025000
RE12	Inner reef	-2.79760000	-171.71198300
B1	Bird	-2.81124985	-171.70862140
B2	Bird	-2.81851919	-171.71043873
B3	Bird	-2.81120552	-171.71256635
B4	Bird	-2.81426396	-171.71682157
B5	Bird	-2.77800591	-171.71664427
VE1	Vegetation	-2.78004488	-171.71620102
VE2	Vegetation	-2.79143646	-171.71872756
VE3	Vegetation	-2.82055815	-171.71003981
VE4	Vegetation	-2.81727808	-171.71039441

APPENDIX B: INDICATOR FISH SPECIES FOR REEF ZONES

Fish species are listed by both common names and Latin species name. S coverage incorporates the probability of finding a species at each grouping factor compared to the probability of finding the same species in a different grouping factor.

Grouping Factor	Fish Species	S Coverage and *p* Values
Inner reef	Whitetail Dascyllus *Dascyllus aruanus*	S = 93.9%, $p = 0.047$
	Sailfin Tang *Zebrasoma veliferum*	S = 91.3%, $p = 0.011$
	Steephead Parrotfish *Chlorurus microrhinus*	S = 84.7%, $p = 0.047$
	Orange Striped Emperor *Lethrinus obsoletus*	S = 81.6%, $p = 0.045$
	Dash-and-Dot Goatfish *Parupeneus barberinus*	S = 81.6%, $p = 0.045$
	Peacock Damselfish *Pomacentrus pavo*	S = 80.1%, $p = 0.043$
Transition zone	Brassy Chub *Kyphosus vaigiensis*	S = 99.8%, $p = 0.003$
	Brown-Marbled Grouper *Epinephelus fuscoguttatus*	S = 86.6%, $p = 0.024$
	Yellow and Blueback Fusilier *Caesio teres*	S = 86.6%, $p = 0.024$
Fore reef	Bluespotted Hind *Cephalopholis cyanostigma*	S = 96.3%, $p = 0.0023$
	Orangespine Unicornfish *Naso lituratus*	S = 92.8%, $p = 0.012$
	Yellowlip Emperor *Lethrinus xanthochilus*	S = 89.4%, $p = 0.019$
	Red Spot Wrasse *Pseudocoris yamashiroi*	S = 89.4%, $p = 0.024$
	Black Triggerfish *Melichthys niger*	S = 88.9%, $p = 0.037$
Inner reef + fore reef	Humpback Red Snapper *Lutjanus gibbus*	S = 94.3%, $p = 0.027$
Transition zone + inner reef	Blue-Barred Parrotfish *Scarus ghobban*	S = 92.6%, $p = 0.015$
	Neon Damselfish *Pomacentrus coelestis*	S = 91.8%, $p = 0.029$

APPENDIX C: FISH CATEGORISED BY TROPHIC GROUP

[a] and [b] refer to significant differences observed through Kruskal-Wallis test and Dunn-Bonferroni post-hoc analysis. Median and IQR are shown to better represent the skewed distribution of these individuals.

	Inner Reef		Transition Zone		Fore Reef		Overall	
Trophic Group	**Median**	**IQR**	**Median**	**IQR**	**Median**	**IQR**	**Count Fish**	**% of all**
Herbivore	252	135	192.5	73	163	65	2318	24.2
Corallivore	23	38.5	2.5	18	3	5	196	2.05
Omnivore	117	80.5	306	137.5	104	37	2059	21.5
Planktivore	88[a]	53	84[b]	126.3	501[ab]	184	3190	33.3
Piscivore	14	12.5	43.5	106.5	156	133	1437	15.00
Other*	17	25	13	7.5	15	54	377	3.94

* Carnivorous organisms that could not be meaningfully classified (for example: cleaner wrasses). Detritivores were grouped with other omnivores.