2016 Stock assessment of *Trochus niloticus* in Palau

Marine Gouezo[1], Percy Bitoch Rechellul[2] and Geory Mereb[1]

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[1]: Palau International Coral Reef Center

[2]: Bureau of Marine resources

1. Introduction

Trochus niloticus, called *Semum* in Palauan, is a valuable reef gastropod because of its usefor mother-of-pearl buttons, jewelry, handicrafts and polishing agents (Gillett 1997). This species has been historically harvested in many Pacific islands including Palau (Kitalong 1992; Gillett 1997) so different management programs have been put in place in efforts to make the fishery sustainable.

In Palau, Trochus season is always closed unless the national congress, the Olbiil Era Kelulau (OEK), opens the season by resolution. The decision whether to open the season for trochus harvesting is based on findings from stock assessment surveys conducted by the Bureau of Marine Resources (BMR) and other partner agencies. During open season, only mature individuals with a basal diameter greater than 3 inches can be harvested. In 2016, the 9th OEK requested BMR to conduct a stock assessment to determine the population status of *Trochus niloticus* in Palau. BMR requested assistance from the Palau International Coral Reef Center (PICRC) to design the surveys, analyze the data and write a report of main findings. BMR conducted the stock assessment in the field and entered the data.

The aim of this study is to provide an estimation of population density and status of *Trochus niloticus* in Palau. The data and the report will be the basis for any recommendations that will be made by the Bureau of Marine Resources.

2. Methods

2.1. Site selection

The survey design was prepared by PICRC as requested by BMR. The design focused on the main habitats where *Trochus niloticus* are most commonly found: fore reef and reef crest. The total area of each habitat was calculated using the NOAA shallow habitats map of Palau (NOAA 2014) and QGIS (QGIS Development Team 2015). Palau was split into four regions of approximately equal areas (Figure 1) for good spatial coverage of survey sites. Fore reef and reef crest layers were clipped for each region and areas were calculated from the clipped layers. Collection hotspots were also identified on the reef map by PICRC staff and polygon areas were drawn on the map in blue (Figure 2). Marine protected areas reef habitats (in red) were excluded from the sampling design (Figure 2).

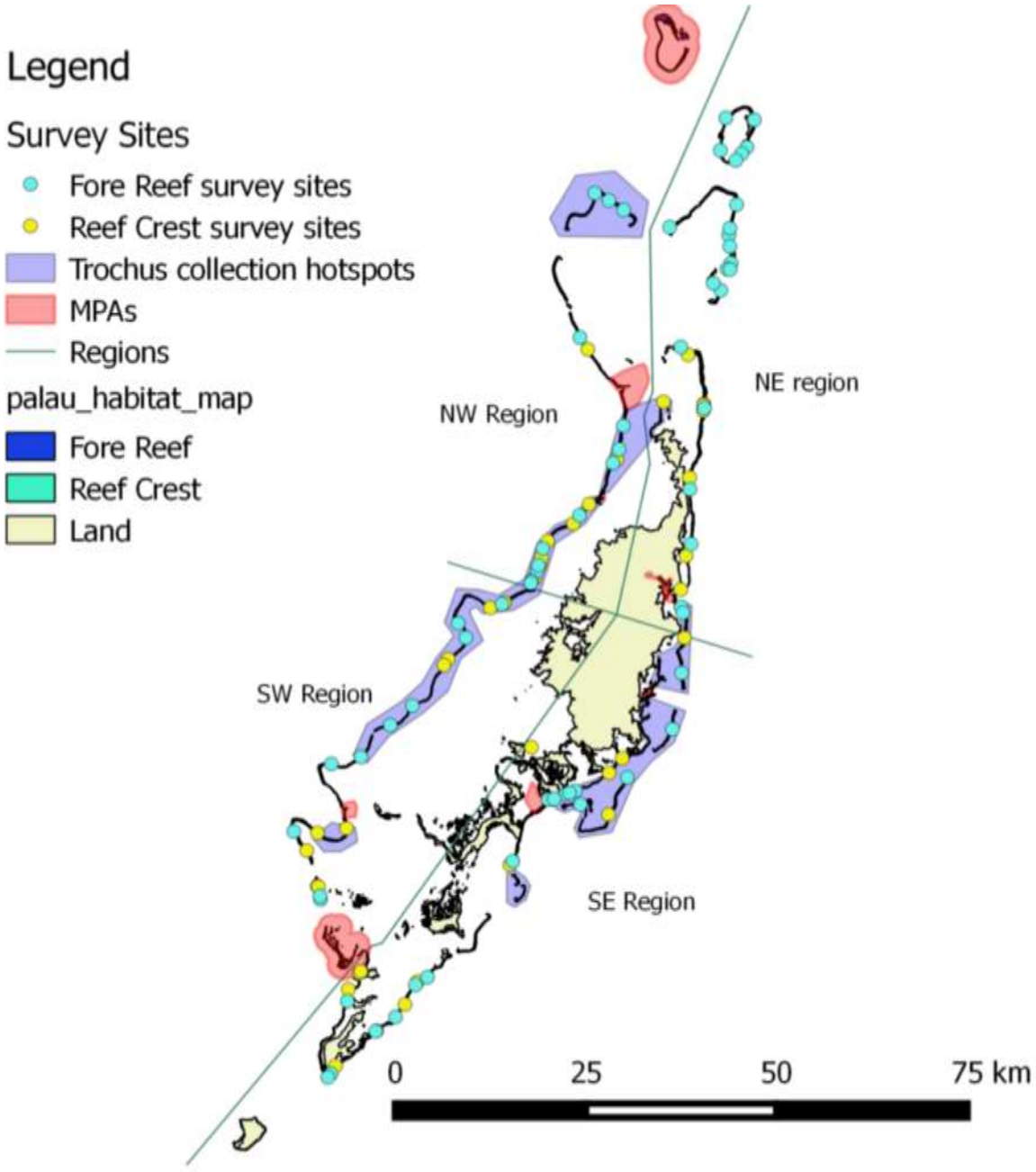


Figure 1: Map of Palau showing the surveyed sites

The number of survey sites within each region and habitats was proportional to their size. One random survey site per 600,000 m^2 of habitat was allocated (Table 1). Twenty additional survey sites were allocated to hotspot areas.

Table 1: Reef area size and number of survey sites per region

Region (area in m^2)	**NE**	**NW**	**SE**	**SW**
Fore Reef	13,200,000	8,060,000	11,500,000	5,900,000
Reef Crest	4,980,000	4,810,000	6,330,000	6,220,000
1 random survey site per 600,000 m^2 of habitat				
Fore Reef	22	13	19	10
Reef Crest	8	8	11	10
TOTAL per region	30	21	30	20
Collection Hotspots survey sites	20			
Total Number of survey sites	121			

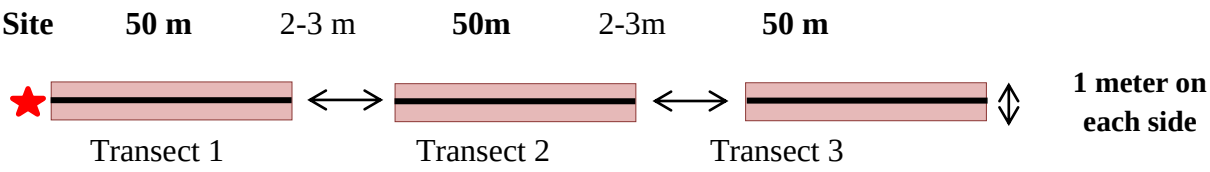
The fieldwork was conducted during 3 weeks by BMR from March 21st to April 29th (see photo below).

Due to weather conditions (constant easterlies and swell); surveys at 95 sites out of 121 were conducted. Ngkesol reefs and Kayangel reefs were not surveyed because of bad weather conditions.

Region	NE	NW	SE	SW
Fore Reef	13	13	12	10
Reef Crest	4	8	5	10
Hotspot	20			
Total survey Sites	95			

2.2. Data collection

Using a GPS the survey team went as close as possible to the chosen sites (Figure 1, Appendix 1 & 2). At each site, 3 transects of 50 meters long were laid at the same depth, leaving 2-3 meters in between transects. For the fore reef sites, the maximum depth was 2-3 m. A qualified observer swam along each transect and counted and measured all the observed *T. niloticus* within 1 meter on each side of the transect. The total surveyed area was 300m^2 at each site. However, to decrease the variation at the site we use the mean among the three transects to have a number of individuals per 100 m^2 for further density estimation.



For measurements, the observer measured the basal diameter of each observed individuals within the survey area using a ruler or a caliper (see photo below).

2.3. Data analysis

At each site, the count of *T. niloticus* individuals was averaged among the 3 transects to account for variation within the site. The mean among the 3 transect was used for further density estimation. For each habitat (fore reef and reef crest), the total surveyed area was calculated by multiplying the surveyed area (100 m^2) per site by the number of sites. Within each habitat, the count of *T. niloticus* at each site was summed to get the number of individuals per total surveyed area. This was then converted into number of individuals per hectares (ha; 1ha = 10,000 m^2) for ease of interpretation and comparison with past studies.
The total area of the two habitats (fore reef and reef crest) was calculated using the NOAA shallow habitat maps (NOAA 2014) and was converted into hectares. The number of *T. niloticus* was then estimated within each habitat depending on their total size.
The size distribution of *T. niloticus* was explored graphically using histograms and calculation of mean size within each habitat using R statistical software (R Development Core Team 2015).

3. Results

3.1. Population density

There was a mean abundance of 2.6 (± 0.2) individuals of *T. niloticus* per 100 m^2 in the fore reef habitat. There was a mean abundance of 3.1 (± 0.4) individuals of *T. niloticus* per 100 m^2 in the reef crest habitat (Figure 2).

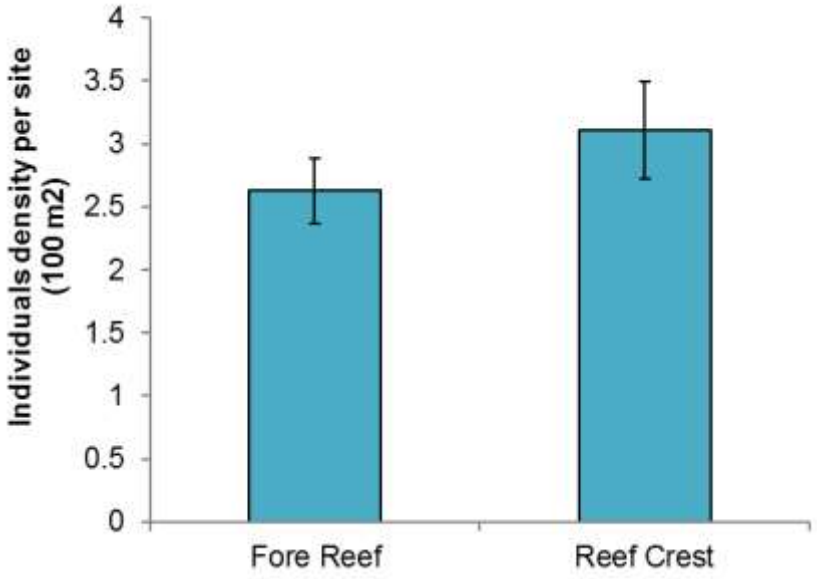


Figure 2: Mean number of *T. niloticus* per 100 m^2 with standard errors showing the variation within the sample (site level)

The total surveyed area was 9,500 m^2 where a total of 267 *T. niloticus* were counted. This makes an approximate 281.4 individuals per hectare (Table 2). The total area of reef (including fore reef and reef crest) is 6,582 hectares. Therefore the estimated population of *T. niloticus* in 2016 is 1,839,633 (Table 2).

Table 2: Calculations of density of *T. niloticus* per hectare within each habitat and overall and estimation of *T. niloticus* population number in Palau

	Number of sites surveyed	Reef area surveyed (m2)	Total count of individuals within surveyed area	Ind ha^{-1} (10,000 m^2)
Fore Reef	58	5,800	152.3	262.6
Reef Crest	37	3,700	115	310.8
Overall	95	9,500	267.3	**281.4**

	Total area of reef in Palau (m^2)	Total area of reef in Palau (ha)	Estimated number of individuals in Palau
Fore Reef	42,796,000	4,280	1,124,010
Reef Crest	23,024,400	2,302	715,623
Overall	65,820,400	6,582	**1,839,633**

3.2. Size

The mean size of *T. niloticus* was a slightly higher on the fore reef (8.21 cm basal diameter) than on the reef crest (7. 8 cm basal diameter) (Figure 3). Over both habitats, the mean basal diameter was 8 cm (Figure 3). Overall the size of *T. niloticus* followed a normal distribution (Figure 4).
The mean size of the population was higher than the legal harvesting size of 3'' (7.62 cm) and 57.5 % of the population had a basal diameter greater than 3". Few individuals had a basal diameter greater than 11 cm.

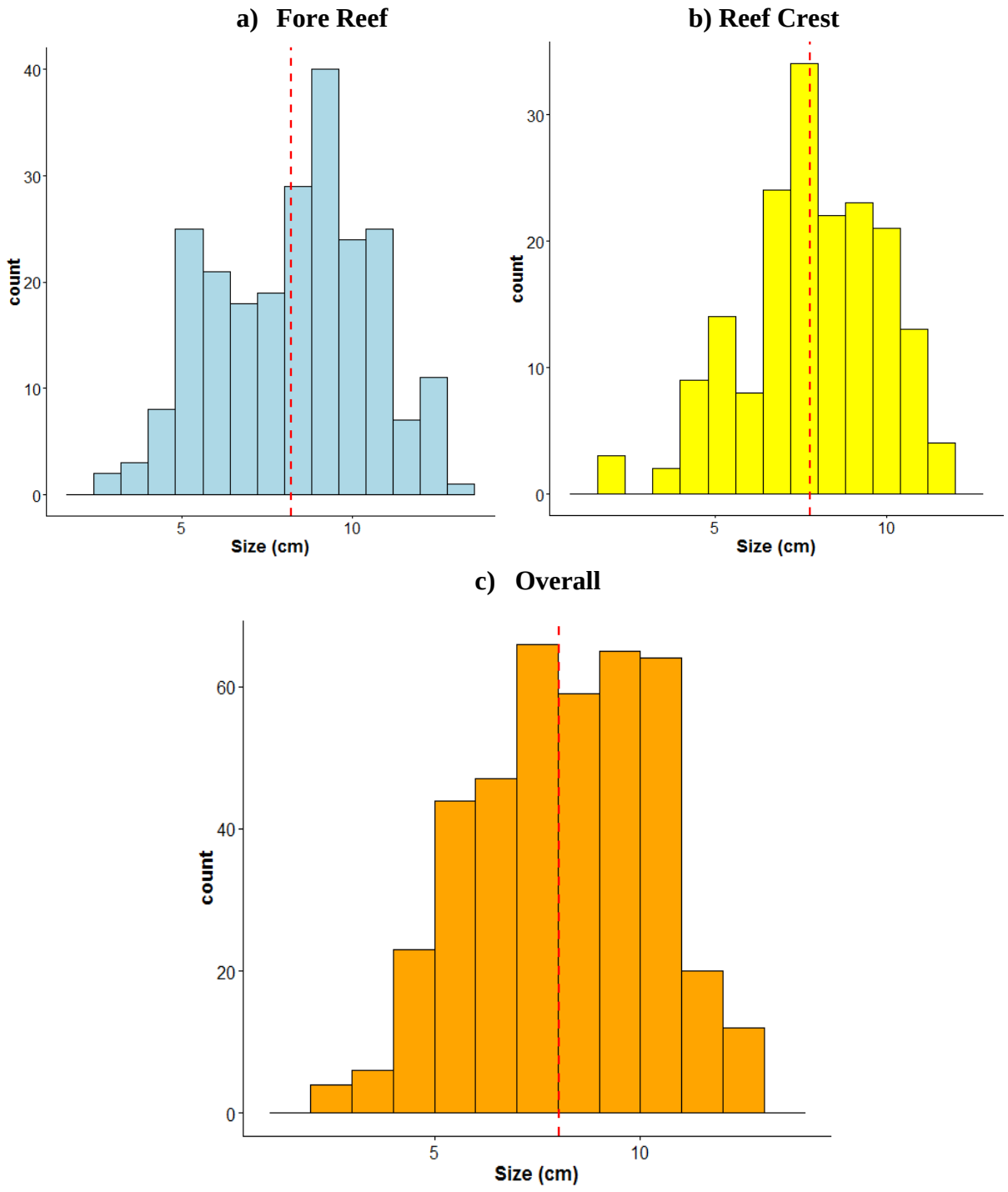


Figure 3: histograms showing the size distribution of *T. niloticus* population within each habitat (a,b) and within both (c)

4. Discussion

Our findings showed that the density *T. niloticus* in 2016 is 281 ind ha^{-1}. Some variability was found among sites as well as between habitats. The reef crest has a slightly higher density than the fore reef. About 57.5 % of the population had a basal diameter greater than the legal harvesting size of 3 inches (7.62 cm). Only few individuals had a basal diameter greater than 11 cm.

A previous study done in the Pacific in 1956 stated that dense population approached 600-800 ind ha^{1} in Palau (McGowan 1957). Another study in the Philippines showed that abundance between 0-100 ind ha^{-1} are common on exploited reefs but density within Marine Protected Areas were found between 4,000 to 11,000 ind ha^{-1} (Dolorosa et al. 2010). Studies in the Cook Islands advised harvesting if population had densities around 600 ind ha^{1} (Adams et al. 1992; Nash et al. 1995). In addition, the current population is always dependent on previous recruitment events, which are very variable though time. Therefore, in some cases the decrease in population might be the result of overharvesting, but in other cases, it might be the result of variable recruitment events. Additional research should be focused on the recruitment process of *T. niloticus* in Palau.

Stock assessments done in Palau in 2002 showed a density of 961ind ha^{-1} (Kitalong 2002) which is about 3 times higher than today. In addition, in 2002, approximately 70% of the population had a shell greater than 3" (Kitalong 2002). Today our findings show that 57.5% of the population is bigger than the legal harvest size. In 2010, a stock assessment done by BMR revealed a density of 341.1 ind ha^{1} of legal sized individuals (Bureau of Marine Resources 2010). Today, the density of legal sized individuals is 162.6 ind ha^{-1} (57.5% of 281 ind ha^{-1}). The sampling effort in the past stock assessments was different than this present study; the sampling was non-random, non-habitat-stratified and non-proportional to the size of the habitat. Therefore density estimates might have been biased. Despite these sampling issues, it seems obvious that overall the population of *T. niloticus* in Palau is much lower than before and lower than undisturbed reefs, such as those in the Philippines (Dolorosa et al. 2010).

Past studies show that today's population of *T. niloticus* is less dense and has fewer large individuals. Therefore, the population should be managed carefully. Based on the results of this survey, we conclude that it is not a good time to open the Trochus harvest season.

Acknowledgment

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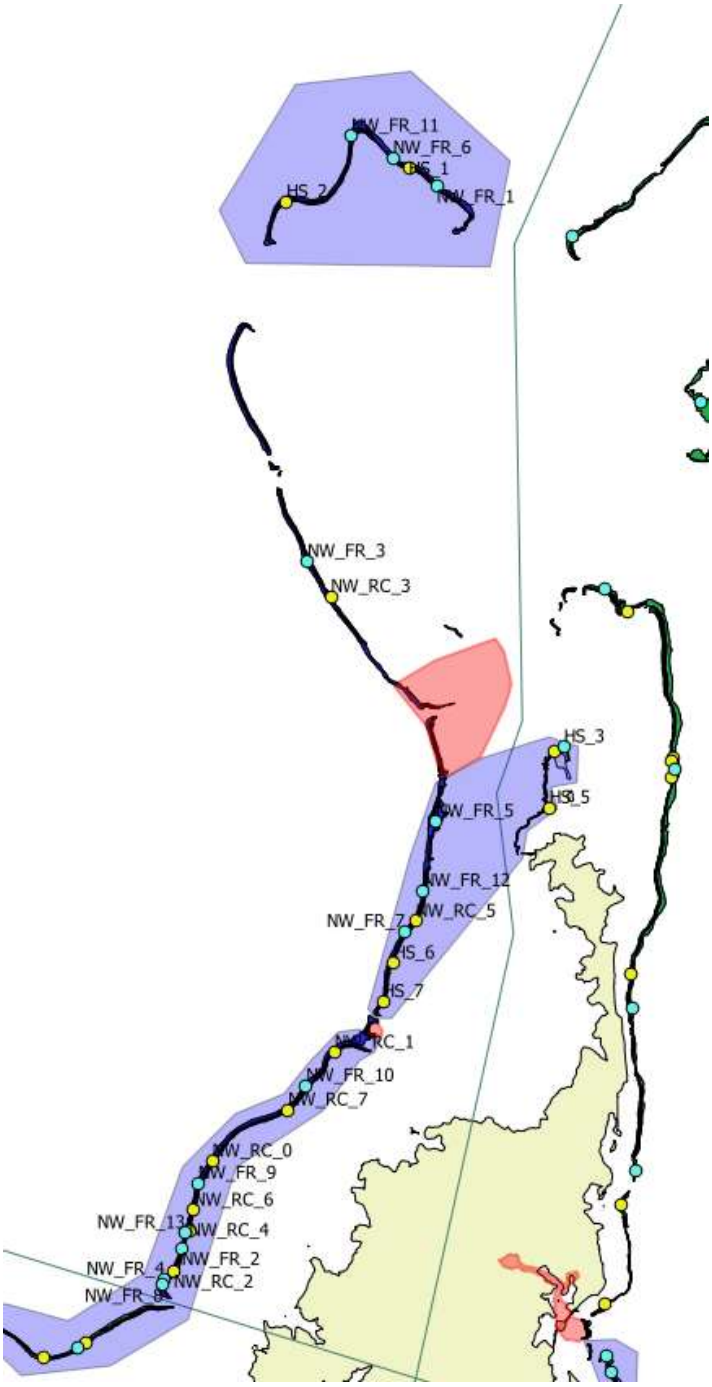
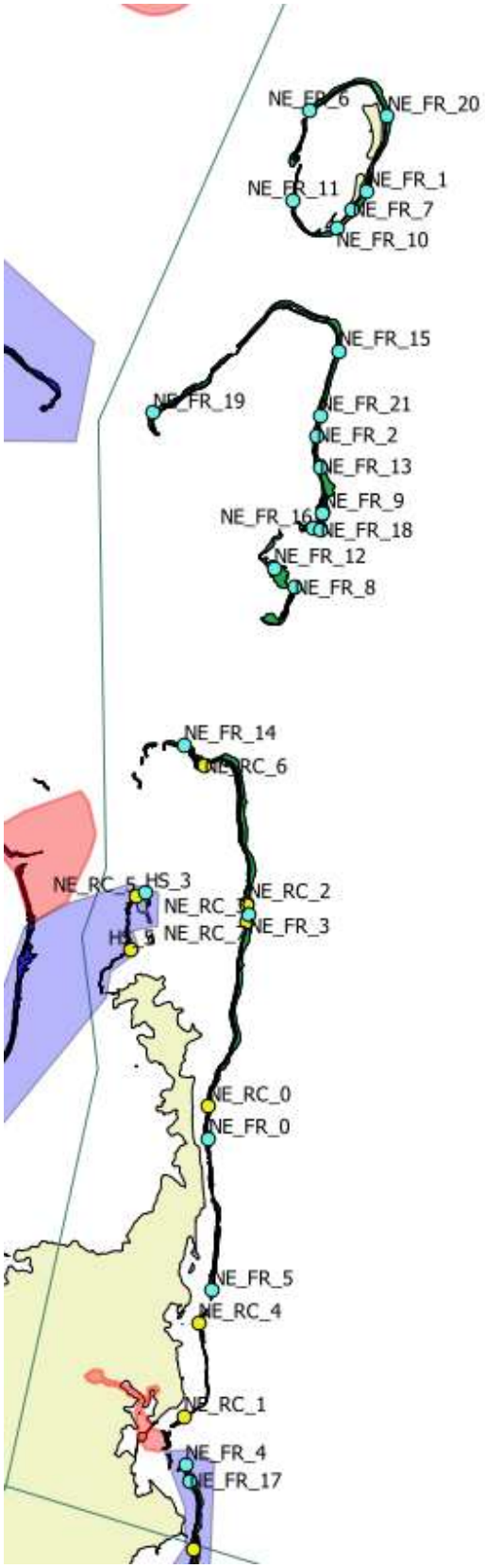
APPENDIX 1

Close-up maps of the four regions with the labels of survey sites (Region_Habitat_site number), with regions (NW, NE, SW, SE), habitat (FR (fore reef), RC (reef crest), HS (hotspots), and sites numbers

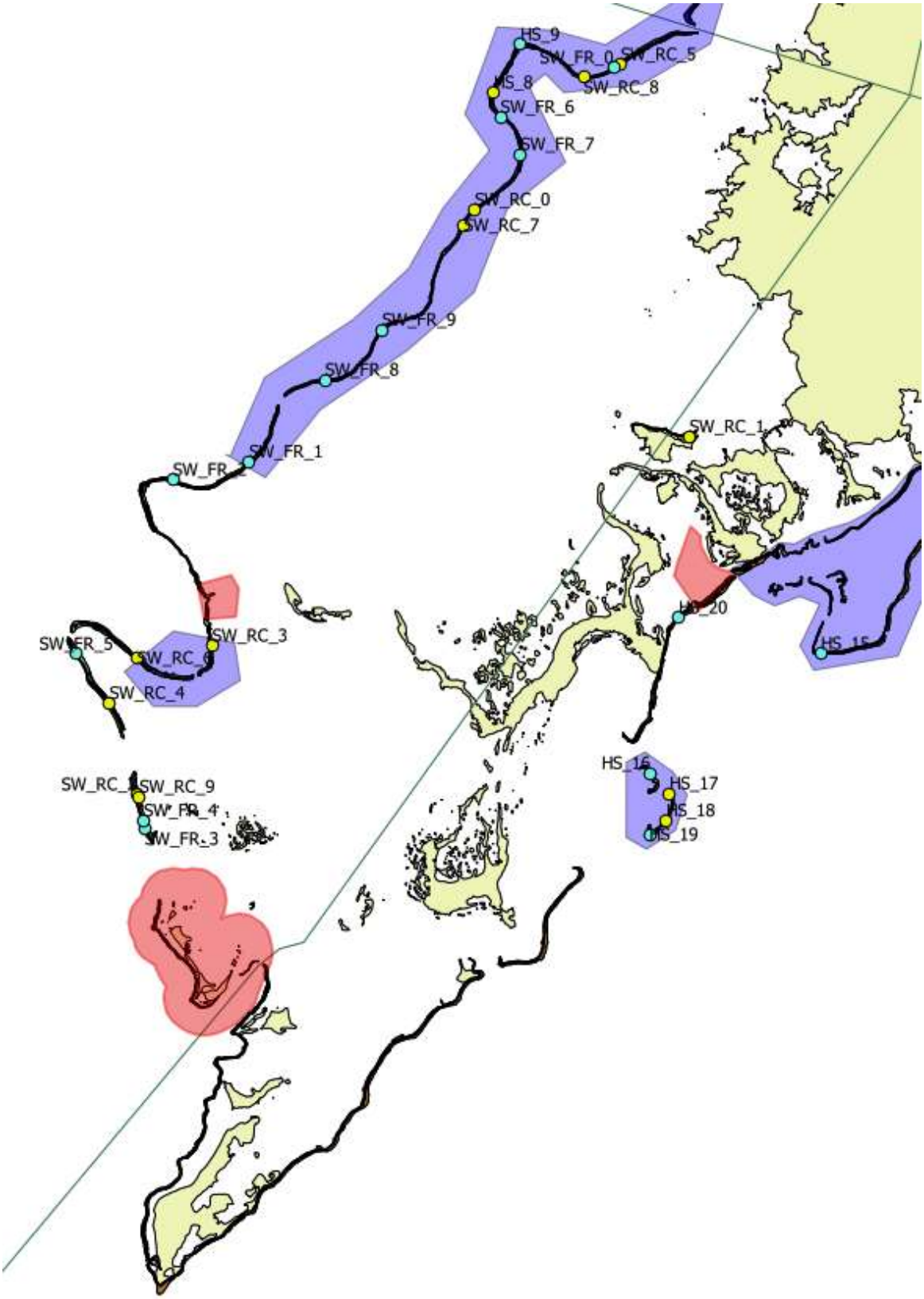
NW region



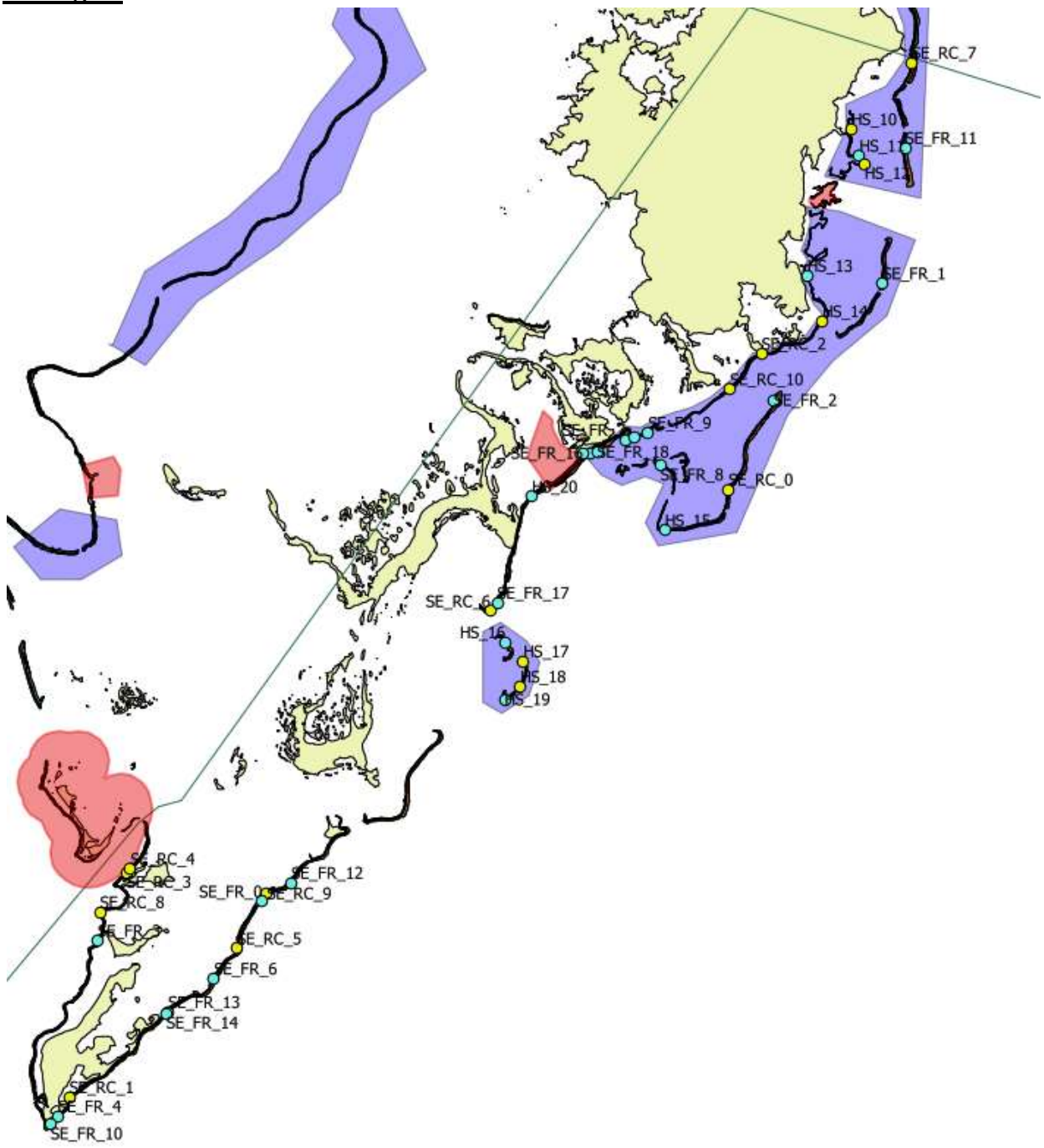
NE region


NE_FR_6
NE_FR_20
NE_FR_11
NE_FR_1
NE_FR_7
NE_FR_10
NE_FR_15
NE_FR_19
NE_FR_21
NE_FR_2
NE_FR_13
NE_FR_9
NE_FR_16
NE_FR_18
NE_FR_12
NE_FR_8
NE_FR_14
NE_RC_6
NE_RC_5
HS_3
NE_RC_2
NE_RC_3
NE_FR_3
HS_5
NE_RC_7
NE_RC_0
NE_FR_0
NE_FR_5
NE_RC_4
NE_RC_1
NE_FR_4
NE_FR_17

SW region


HS_9
SW_FR_0
SW_RC_5
HS_8
SW_RC_8
SW_FR_6
SW_FR_7
SW_RC_0
SW_RC_7
SW_FR_9
SW_FR_8
SW_RC_1
SW_FR_1
SW_FR_2
SW_RC_3
SW_FR_5
SW_RC_6
SW_RC_4
HS_20
HS_15
HS_16
HS_17
HS_18
HS_19
SW_RC_9
SW_FR_4
SW_FR_3

SE Region


SE_RC_7
HS_10
SE_FR_11
HS_13
SE_FR_1
SE_RC_10
SE_FR_2
SE_FR_9
SE_FR_18
SE_RC_0
HS_20
HS_15
SE_RC_6
SE_FR_17
HS_16
HS_17
HS_18
HS_19
SE_RC_4
SE_RC_3
SE_FR_12
SE_RC_9
SE_RC_8
SE_RC_5
SE_FR_6
SE_FR_13
SE_FR_14
SE_RC_1
SE_FR_4
SE_FR_10

APPENDIX 2

List of survey sites and GPS coordinates:

		GPS coordinates (UTM)	
Habitat	name	X	Y
Fore reef	NW_FR_1	452708	882475
Fore reef	NW_FR_2	441573	836025
Fore reef	NW_FR_3	447060	866060
Fore reef	NW_FR_4	440826	834675
Fore reef	NW_FR_5	452665	854693
Fore reef	NW_FR_6	450801	883700
Fore reef	NW_FR_7	451310	849878
Fore reef	NW_FR_8	440744	834420
Fore reef	NW_FR_9	442289	838876
Fore reef	NW_FR_10	447006	843138
Fore reef	NW_FR_11	448981	884662
Fore reef	NW_FR_12	452095	851662
Fore reef	NW_FR_13	441716	836706
Fore reef	NE_FR_0	461232	846513
Fore reef	NE_FR_1	468585	890577
Fore reef	NE_FR_2	466242	879240
Fore reef	NE_FR_3	463082	856954
Fore reef	NE_FR_4	460129	831326
Fore reef	NE_FR_5	461385	839455
Fore reef	NE_FR_6	465872	894343
Fore reef	NE_FR_7	467898	889744
Fore reef	NE_FR_8	465212	872152
Fore reef	NE_FR_9	466540	875629
Fore reef	NE_FR_10	467155	888883
Fore reef	NE_FR_11	465165	890163
Fore reef	NE_FR_12	464251	873059
Fore reef	NE_FR_13	466381	877784
Fore reef	NE_FR_14	460069	864829
Fore reef	NE_FR_15	467251	883183
Fore reef	NE_FR_16	466038	874890
Fore reef	NE_FR_17	460324	830596
Fore reef	NE_FR_18	466414	874823
Fore reef	NE_FR_19	458628	880273
Fore reef	NE_FR_20	469529	894092
Fore reef	NE_FR_21	466376	880133
Fore reef	SW_FR_0	437012	831707

Fore reef	SW_FR_1	418837	812021
Fore reef	SW_FR_2	415033	811115
Fore reef	SW_FR_3	413635	793688
Fore reef	SW_FR_4	413571	794092
Fore reef	SW_FR_5	410205	802418
Fore reef	SW_FR_6	431376	829237
Fore reef	SW_FR_7	432372	827381
Fore reef	SW_FR_8	422626	816111
Fore reef	SW_FR_9	425472	818611
Fore reef	SE_FR_0	425870	782634
Fore reef	SE_FR_1	458986	815597
Fore reef	SE_FR_2	453173	809358
Fore reef	SE_FR_3	417092	780537
Fore reef	SE_FR_4	414983	771178
Fore reef	SE_FR_5	443354	806556
Fore reef	SE_FR_6	423303	778518
Fore reef	SE_FR_7	445251	807258
Fore reef	SE_FR_8	447122	805891
Fore reef	SE_FR_9	446470	807634
Fore reef	SE_FR_10	414582	770746
Fore reef	SE_FR_11	460179	822830
Fore reef	SE_FR_12	427426	783629
Fore reef	SE_FR_13	420854	776732
Fore reef	SE_FR_14	420751	776663
Fore reef	SE_FR_15	445719	807403
Fore reef	SE_FR_16	442979	806539
Fore reef	SE_FR_17	438412	798567
Fore reef	SE_FR_18	443739	806598
Reef crest	NE_RC_0	461189	848015
Reef crest	NE_RC_1	460059	833584
Reef crest	NE_RC_2	463030	857462
Reef crest	NE_RC_3	462989	857331
Reef crest	NE_RC_4	460744	837923
Reef crest	NE_RC_5	457836	857765
Reef crest	NE_RC_6	461013	863836
Reef crest	NE_RC_7	462981	856624
Reef crest	NW_RC_0	442910	839841
Reef crest	NW_RC_1	448248	844591
Reef crest	NW_RC_2	441216	835035
Reef crest	NW_RC_3	448086	864526
Reef crest	NW_RC_4	441902	836827

Reef crest	NW_RC_5	451804	850329
Reef crest	NW_RC_6	442097	837695
Reef crest	NW_RC_7	446214	842083
Reef crest	SE_RC_0	450752	804608
Reef crest	SE_RC_1	415582	772199
Reef crest	SE_RC_2	452516	811849
Reef crest	SE_RC_3	418638	784165
Reef crest	SE_RC_4	418840	784374
Reef crest	SE_RC_5	424524	780128
Reef crest	SE_RC_6	438047	798116
Reef crest	SE_RC_7	460528	827376
Reef crest	SE_RC_8	417212	782068
Reef crest	SE_RC_9	426121	783045
Reef crest	SE_RC_10	450834	809956
Reef crest	SW_RC_0	430090	824614
Reef crest	SW_RC_1	440805	813274
Reef crest	SW_RC_2	413223	795397
Reef crest	SW_RC_3	416988	802829
Reef crest	SW_RC_4	411866	799960
Reef crest	SW_RC_5	437369	831865
Reef crest	SW_RC_6	413247	802222
Reef crest	SW_RC_7	429543	823837
Reef crest	SW_RC_8	435517	831236
Reef crest	SW_RC_9	413361	795285
Reef crest	HS_1	451491	883237
Reef crest	HS_2	446152	881783
Fore reef	HS_3	458262	857953
Fore reef	HS_4	457394	8560996
Reef crest	HS_5	457628	855296
Reef crest	HS_6	450840	848502
Reef crest	HS_7	450362	846816
Reef crest	HS_8	431031	830461
Fore reef	HS_9	432366	832864
Reef crest	HS_10	457308	823825
Fore reef	HS_11	457736	822408
Reef crest	HS_12	458011	821980
Fore reef	HS_13	454955	816004
Reef crest	HS_14	455759	813581
Fore reef	HS_15	447360	802433
Fore reef	HS_16	438846	796462
Reef crest	HS_17	439807	795450

Reef crest	HS_18	439650	794095
Fore reef	HS_19	438807	793403
Fore reef	HS_20	440266	804230