The status of sea cucumber resources

at Aitutaki, Mangaia, Palmerston and Rarotonga, Cook Islands

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by

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The survey team in Aitutaki, September 2012.

Summary

Of the various sea cucumber species that occur in Cook Islands, some are used for subsistence food, and others have commercial value. Over the past three decades there has been sporadic small-scale exploitation of sea cucumber for the beche-de-mer trade. With stocks of sea cucumber in traditional beche-de-mer producing countries diminishing and countries responding by introducing tighter management controls such as limits to access or exports, or introducing moratoria, there have been increasing requests to the Ministry of Marine Resources for the commercial exploitation and export of these resources in Cook Islands.

This report presents the results of sea cucumber stock assessments completed in Aitutaki (October 2012), Rarotonga (November 2012), Palmerston (May 2013) and Mangaia (June 2013). Densities of lollyfish (*Holothuria atra*) and surf redfish (*Actinopyga mauritiana*) in Aitutaki, Mangaia and Rarotonga were greater than regional healthy reference densities for sea cucumbers as determined by SPC for the region. However, greenfish (*Stichopus chloronotus*) densities were below the regional reference density. Greenfish was absent in Mangaia. Mean and maximum sizes for sea cucumbers at all sites were smaller than those reported for the region overall.

This assessment and previous studies enabled the determination of reference densities for lollyfish and surf redfish at all sites and for greenfish at Aitutaki, Palmerston and Rarotonga.

Stocks of lollyfish are considered to be healthy and could support low to moderate exploitation. Surf redfish densities are high; however, most of the stock inhabits a thin strip of surf zone. Greenfish stock levels are moderate at the three sites at which they are present.

Sea cucumber fisheries throughout the region have experienced periods of booming production and high revenue followed by periods of low production, primarily due to less than ideal fishery management strategies. Should Cook Islands choose to harvest sea cucumber resources for the beche-de-mer trade, it will be important to develop, implement and monitor effective fishery management frameworks. Management tools and harvest strategies for consideration are outlined in the recommendations of this report.

1. Introduction

Cook Islands' reefs and fauna have tremendous economic, social, cultural and ecological importance and communities enjoy the nutritional and economic benefits of the marine resources. Coastal resources exploited for domestic and export gain include a variety of finfish and invertebrates such as lobsters, coconut crabs, giant clams, sea cucumbers, trochus and pearl oysters, with the latter two invertebrate groups used for export revenue.

Of the various sea cucumber species that occur in Cook Islands, some are used for subsistence food, and other species have potential commercial value. Several characteristics make tropical sea cucumber species vulnerable to overfishing, including the high economic value of some species, the fact that all are sedentary and slow moving – living in shallow lagoon / reef habitats, and the fact that many adults of the species are easy to find.

1.1 Sea cucumber resources of Cook Islands

In total, 14 Holothuroides, or sea cucumber species, have been reported in Cook Islands (Zoutendyk 1989; Pinca et al. 2009) (Table 1), and additional species are likely to occur in areas yet to be assessed. With the exception of *Synapta maculate*, all species listed have some traditional use or commercial food importance.

Table 1. Sea cucumber species reported from in Cook Islands.

Scientific name	Common/trade name	Local name
Actinopyga mauritiana	Surf redfish	*Rori Puakatoro*
Bohadschia argus	Leopardfish	*Rori Kuru*
Holothuria atra	Lollyfish	*Rori Toto*
Holothuria cinerascens	Flower sea cucumber	*Rori Pua*
Holothuria coluber	Snakefish	-
Holothuria hilla	Tiger tailfish	*Kanaenae*
Holothuria impatiens	Impatient sea cucumber	-
Holothuria leucospilota	White snakefish	*Matu Rori/Rori Ka'a/Rori tapou*
Holothuria pervicax	-	Urari
Holothuria whitmaei	Black teatfish	*Rori U*
Stichopus chloronotus	Greenfish	*Rori Matie*
Stichopus horrens	Dragonfish	*Ngata*
Synapta maculate	Kingfish	*Veri-aria*
Thelenota ananas	Prickly redfish	-

1.2 Subsistence use of sea cucumber

Sea cucumber products have been part of the diet of Cook Islanders for many years, particularly those in the islands of the Southern Group. Apart from serving as food, sea cucumbers form the ingredients to traditional medicines. Two species of sea cucumbers (*Holothuria atra* and *Holothuria leucospilota*) are harvested for their mature gonads (*matu rori*), which are eaten raw or cooked. The harvesting and the consumption of mature sea cucumber gonads generally occur from November to February in the Southern Group, mainly on Rarotonga. *Holothuria cinerascens* and *Actinopyga mauritiana* are harvested for their body wall, which is salted, briefly fermented or cooked prior to consumption. These local delicacies are sometimes sold fresh for around

NZD 50 to NZD 100 for a 1–1.5 litre bottle (R. Purua, pers. comm. 2013). Women are more engaged in the harvesting of sea cucumber, which contributes greatly towards household food sources. Communities in the northern Cook Islands seldom harvest sea cucumber gonads or body wall. There is little data or information available that capture the proportions of sea cucumber products that are harvested or sold, or how much is consumed by households.

Lately, there has been increasing demand for these foods by the general public, contributing to the growing fishing pressure on these resources. The re-establishment of the *Ra'ui* (a traditional management system to protect resources) since 1998 around Rarotonga and some of the outer islands gives emphasis to the need to manage and maintain lagoon resources before they are overharvested.

Some species (e.g. lollyfish) are used to stun or kill fish and invertebrates that are trapped in reef pools or that hide in reef crevices. The body wall of lollyfish is rubbed on rocks or on other hard substrates to produce a reddish-pink dye that is toxic to some marine organisms.

1.3 Commercial beche-de-mer fishing

Sporadic commercial fishing of sea cucumber for the beche-de-mer trade occurred in the past on a small scale. According to Zoutendyk (1989) and Preston et al. (1995), Palmerston and some of the islands of the Northern Group exported dried surf redfish of unknown quantity to Tahiti from 1934 to 1935. The cessation of shipping services and the advent of the World War II terminated the trade. In 2001, 1.2 tonnes of dried sea cucumber, mainly surf redfish and prickly redfish, were harvested and exported from Rarotonga, Aitutaki and possibly Rakahanga (I. Bertram and T. Tatuava, pers. comm., 2013). In 2009, around 50 kg of gutted/frozen surf redfish and prickly redfish were harvested and exported from Rarotonga; the activity was later halted by the Ministry of Marine Resources (MMR) as it was being conducted without adequate resource management.

1.4 Past resource assessments

A number of surveys and invertebrate assessments have been carried out in Cook Islands. Zoutendyk (1989) conducted dedicated sea cucumber assessments in Aitutaki, Palmerston and Rarotonga and estimated total stock biomass of surf redfish at 171 tonnes wet weight (translating to 14 tonnes dry weight) for Aitutaki, 21 tonnes wet weight (1.5 tonnes dry weight) for Rarotonga and 14 tonnes wet weight (1 tonne dry weight) for Palmerston. Other assessments (e.g. Ponia et al. 1998; Drumm 2004; Pinca et al. 2009) have been undertaken in some parts of Cook Islands. Some of these surveys were dedicated sea cucumber assessments, while others assessed a range of invertebrates, including sea cucumbers. A summary of some densities derived from these previous studies is provided in Appendix 1. Ministry of Marine Resources (1999) estimated preliminary total allowable catch in numbers for surf redfish (*A. mauritiana*) greater than 150 mm for Aitutaki, Palmerston and Rarotonga at 45,500, 3750 and 10,600 animals respectively.

1.5 Fishery management

The traditional *Ra'ui* system of resource management was re-introduced by the traditional leaders in Rarotonga in 1998 and in Aitutaki in 2000. The system prohibits the extraction of nearshore marine species and protects the marine environment. Initially, the *Ra'ui* around Rarotonga was declared in five selected coastal areas, but by 2002 it had been expanded to include eight areas. Overall, the *Ra'ui* in Rarotonga covers about 10 per cent of the lagoon and the reef system. Other islands also manage resources through *Ra'ui*.

There are no regulations governing the commercial exploitation or export of sea cucumber from Cook Islands. In response to the increasing number of request to commercially harvest and export sea cucumber over the past five years in Cook Islands, the government announced the 'prohibition of trade for sea cucumber and trochus' in August 2012, until management frameworks have been developed and endorsed. There are many examples of mismanaged sea cucumber fisheries around the region that Cook Islands could learn from to ensure it has robust systems in place to address sustainable commercial exploitation whilst allowing subsistence harvesting to continue. MMR and SPC are working on finalising sea cucumber management plan and regulations.

1.6 Objective of the assessment surveys

To address the continuous requests for commercial exploitation of sea cucumber resources in Cook Islands, MMR undertook invertebrate resource assessments, with a focus on sea cucumber species. The main objective of the studies was to collect data to provide estimates of density and size structure of sea cucumber species in Aitutaki, Mangaia, Palmerston and Rarotonga. The goal is to provide quantitative data on the current status of sea cucumber resources in these locations to determine whether these resources have the potential for commercial exploitation, and to explore sustainable harvest strategies, should some species be determined viable for commercial harvest. Specifically, the objectives of the surveys were to:

- Assess the status of sea cucumber resources on several islands in Cook Islands using the same method of assessment to provide information on sea cucumber species present.
- Provide population estimates of stocks and fishable stock estimates for those species present in commercially viable quantities for decision-making purposes.
- Provide status information on the species of importance to subsistence fishing, and determine whether or not there is a need for management.

This report will also serve as an information paper for the government, island councils and fishing communities in developing policy strategies for the management of sea cucumber resources.

2. Methods

2.1 Survey design and planning

The surveys varied in terms of time allocated and cost. With the aim of ensuring adequate coverage of sites, the survey designs varied based on the complexity of reef systems. These factors influence sampling effort required at different sites, so variation in the number of stations is expected, with the overall aim to increase coverage of potential sea cucumber habitats within a site. Distribution of stations in each site was plotted on site maps obtained from Google Maps. Using baseline information from prior SPC assessments at these sites (Pinca et al. 2009), the assessments focused mainly on fringing reef flats, reef crests, the shallow parts of the lagoon and back reef zones.

The assessment at Aitutaki was part of an SPC in-country training initiative for MMR fisheries officers. Following this training, MMR continued assessments at the other sites (Rarotonga, Palmerston and Mangaia). Survey coverage in Palmerston was impacted by the shipping schedule, which limited the work to two and a half days. All surveys were conducted during daylight hours and no assessments occurred on the fore reef (outer reef slope). After the completion of the surveys in Rarotonga and Palmerston, two officers travelled to SPC Noumea to undergo further training on data processing and reporting. The Mangaia field assessment was completed after the data analysis training in Noumea, and the analysis for this site was done in Cook Islands.

2.2 Survey methodologies

Fine scale reef benthos transects (RBT) were used to assess invertebrate resources (abundance, size structure) and to determine population estimates. RBT surveys are conducted on hard bottom habitats on the back reef, reef flat and reef crest areas to survey invertebrates associated with these habitats. RBT assessments give high accuracy by assessing the range, abundance, size and condition of invertebrate species and their habitats at fine spatial scales (SPC in press). The method involves two snorkelers equipped with measuring record boards or slates for recording abundance and size of sea cucumbers within transects. An RBT station comprises six 40 x 1 metre transects spaced approximately 5 metres apart (Figure 1). Assessments along the reef crest were conducted at low tide using a similar method; however, the observer walked the reef crest and used GPS to measure the 40 m x 1 m transects. Species and habitat data were recorded and a waypoint logged for each station (to an accuracy of ≤ 10 m).

2.3 Data analysis and reporting

Data entry, validation and analysis were done using the Reef Fisheries Integrated Database (RFID) at the Cook Islands Ministry of Marine Resources and at SPC in Noumea in May 2013 as part of a further training attachment on data entry, analysis and reporting.

Analysis of stock status indicators follows standard assessment of sea cucumber fishery status indicators (Friedman et al. 2008), the Regional Coastal Fisheries Status Report (Pinca et al. 2010) and the Cook Islands reef resources status report (Pinca et al. 2009). A preliminary report was submitted to MMR at the end of 2012 to provide advice on the results of the Aitutaki assessments while the other sites were being assessed and the report was being finalised. The preliminary report used regional reference sea cucumber densities from manta tow and RBT assessments combined. These reference densities were revised in April 2013 and a reference density was calculated for each method of assessment.

2.4 Stock estimation procedures

The reef habitat areas for Aitutaki, Mangaia, Palmerston and Rarotonga used during the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish) (Pinca et al. 2009) were used in the calculation of population estimates. Population estimates were derived by extrapolating average densities for habitat areas where the species are commonly found. Biomass estimates for three species were based on multiplying the proportion of the population greater than 200 mm by average live weights of a range of specimens for each species greater than 200 mm. This was further converted to live/wet and gutted weight for a harvest level of 20% of the proportion of populations over 200 mm. The average weights and proportions retained used for the conversions from numbers of sea cucumbers to weight were based on a study conducted by MMR in October 2012, where 20 specimens of each species were harvest, measured and weighed at the time of capture, and four hours after capture and after gutting.

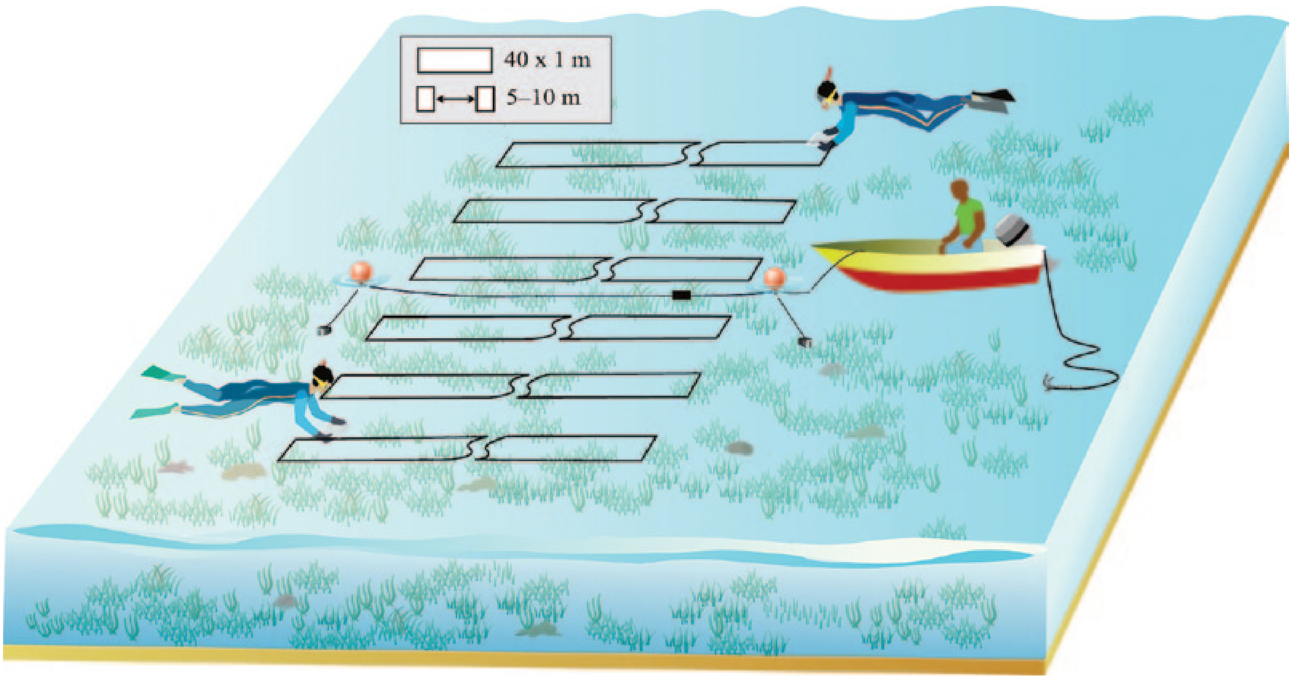

Figure 1. Illustration of reef benthos transect method (source SPC in press).

3. Results

3.1 Survey coverage

Over 50 reef benthos transect stations were distributed among habitats in Aitutaki and Rarotonga, and 40 transect stations were surveyed in Mangaia. Due to the limited time available for the survey, only 21 stations were completed in Palmerston (Table 2). This corresponds to area of 1.30, 1.44, 0.50 and 0.96 hectares covered in Aitutaki, Rarotonga, Palmerston and Mangaia respectively (Table 2). Appendix 2 contains GPS coordinates for transect stations.

Table 2. The number of stations transects and area covered during the assessment at each island.

Island	Survey period	Survey days	Number of stations	Replicates transects	Area assessed (ha)
Aitutaki	Oct. 2012	6.0	54	324	1.30
Mangaia	June 2013	2.5	40	240	0.96
Palmerston	May 2013	2.5	21	126	0.50
Rarotonga	Nov. 2012	9.0	60	360	1.44

3.2 Species presence and total counts

The survey recorded ten sea cucumber species at Aitutaki, seven at Rarotonga, six at Palmerston and five at Mangaia (Table 3). Lollyfish was the most commonly recorded species at all sites (Figure 2). Two forms (morphs) of lollyfish were recorded, the common soft bodied lollyfish (generally found in shallow reef areas) and the large lollyfish (larger than common lollyfish and occurring in deeper waters). Beche-de-mer traders offer higher prices for the large lollyfish compared to the common lollyfish; however, they are the same species. Of the lollyfish (*Holothuria atra*) recorded at Aitutaki, 10% were the larger form, for Mangaia 14% were the larger morph, and for Palmerston and Rarotonga 20% comprised the larger form recorded for the species. *H. coluber*, *H. hilla*, *H. whitmaei* and *Synapta maculate* were rare in Aitutaki and were not recorded in Palmerston and Rarotonga (Table 3). Greenfish was not found in Mangaia.

Table 3. Total counts of specimens recorded by sites recorded for each species.

Species	Aitutaki	Mangaia	Palmerston	Rarotonga
Lollyfish	13,106	5302	677	10,144
Lollyfish (big)	1328	732	132	2190
Surf redfish	2043	521	41	840
Greenfish	320	-	832	1053
Flower sea cucumber	2956	3512	36	4141
White snakefish	1821	356	22	3035
Snakefish	5	-	-	-
Tiger tailfish	1	-	-	-
Black teatfish	1	3	-	1
Kingfish	1	-	-	-

Figure 2. Common sea cucumber species recorded in the assessments.
From left to right: lollyfish, surf redfish and greenfish.

3.3 Species densities

Overall mean densities for the five main commercial and subsistence species are presented in Table 4, and Appendix 3 summarises density statistics for the four sites assessed. Overall mean density is the calculated density from all stations and present mean density is the calculated density using only stations where the species was recorded (i.e. stations were the species was not recorded are not used in density calculations). The overall densities and present densities were generally similar for *H. atra*, *Actinopyga mauritiana*, and *H. leucospilota* among sites, indicating that these species were relatively common and widely distributed among the habitats assessed (Figure 3). Overall and mean densities for *Stichopus chloronotus* were similar at Aitutaki, Palmerston and Rarotonga; this species was not recorded at Mangaia. Marked difference in overall mean and present densities for *H. cinerascens* indicates the patchiness of this species, reflecting its high densities on the reef crest. Species densities for the three sites are compared with the 2007 assessment (Pinca et al. 2009), and the differences in densities between the two surveys may reflect differences in the number of replicate sampling stations at each site. The assessment in 2007 was based on 21, 15, 17 and 13 RBT stations, while this survey was based on 54, 40, 21 and 60 stations for Aitutaki, Mangaia, Palmerston and Rarotonga respectively (Table 4). In addition, few sampling stations were established on the reef crest in 2007 compared to the current study. Densities for Aitutaki and Rarotonga for the current study are deemed to be more representative of stocks, as sampling effort was larger than the 2007 study. Coverage in Palmerston during the current study was similar to the 2007 study (Pinca et al. 2009).

Table 4. Overall mean density estimates (individuals ha^{-1}) of five sea cucumber species for the four sites in comparison with 2007 assessment.

Species	Aitutaki		Mangaia		Palmerston		Rarotonga	
	2007	2012	2007	2013	2007	2013	2007	2013
Lollyfish	21,341	11,138	3769	6285	3442	1634	10,772	8543
Surf redfish	26	1598	386	549	179	81	131	579
Greenfish	447	248	-	-	3340	2174	1407	731
Flower sea cucumber	-	2279	597	3658	-	71	106	2875
White snakefish	1175	1417	269	371	66	44	6782	2108
Number of RBT stations	**21**	**54**	**15**	**40**	**17**	**21**	**13**	**60**

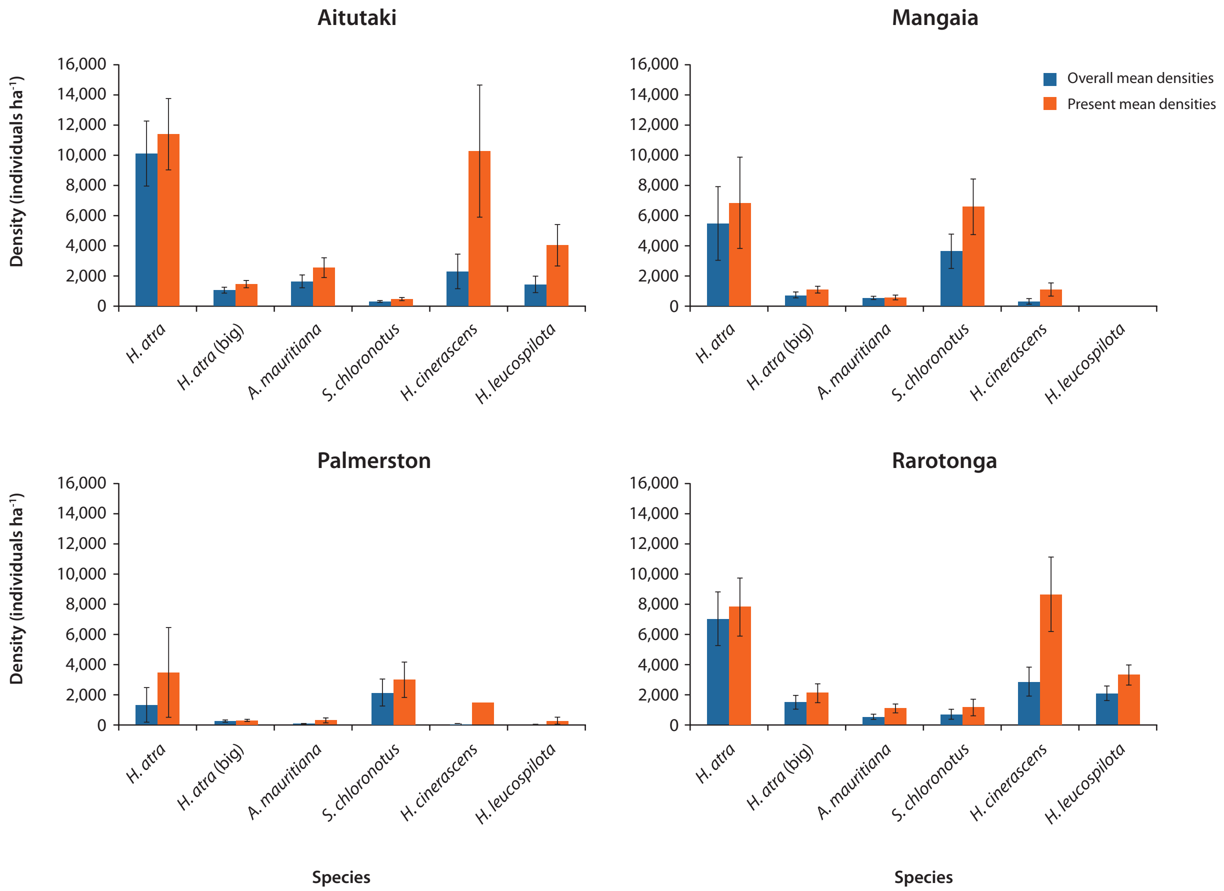

Figure 3. Overall mean and present mean densities (± SE) of *Holothuria atra*, *Actinopyga mauritiana*, *Stichopus chloronotus*, *H. cinerascens* and *H. leucospilota* for Aitutaki, Mangaia, Palmerston and Rarotonga.

3.4 Density comparison with regional reference

Reference densities are useful to managers for comparing densities from study sites to gain insight as to the status of stocks assessed. Here, the regional reference densities were derived from data held at SPC for the highest 25% of density estimates for sea cucumber species assessed by reef benthos transect stations across the Pacific during 2002–2012. For this analysis, assessment covered 17 countries, 91 sites and over 1493 RBT stations in the region.

Densities for lollyfish in Aitutaki and Rarotonga were twice and 1.5 times higher than the regional reference of 5600 individuals per hectare, respectively. For Mangaia, lollyfish density was 10% higher, and for Palmerston, lollyfish density was around 45% lower than the regional reference density. Greenfish density was greater in Palmerston than in Aitutaki and Rarotonga, and for all sites the greenfish densities were lower than the regional reference density. For surf redfish, the density was eight and nearly three times higher than the regional reference density in Aitutaki and Rarotonga respectively (Table 5). Density estimates are not summarised here for species at sites where less than 40 individuals were observed during the assessments (refer to Appendix 3).

Table 5. Sea cucumber species densities by site compared to regional reference densities for reef benthos transects (standard errors shown in brackets).

Species	Aitutaki	Mangaia	Palmerston	Rarotonga	Regional reference (RBT)
Lollyfish	11,138 (975)	6285 (1265)	1634 (850)	8543 (1780)	5600
Surf redfish	1598 (446)	549 (106)	81 (48)	579 (168)	200
Greenfish	248 (59)	-	2174 (891)	731 (356)	3500
Flower sea cucumber	2279 (1111)	3658 (1131)	-	2875 (966)	na
White snakefish	1417 (541)	371 (169)	-	2108 (469)	na

3.5 Sea cucumber reference densities for study sites

The regional sea cucumber reference densities can be improved for specific sites, if data permit, for the development of site-specific reference densities. Reference densities offer useful information (rules of thumb) that fisheries managers can use to assess whether stocks are harvested to a point of potential recruitment depletion or are still in good shape. Here we determine reference densities for the commercial species lollyfish and surf redfish for the four sites, and reference densities for greenfish for Aitutaki, Mangaia, Palmerston and Rarotonga. Several factors were taken into account in the analysis, including:

- The relative long periods of rest that the stocks have had. Commercial fishing of sea cucumbers in Cook Islands has occurred sporadically in the past but has not been active for many years. This has allowed stocks to grow to the present status, which is likely to be close to natural or un-fished densities of these species.
- The presence of exceptionally high abundance of lollyfish and surf redfish in the sites assessed – among the highest recorded in the sites assessed around the region and stored in the SPC RFID dataset.
- The larger survey coverage area in this assessment compared to previous assessments.
- The fact that this assessment is a follow-up from the 2007 surveys and other similar surveys conducted by MMR, providing an opportunity to compare results to establish reference densities for these sites.

The site-specific reference densities for the three commercially important sea cucumbers present at these sites (Table 6) are based on 75% of the overall mean densities recorded in this assessment (Table 5). These reference densities will be useful for future resource assessments to determine healthy stocks for the three species.

Table 6. Sea cucumber reference densities (individuals ha^{-1}) by site.

Species	Aitutaki	Mangaia	Palmerston	Rarotonga
Lollyfish	8300	4700	1900	6400
Surf redfish	1200	400	100	450
Greenfish	200	-	2100	550

a Densities for lollyfish, surf redfish and greenfish are averaged with those of Pinca et al. (2009) to provide the reference densities for Palmerston.

3.6 Size distribution

The low survey effort at Palmerston led to the smaller sample size for length frequency histograms for lollyfish and surf redfish compared to Aitutaki, Mangaia and Rarotonga (Figures 4, 5 and 6).

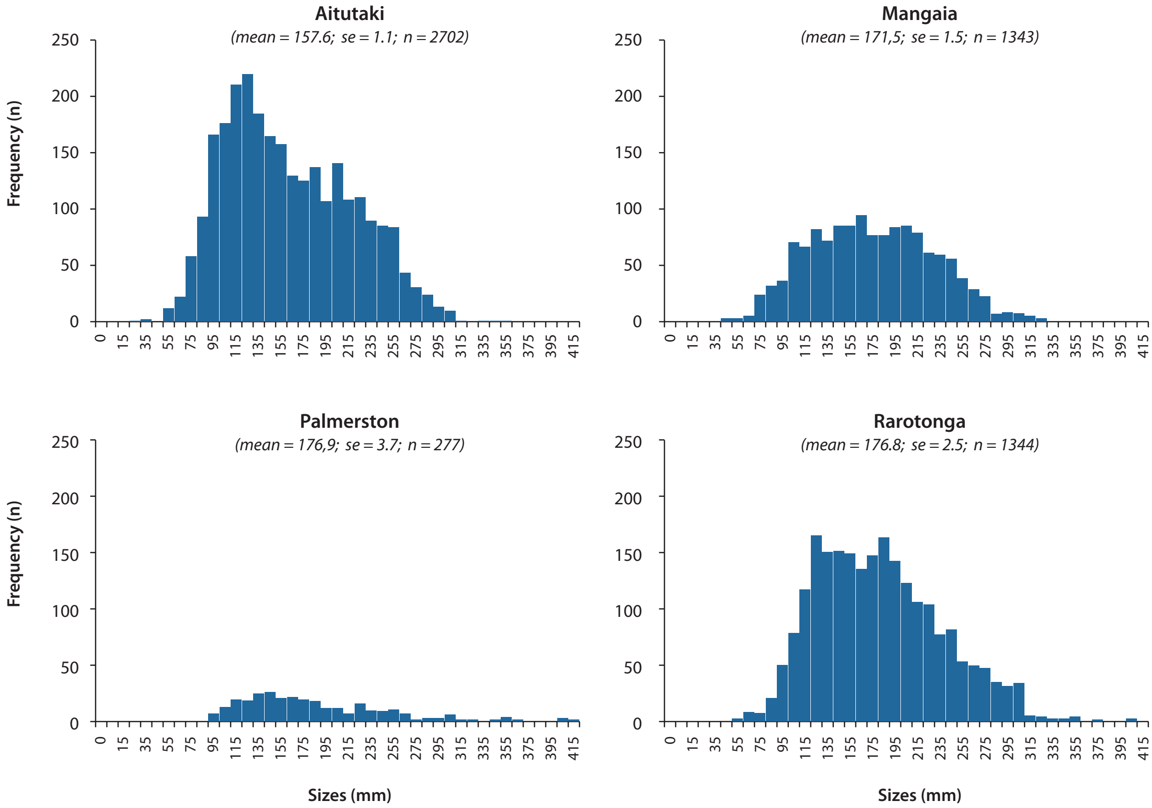

Figure 4. Size structure and associated statistics for *H. atra* (lollyfish) at Aitutaki, Mangaia, Palmerston and Rarotonga.

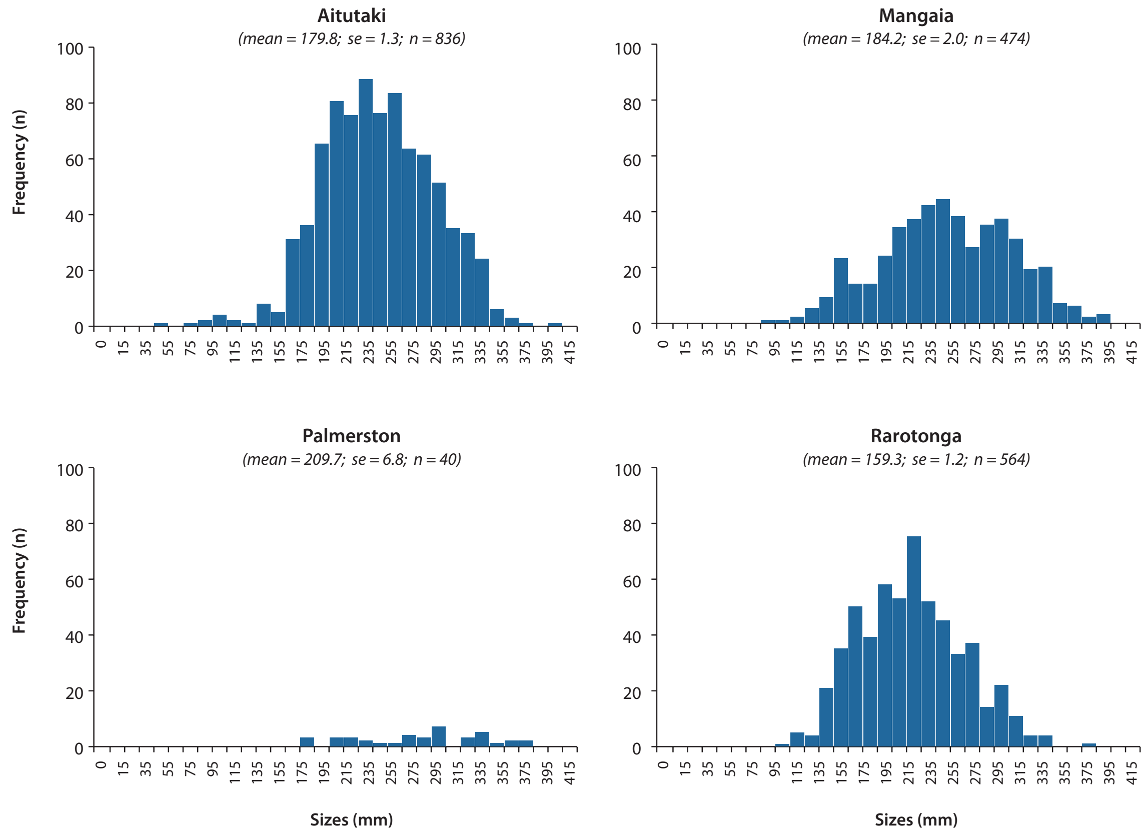

Figure 5. Size structure and associated statistics for *A. mauritiana* (surf redfish) at Aitutaki, Mangaia, Palmerston and Rarotonga.

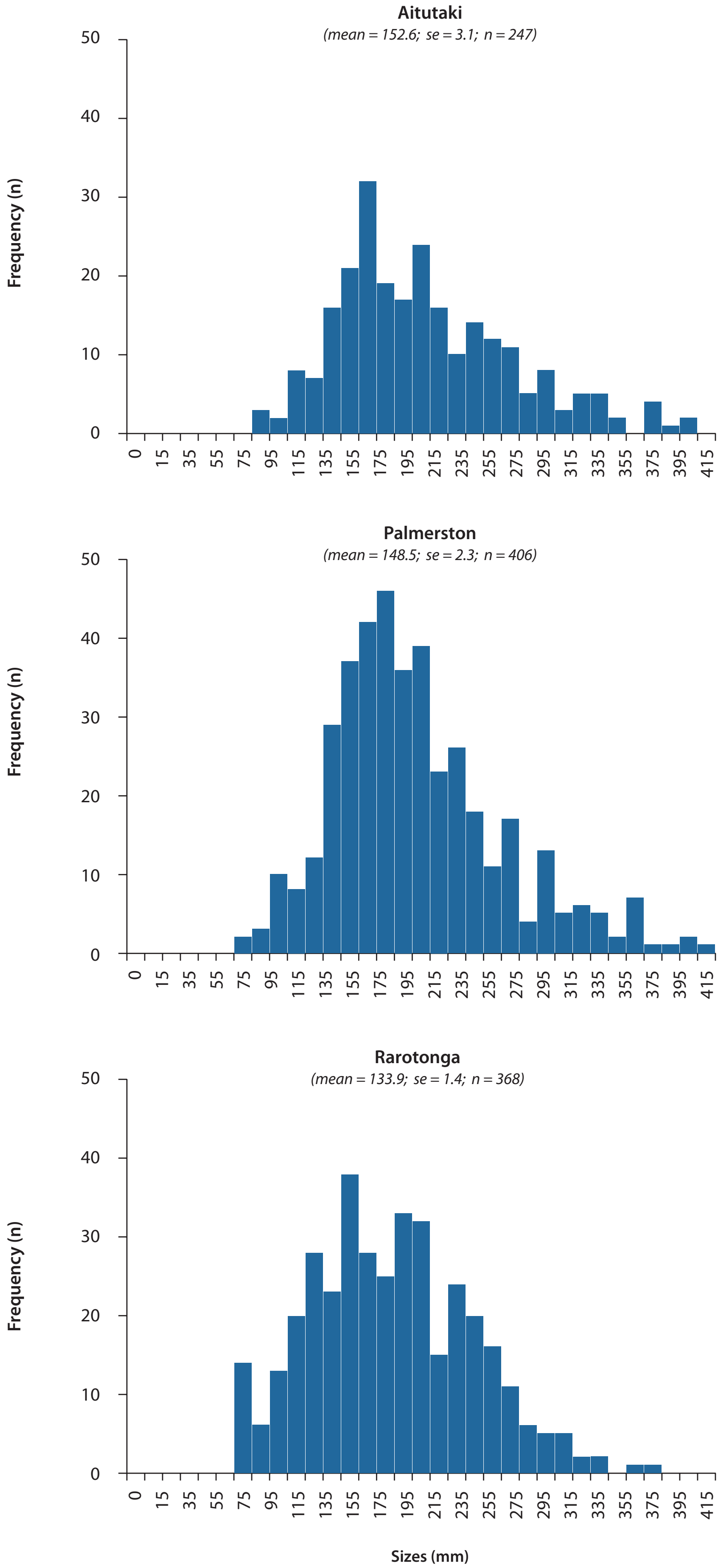

Figure 6. Size structure and associated statistics for *Stichopus chloronotus* (greenfish) at Aitutaki, Palmerston and Rarotonga.

3.7 Stock estimate and fishable quantity by island

Stock extrapolation analysis uses the species habitat area estimates (Table 7) with species densities (Table 5) and weight information (Table 8) to determine population and biomass (Table 9). For each site, the habitats where lollyfish and greenfish were commonly found were deep terrace, shallow terrace, inner reef slope, diffuse reef and reef flat. For surf redfish, the main habitat was a thin strip of reef flat near the surf zone (Appendix 4). Of the three species for which fishable quantities were determined, only lollyfish has reasonable quantities for beche-de-mer production.

Table 7. Habitat types, areas for each island (site) and the habitats where species were more commonly found.

Aitutaki

Habitat	km²	ha	Species
Deep terrace	4.28	428	LF
Linear reef flat[a]	2.63	263	SRF
Reef flat	18.25	1825	LF, GF
Shallow terrace	19.04	1904	LF, GF

Mangaia

Habitat	km²	ha	Species
Linear reef flat[a]	1.01	101	SRF
Reef flat	3.59	359	LF

Palmerston

Habitat	km²	ha	Species
Linear reef flat[a]	1.35	135	SRF
Inner slope	6.20	620	LF
Lagoon pinnacle	0.27	27	GF
Reef flat	19.12	1912	LF, GF

Rarotonga

Habitat	km²	ha	Species
Diffuse fringing	0.17	17	LF, GF
Linear reef flat[a]	2.29	229	SRF
Reef flat	7.63	763	LF, GF
Shallow terrace	3.44	344	LF

a: Linear reef flat represents the linear distances of the surf zone multiplied by width of surf redfish habitat.
LF = Lollyfish; SRF = surf redfish; GF = greenfish.

Table 8. Average live weights of specimens greater than 200 mm and proportion retained after gutting for lollyfish, surf redfish and greenfish.

Species	Lollyfish	Surf redfish	Greenfish
Live weight (g)	355	510	210
% retained after gutting	31	54	58

Table 9. Population estimates of sea cucumber species and proportions of populations (numbers and weight) greater than 200 mm in live length for the four sites. Fishable stock (live and gutted weights) is estimated as 20% of the populations greater than 200 mm.

Lollyfish

Island	Estimate population (numbers)	Proportion > 200 mm	Population > 200 mm	Wet biomass (mt)	Harvest level 20% of biomass (mt)	
					Live weight	Gutted weight
Aitutaki	41,533,600	27%	11,214,000	3981	796	247
Mangaia	2,256,300	34%	767,100	272	54	17
Palmerston	4,137,300	30%	1,241,200	441	88	27
Rarotonga	9,602,300	34%	3,264,800	1159	232	72

Surf redfish

Island	Estimate population (numbers)	Proportion > 200 mm	Population > 200 mm	Wet biomass (mt)	Harvest level 20% of biomass (mt)	
					Live weight	Gutted weight
Aitutaki	420,300	33%	138,700	71	14	7.6
Mangaia	55,500	39%	21,600	11	2	1.2
Palmerston	10,900	67%	7,300	4	0.7	0.4
Rarotonga	132,700	16%	21,200	11	2	1.2

Green fish

Island	Estimate population (numbers)	Proportion > 200 mm	Population > 200 mm	Wet biomass (mt)	Harvest level 20% of biomass (mt)	
					Live weight	Gutted weight
Aitutaki	924,800	18%	166,500	35	7	4.1
Palmerston	4,215,400	16%	674,500	142	28	16.4
Rarotonga	570,200	9%	51,300	11	2	1.3

White snakefish

Island	Overall density (individuals ha^{-1})	Habitat area (ha)	Estimate population (numbers)
Aitutaki	1417	3729	5,284,000
Mangaia	371	359	133,200
Rarotonga	2108	1124	2,369,400

Flower sea cucumber

Island	Overall density (individuals ha^{-1})	Habitat area (ha)	Estimate population (numbers)
Aitutaki	2279	1825	4,159,200
Mangaia	3658	359	1,313,200
Rarotonga	2875	780	2,242,500

4. Economic analysis

In this section, we estimate the potential revenues[1] that would be derived by sea cucumber collectors and processors, and exporters of beche-de-mer. We first describe the data used to make these estimates and the assumptions that are applied where data are lacking. Second, we provide estimates of potential revenues throughout the domestic marketing channel, based on available data and assumptions in combination with the recommended harvest levels presented above. Finally, discussion is provided on various economic management tools that may be applicable to monitor and manage the trade.

Due to the limited data available, especially with regard to processing conversions (e.g. wet-to-dry conversion weights) and price, and the requirement that we incorporate assumptions in some cases, this section is intended to be indicative only.

4.1 Assumptions and descriptions of the data source

The study sampled average live and gutted weights of 20 specimens (Table 8); however, assumptions must be made about the wet-to-dry weight (i.e. ex-processed) conversion factors. Some studies have reported standard wet-to-dry conversion factors of 5% (Carleton et al. 2013), whilst others have reported the following:

- Lollyfish – 6% (Ngaluafe et al. 2013); 2.6% (Harriot 1984) and 7.7% (Preston 1990)
- Surf redfish – 6.7% (Zoutendyk 1989) and 4.9% (Preston 1990)
- Greenfish – 2.7% (Preston 1990)

For this analysis, wet-to-dry conversion ratios of 3%, 5.5% and 3% have been assumed for lollyfish, surf redfish and greenfish respectively. These ratios are based on the above research, but also take into account advice from SPC.

Collector, processor and exporter prices

Price data at each level of the marketing channel are not well understood or documented. Table 10 is formed from a mix of data sets, based on published material and anecdotal data (interviews with collectors, processors and exporters from the region).

Table 10. Price data for sea cucumber collectors, processors and exporters.

Species	Paid to fishers		Paid to processors		Paid to exporters	
	NC (NZD kg^{-1} wet)	Fiji (NZD kg^{-1} wet)	PNG (NZD kg^{-1} dried)	Philippines (NZD kg^{-1} dried)	Carleton (NZD kg^{-1} dried)	NC (NZD kg^{-1} dried)
Surf redfish	2.59	7.78[a]	16.21[b]		50.57	38.90
Lollyfish		1.30[c]	3.24	11.67[d]	14.26	
Greenfish		2.97[f]	18.80[e]	77.80	64.83	32.42

Notes: NC (New Caledonia), Fiji and PNG (Papua New Guinea) prices are reported in Purcell et al. (2012); Carleton prices are reported in Carleton et al. (2013).

a: Fiji prices are reported to range from $2.59 to $5.19 per piece, fresh. To convert to $ kg^{-1}, the average weight of 500 g (range of 300 to 700 g) and price of $3.89 per piece is applied, resulting in a price of $7.78 kg^{-1} (range $3.70 to $17.29). Refer to Appendix 5 for price matrix.

b: PNG price range is $12.96 to $19.45.

c: Fiji prices are reported to range from $0.78 to $1.82 kg^{-1}, fresh and gutted.

d: Philippines traded price range is from $5.19 to $25.93 kg^{-1}.

e: PNG price range is $15.56 to $22.

f: Fiji data are reported to range from $0.52 to $0.91 per piece, fresh. To convert to $ kg^{-1}, the average weight of 240 g (range of 80 to 400 g) and price of $0.71 per piece is applied, resulting in a price of $2.97 kg^{-1} (range of $1.30 to $9.08). Refer to Appendix 5 for price matrix.

[1] Revenues and price data are reported in NZD using a conversion rate of 0.77 USD/NZD.

Although statistically, the sample size is insufficient, resulting in potential for large variance, Figure 7 makes clear that prices have increased over a period of five years. In consideration of the number of sea cucumber fisheries that are currently closed around the region (affecting supply) and the growth in the main consumer markets in China (driving demand), it is reasonable to assume that prices will remain high and perhaps continue to increase. Considering this and based on the price data presented in Table 10, the prices shown in Table 11 are applied to allow for estimation of potential collector, processor and exporter revenue generation in Cook Islands.

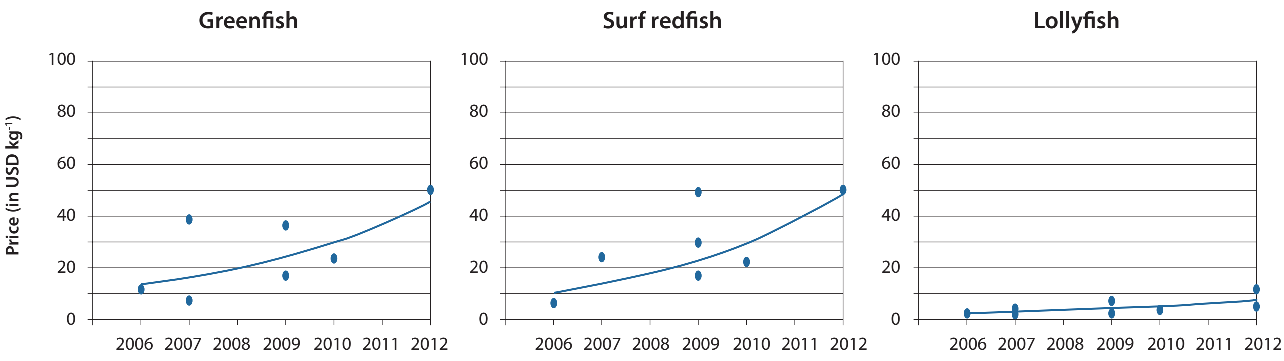

Figure 7. Anecdotal prices (in USD kg^{-1}) paid to processors for greenfish, surf redfish and lollyfish, 2006 to 2012.

Table 11. Prices applied in economic analysis.

Species	Paid to fishers (NZD kg^{-1} wet, gutted)	Paid to processors (NZD kg^{-1} dry)	Paid to exporters (NZD kg^{-1} dry)
Surf redfish	$1.95	$25.93	$38.90
Lollyfish	$0.65	$9.73	$19.45
Greenfish	$2.59	$32.42	$45.38

4.2 Revenue estimates for fishers, processors and exporters

The revenue estimates presented in Table 12 are based on the processing conversion factors and prices presented above. It is noted that some of the prices reported in Purcell et al. (2012) are unrealistic, especially in the case of prices paid to collectors. This statement is based on the wet-to-dry conversion factors. For example, surf redfish are reported to be purchased wet in New Caledonia for $2.59 kg^{-1} with a wet-to-dry conversion factor of 5.5%, equating to a dry price of $47.23 kg^{-1}, which is greater than the reported export price.

Prices paid to collectors have been deflated to reflect this.

Table 12. Revenue estimates for collectors, processors and exporters of lollyfish, surf redfish and greenfish by island group.

Lollyfish

Site	Collector			Processor			Exporter		
	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)
Aitutaki	$0.65	246,822	$160,025	$9.73	23,886	$232,294	$19.45	23,886	$464,588
Mangaia	$0.65	16,885	$10,947	$9.73	1634	$15,891	$19.45	1634	$31,782
Palmerston	$0.65	27,319	$17,712	$9.73	2644	$25,711	$19.45	2644	$51,421
Rarotonga	$0.65	71,858	$46,589	$9.73	6954	$67,629	$19.45	6954	$135,257
TOTAL		**362,883**	**$235,272**		**35,118**	**$341,524**		**35,118**	**$683,049**

Surf redfish

Site	Collector			Processor			Exporter		
	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)
Aitutaki	$1.95	7639	$14,858	$25.93	778	$20,178	$38.90	778	$30,267
Mangaia	$1.95	1191	$2317	$25.93	121	$3146	$38.90	121	$4719
Palmerston	$1.95	404	$785	$25.93	41	$1066	$38.90	41	$1599
Rarotonga	$1.95	1169	$2274	$25.93	119	$3088	$38.90	119	$4633
TOTAL		**10,403**	**$20,234**		**1060**	**$27,478**		**1060**	**$41,218**

Greenfish

Site	Collector			Processor			Exporter		
	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)	Price (NZD kg^{-1})	Quantity (kg)	Revenue (NZD)
Aitutaki	$2.59	4055	$10,516	$32.42	210	$6799	$45.38	210	$9519
Palmerston	$2.59	16,430	$42,609	$32.42	850	$27,549	$45.38	850	$38,568
Rarotonga	$2.59	1250	$3242	$32.42	65	$2096	$45.38	65	$2934
TOTAL		**21,735**	**$56,367**		**1124**	**$36,444**		**1124**	**$51,022**
GRAND TOTAL		**395,021**	**$311,873**		**37,302**	**$405,447**		**37,302**	**$775,288**

Overall, the recommended sustainable exploitable biomass (20% of populations greater than 200 mm) is estimated to generate revenues of $312,000, $405,000 and $775,000 to collectors, processors and exporters respectively. Due to the large population of exploitable biomass, revenues generated from lollyfish amount for approximately 80% of total revenues (depending on what level of the marketing channel we look at); considering this, fishery managers might consider primarily exploiting lollyfish during the early stages of fishery development in order to establish effective management arrangements prior to introducing the complexity of managing a multispecies fishery. That is, only collection, processing and export of lollyfish would be permitted until management protocols are well established. However, for Palmerston collectors, this significantly reduces potential revenues, given that majority of the value of the exploitable biomass is greenfish.

4.3 Economic management tools

Carleton et al. (2013) provide a comprehensive description of economic management tools that are applicable to sea cucumber fisheries management in Cook Islands. In combination with biological controls, including target and limit reference points (stocking density, length frequencies, catch rates) and agreed harvest control rules, the following economic management measures might be considered.

Monitoring

- Collect fishery and marketing channel data, by species and producing island.
- Inspect all beche-de-mer shipments and obtain comprehensive export documentation, including a valid commercial invoice and packing list by species and source fishery.

Resource access

- Allocate a predefined number of export licenses (and perhaps processing licenses) and utilise licensing revenue as a component to recover costs for management of sea cucumber fisheries and the beche-de-mer trade. A set of eligibility criteria to qualify for a license should be drafted, which, among other things, might consider a percentage of local ownership.
- Consider centralised processing to create efficiency and improved quality control, and apply similar licensing and eligibility criteria to those required for exporters.

Production and export caps

- To prevent overexploitation, application of annual precautionary export caps, by species, is recommended. These form the basis for 'backstopping' provincial quotas (which may be based on stock assessment), allow for greater control at the point of export and create disincentive for processors and traders to encourage collectors to continue fishing after quotas are met. Based on the above harvest recommendations (20% of stock greater than 200 mm), a total export cap of 37 mt of beche-de-mer is recommended, of which 35 mt would be lollyfish.
- Consider the application of localised (by island) production quotas.

Cost recovery and economic incentive

- Consider applying an ad valorem export tariff that is calculated on the value of the commercial invoice.
- Although it is noted that size limits are recommended above, consideration might be given to applying a levy per piece to discourage trade of undersized animals.
- The exporter and processor licensing fee and export tariff should represent the value of the trade and cost of management.

The economic analysis of the estimated harvestable stock is a guide or baseline reference on product valuation based on current market valuation in the Pacific Island region. As demand escalates and supply diminishes, resource custodians are in a position to determine best economic values for their resources.

5. Discussion

The four islands assessed in this study are relatively isolated from major coral reef systems in the tropical western Pacific region. As a consequence many of the coral reef invertebrates, including sea cucumbers, are generally isolated from outside sources of replenishment; therefore replenishment is heavily dependent on local healthy spawning biomass. The low number of sea cucumber species recorded in this assessment is expected as these sites are located further east (20° south latitude and 160° west longitude) from the centre of biodiversity (Palau / Papua New Guinea / Indonesia region). Of the 10 species recorded at all sites, black teatfish, lollyfish, greenfish and surf redfish are of commercial importance in the beche-de-mer trade. Lollyfish and surf redfish are common to abundant at these sites. Greenfish densities were lower at Aitutaki, Palmerston and Rarotonga than the regional reference density and the species was not recorded in Mangaia. Two other commercially important species in the beche-de-mer trade (leopard fish and prickly redfish) were sighted during in-water assessments but were outside of transect areas. These two species and black teatfish were rare at study sites. In the interest of maintaining biodiversity and ecological health commercial exploitation of these rare species should not be permitted.

The similarities in overall mean and present mean densities for lollyfish, surf redfish, and white snakefish among four sites (Figure 3) demonstrate relative widespread occurrence of these species at the stations assessed. This is generally not the case in species distribution in the more complex habitat systems where certain species exhibit preference for certain types of habitats. However these sites have less complex habitats compared to many of the higher, larger islands in the tropical Pacific region. In addition, survey stations at these sites targeted the habitat types where the species are commonly found. Despite the less complex habitats at these sites flower sea cucumber demonstrated a more aggregated pattern of dispersion. Flower sea cucumber was generally found in aggregated patches on reef flats with moderate to strong wave action. The species seeks refuge in rocky substrates but exposes its tentacles (peltate) on the substrate, allowing it to be spotted during enumeration. If exposure of tentacles is related to tidal influences, this could cause some bias during underwater visual assessment for the species. Greenfish was absent in Mangaia. This site is a raised reef platform type island (locally referred to as makatea), with limited reef / lagoonal habitats exposed to strong wave action which may be too dynamic for greenfish. The survey team for these assessments also observed the general absence of greenfish in three other makatea islands in Cook Islands, indicating that habitats on these islands may not be suitable for greenfish.

Lollyfish and surf redfish densities at Aitutaki, Mangaia and Rarotonga are considerably higher than the regional reference densities, indicating that the populations are in a relatively healthy state. This is expected in populations that are very lightly fished or that have not been exposed to commercial exploitation. Two previous studies provide similar density estimates for surf redfish at Aitutaki. Zoutendyk (1989) estimated 1400 ind. ha^{-1}, while a second study (MMR unpublished data 2011) estimated 1800 ind. ha^{-1}; results of these two studies are consistent with the estimate of 1600 ind. ha^{-1} derived from the current study conducted in preferred surf redfish habitat (surf zone). Similarly, for Rarotonga, Zoutendyk estimated 400 ind. ha^{-1}, and this study estimates 600 ind. ha^{-1} for surf redfish. Other estimates vary significantly from those obtained in this study, which likely reflects differences in assessment methods used, various transect sizes or the placement of transects over very different habitat types. No records could be located that refer to greenfish exploitation from these islands in the last three decades. Densities for greenfish were lower at all sites than the regional reference densities. The densities for greenfish could be considered natural for this species at the three sites.

Size structures observed for lollyfish, surf redfish and greenfish at all sites were similar and exhibited relatively small mean sizes. The size structures were skewed towards the larger size classes, which is likely related to the cryptic nature of smaller individuals. Sizes when the species become fully visible for enumeration were estimated at 125 mm for lollyfish and greenfish and 165 mm for surf redfish. Purcell et al. (n.d.) provides common and maximum sizes for commercially important holothurians in the tropical Pacific. The common and maximum sizes for these three species at the study sites are generally smaller than that observed in the region. For example, average sizes of lollyfish at the three sites ranged from 157 to 177 mm, and maximum size ranged from 355 to 400 mm, while in the region the common and maximum sizes for lollyfish are reported as 230 mm and 650 mm, respectively. Similarly for surf redfish, the average and maximum sizes observed at the islands assessed were 25% smaller and for greenfish the average and maximum sizes were 37% and 31% smaller than those reported for the region. Causes for the smaller sizes observed could be a lack of genetic or nutritional diversity; however, more in-depth studies are required to confirm this. The general smaller size structures of these populations may have important implications for the sizes at which these species become reproductively mature or levels of fecundity and viable gamete production capacities, and this is worth exploring further. There are also economic implications when trading smaller products.

Size at maturity is related to the mean size of a species and is attained earlier in smaller species. Size at reproductive maturity for lollyfish is reported to be 165 mm (or 160 g) in New Caledonia (Conand 1993). New Caledonia surf redfish mature at 220 mm (or 370 g) (Conand 1993). We were unable to locate information on size at maturity for greenfish. However Uthicke et al. (2001) and Conand et al. (2010) reported greenfish and lollyfish to reproduce sexually through spawning and asexually by fission.

Proportions of populations of lollyfish, surf redfish and greenfish greater than 200 mm were chosen as a basis to determine biomass and to provide preliminary harvest level estimates, due to reported size at maturity and the population size structures at these sites being smaller than those reported for the region. Biomass and preliminary harvest levels (wet and gutted volumes) for the three species illustrated in Table 9 are large when taking into account processing or storage of raw perishable product. Should harvesting occur, we recommend collecting biological information to fill the knowledge gaps for these species. Of importance for sea cucumber fisheries in Cook Islands are reproductive patterns, sizes at maturity and conversion from live to processed ratios (wet:dry).

Beche-de-mer markets are continuously looking for new sources of supply, and many countries in the region are striving to control and manage their sea cucumber fisheries. Sea cucumber export fisheries are closed in Marshall Islands, Palau, Papua New Guinea, Solomon Islands, Tonga and Vanuatu in an attempt to rehabilitate stocks and introduce more vigorous fishery management controls. With the closure of these fisheries, countries with lightly fished stocks like Cook Islands will experience increasing demand for supplies of beche-de-mer.

6. Recommendations

Assessment of other sites should follow the same method as this survey to allow comparison of results.

Should Cook Island aspire to harvest sea cucumber resources for the beche-de-mer trade, adaptive fishery management frameworks need to be developed, endorsed and implemented prior to harvesting to ensure long-term sustainability for coastal communities. Management or regulatory tools for consideration could include the following:

- prohibit rare sea cucumber species from commercial export;
- introduce minimum size or weight limits for export species;
- allocate species-specific and island-specific harvest/export quotas;
- establish closed areas and/or support the current *Ra'ui*;
- introduce short harvest periods;
- limit the number of exporters;
- monitor catches and exports.

Sea cucumber fisheries traditionally have followed a boom–bust pattern, meaning short periods of exceptional catches and revenue followed by periods of poor catches and minimal to no revenue. To avoid this situation, regulatory measures should be accompanied with heavy penalties.

Should any of the three species (lollyfish, surf redfish or greenfish) be open to commercial exploitation, it would be wise not to collect large volumes of sea cucumber over short periods expecting that these could be frozen or processed in a relatively short period. It is important to gather information on how a buyer wishes to buy or process the product or how the island councils wishes to dispose of the product.

The ministry and island councils will need to decide how the products would be processed. This decision should consider that processing of beche-de-mer consumes a considerable quantity of fuel (e.g. firewood), which may be an issue for small islands with limited fuel-wood. It is worth exploring processing options and facilities abroad; however, this would require cold-chain infrastructure and would potentially forego value-adding opportunities, resulting in reduced export value.

Harvest strategies could include the following:

- Conduct a trial harvest, where the quantity harvested is equivalent to a full container of frozen product. Asses the catch, disposal method (processing/freezing etc.), income and catch-per-unit-effort (CPUE) information for further fine tuning of harvest strategies and management approaches.
- Set preliminary minimum size limits at 200 mm for all three species for the trial harvest and refine the minimum size limits to sizes close to those at full maturity.
- Set conservative harvest levels.
- Set several relatively short harvest periods until established harvest levels are reached. For example, harvesting only on weekend days to allow the processor to process or freeze the product during the week. When harvest levels for a particular species are reached, the further harvesting of that particular species should be prohibited.
- Limit the number of buyers/exporters at the island level and carefully monitor species purchased, processing and product quality.
- Collect biological information to determine reproductive patterns, sizes at maturity and conversion ratios (live to processed ratios).

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Appendix 1.

Density estimates (individuals ha^{-1}) of some sea cucumber species over time by various authors.

Author	Year	Island	Surf redfish	Lollyfish	Greenfish	White snakefish
Zoutendyk	1989	Aitutaki	1400.0		600	
Zoutendyk	1989	Palmerston	800.0			
Zoutendyk	1989	Rarotonga	400.0	300	500	300
Ponia et al.	1998	Rarotonga	3070.0	4590	760	6960
Ponia et al.	1998	Aitutaki – Maina	230.0	6300	500	370
Ponia et al.	1998	Aitutaki – Motikitiu	360.0	7800	270	210
Ponia et al.	1998	Aitutaki – O'out	110.0	9100	20	6400
Pinca et al.	2009	Aitutaki	26.5	21,342	447	1175
Pinca et al.	2009	Palmerston	7.4	3443	3400	66
Pinca et al.	2009	Rarotonga	313.0	10,772	1407	6782

Appendix 2.

GPS coordinates for transect stations in each site

Aitutaki survey stations

Date surveyed	RBT number	Longitude	Latitude
15/10/2012	1	-15946524	-1849493
15/10/2012	2	-15946578	-1849394
15/10/2012	3	-15946583	-1849356
15/10/2012	4	-15946975	-1850156
15/10/2012	5	-15947098	-1850043
15/10/2012	6	Missing position	Missing position
15/10/2012	7	-15947683	-1851049
15/10/2012	8	Missing position	Missing position
15/10/2012	9	Missing position	Missing position
16/10/2012	10	-15948746	-1851666
16/10/2012	11	Missing position	Missing position
16/10/2012	12	-15948780	-1851668
16/10/2012	13	-15948993	-1852607
16/10/2012	14	-15948994	-1852607
16/10/2012	15	Missing position	Missing position
16/10/2012	16	Missing position	Missing position
16/10/2012	17	Missing position	Missing position
16/10/2012	18	-15949526	-1853446
16/10/2012	19	-15949431	-1853502
16/10/2012	20	-15950225	-1854499
16/10/2012	21	Missing position	Missing position
17/10/2012	22	-15949483	-1855284
17/10/2012	23	-15948366	-1855445
17/10/2012	24	-15948360	-1855562
17/10/2012	25	-15946507	-1855583
17/10/2012	26	Missing position	Missing position
17/10/2012	27	-15946549	-1855643
17/10/2012	28	-15946526	-1855607
17/10/2012	29	-15945439	-1856158
17/10/2012	30	-15945420	-1856126
17/10/2012	31	Missing position	Missing position
17/10/2012	32	Missing position	Missing position
17/10/2012	33	-15943654	-1856496
17/10/2012	34	Missing position	Missing position

Date surveyed	RBT number	Longitude	Latitude
17/10/2012	35	-15943659	-1856433
17/10/2012	36	Missing position	Missing position
18/10/2012	37	-15943753	-1854771
18/10/2012	38	-15943694	-1854777
18/10/2012	39	-15943596	-1854792
18/10/2012	40	-15944129	-1853883
18/10/2012	41	-15944076	-1853820
18/10/2012	42	-15944038	-1853784
18/10/2012	43	Missing position	Missing position
18/10/2012	44	-15944985	-1852654
18/10/2012	45	Missing position	Missing position
18/10/2012	46	-15945364	-1850904
18/10/2012	47	-15945259	-1850849
18/10/2012	48	-15945206	-1850830
19/10/2012	49	-15949471	-1855204
20/10/2012	50	-15946558	-1849305
20/10/2012	51	-15947260	-1849816
20/10/2012	52	-15948051	-1850790
20/10/2012	53	-15948623	-1851477
20/10/2012	54	-15949609	-1855357

Mangaia survey stations

Date surveyed	Site name	RBT number	Longitude	Latitude
5/06/2013	Avaava Nanue	1	-157.955	-21.9474
5/06/2013	Avaava Nanue	2	-157.955	-21.948
5/06/2013	Tepapa	3	-157.943	-21.9535
5/06/2013	Tepapa	4	-157.943	-21.9543
5/06/2013	Tukoropa	5	-157.93	-21.9587
5/06/2013	Tukoropa	6	-157.93	-21.9591
5/06/2013	??	7	-157.916	-21.9562
5/06/2013	??	8	-157.915	-21.9567
6/06/2013	Irori	9	-157.94	-21.8964
6/06/2013	Irori	10	-157.94	-21.8954
6/06/2013	Te Ana Tura'a	11	-157.946	-21.8993
6/06/2013	Te Ana Tura'a	12	-157.947	-21.898
6/06/2013	Pue'u	13	-157.953	-21.9084
6/06/2013	Pue'u	14	-157.953	-21.908

Date surveyed	Site name	RBT number	Longitude	Latitude
6/06/2013	Kumukumu	15	-157.927	-21.8924
6/06/2013	Kumukumu	16	-157.927	-21.8917
6/06/2013	Araoa	17	-157.915	-21.8913
6/06/2013	Araoa	18	-157.915	-21.8902
6/06/2013	Airport	19	-157.907	-21.8932
6/06/2013	Airport	20	-157.907	-21.8932
6/06/2013	Karanganui	21	-157.903	-21.9006
6/06/2013	Karanganui	22	-157.902	-21.9003
6/06/2013	Te Ruama'anga	23	-157.894	-21.9133
6/06/2013	Te Ruama'anga	24	-157.894	-21.9134
6/06/2013	Anguna	25	-157.888	-21.9209
6/06/2013	Anguna	26	-157.887	-21.9207
7/06/2013	Terere	27	-157.96	-21.9254
7/06/2013	Terere	28	-157.96	-21.9254
7/06/2013	Vai Roronga	29	-157.954	-21.9132
7/06/2013	Vai Roronga	30	-157.955	-21.9126
7/06/2013	??	31	-157.874	-21.9434
7/06/2013	??	32	-157.874	-21.9437
7/06/2013	Mutuonea	33	-157.88	-21.9279
7/06/2013	Mutuonea	34	-157.88	-21.9277
7/06/2013	Tamarua	35	-157.902	-21.9548
7/06/2013	Tamarua	36	-157.902	-21.9553
7/06/2013	Saragossa Wreck	37	-157.89	-21.9563
7/06/2013	Saragossa Wreck	38	-157.891	-21.9563
7/06/2013	Tuaati	39	-157.961	-21.937
7/06/2013	Tuaati	40	-157.962	-21.9373

Palmerston survey stations

Date surveyed	Site name	RBT number	Longitude	Latitude
2/05/2013	Cooks	1	-16310777	-1804489
2/05/2013	Cooks	2	-16310645	-1804424
2/05/2013	Cooks	3	-16310546	-1804218
2/05/2013	Palmerston	4	-16311265	-1803875
3/05/2013	Palmerston	5	-16311100	-1803677
3/05/2013	Toms	6	-16309324	-1805023
3/05/2013	Toms	7	-16309163	-1805120
3/05/2013	Pimrose	8	-16308205	-1803986

Date surveyed	Site name	RBT number	Longitude	Latitude
3/05/2013	Pimrose	9	-16307826	-1804060
3/05/2013	Pinnacle East	10	-16307852	-1802762
3/05/2013	Bird Island	11	-16307354	-1802461
3/05/2013	Bird Island	12	-16306826	-1802458
3/05/2013	Kisup	13	-16308618	-1800923
3/05/2013	Kisup	14	-16308411	-1800762
3/05/2013	Pinnacle North	15	-16309598	-1800916
4/05/2013	North Island	16	-16310001	-1800242
4/05/2013	North Island	17	-16310199	-1800109
4/05/2013	Palmerston	18	-16310409	-1802257
4/05/2013	Palmerston	19	-16310674	-1802052
4/05/2013	Pinnacle South	20	-16310039	-1803333
4/05/2013	Pinnacle West	21	-16310356	-1802834

Rarotonga survey stations

Date surveyed	Site name	RBT number	Longitude	Latitude
1/11/2012	Social Centre	33	-15949256	-2112320
1/11/2012	Social Centre	34	-15949296	-2112288
1/11/2012	Social Centre	35	-15949322	-2112259
1/11/2012	Airport Tower	54	-15948001	-2111916
2/11/2012	Airport Tower	55	-15947995	-2111872
2/11/2012	Airport Tower	56	-15947993	-2111828
2/11/2012	Airport Tower	57	-15947981	-2111789
19/11/2012	Bamboo Jacks	43	-15946302	-2112300
2/11/2012	Bamboo Jacks	44	-15946307	-2112264
2/11/2012	Bamboo Jacks	45	-15946305	-2112229
12/11/2012	Fishing Club	40	-15945477	-2112161
12/11/2012	Fishing Club	41	-15945469	-2112117
12/11/2012	Fishing Club	42	-15945468	-2112100
12/11/2012	Pouara Raui	9	-15943809	-2113823
13/11/2012	Pouara Raui	10	-15943777	-2113811
13/11/2012	Aroko Raui	5	-15943741	-2115017
13/11/2012	Aroko Raui	6	-15943475	-2114974
13/11/2012	Aroko Raui	7	-15943358	-2114990
13/11/2012	Aroko Raui	8	-15943315	-2114985
13/11/2012	Paringaru	50	-15944002	-2115927
13/11/2012	Paringaru	51	-15943928	-2115994

Date surveyed	Site name	RBT number	Longitude	Latitude
13/11/2012	Paringaru	52	-15943826	-2116060
13/11/2012	Paringaru	53	-15943789	-2116083
13/11/2012	Papa Ben	46	-15944293	-2116186
13/11/2012	Papa Ben	47	-15944230	-2116257
13/11/2012	Papa Ben	48	-15944198	-2116328
14/11/2012	Papa Ben	49	-15944159	-2116385
14/11/2012	CICC Titikaveka	36	-15945450	-2116360
14/11/2012	CICC Titikaveka	37	-15945480	-2116501
14/11/2012	CICC Titikaveka	38	-15945495	-2116593
14/11/2012	CICC Titikaveka	39	-15945509	-2116650
14/11/2012	Queens Rep (QR)	1	-15946140	-2116124
14/11/2012	Queens Rep (QR)	2	-15946168	-2116275
14/11/2012	Queens Rep (QR)	3	-15946179	-2116336
14/11/2012	Queens Rep (QR)	4	-15946197	-2116358
15/11/2012	Totokoitu	23	-15946620	-2116183
15/11/2012	Totokoitu	24	Missing position	Missing position
15/11/2012	Totokoitu	25	-15946654	-2116272
15/11/2012	Totokoitu	26	-15946651	-2116335
15/11/2012	Sheraton	19	-15947769	-2115808
15/11/2012	Sheraton	20	-15947793	-2115877
15/11/2012	Sheraton	21	-15946571	-2116045
15/11/2012	Sheraton	22	-15947861	-2116025
15/11/2012	Rutaki School	15	-15948606	-2115475
15/11/2012	Rutaki School	16	-15948630	-2115565
19/11/2012	Rutaki School	17	-15948655	-2115706
19/11/2012	Rutaki School	18	-15948664	-2115719
19/11/2012	Puaikura Lodge	11	-15949414	-2114954
19/11/2012	Puaikura Lodge	12	-15949465	-2114979
19/11/2012	Puaikura Lodge	13	-15949518	-2115019
19/11/2012	Puaikura Lodge	14	-15949536	-2115031
19/11/2012	Arorangi School	27	-15949741	-2113875
19/11/2012	Arorangi School	28	-15949814	-2113875
19/11/2012	Arorangi School	29	-15949828	-2113875
19/11/2012	Edgewater Resort	30	-15949819	-2112961
19/11/2012	Edgewater Resort	31	-15949865	-2112938
19/11/2012	Edgewater Resort	32	-15949878	-2112929

Appendix 3.

Summary statistics for the three study sites

'All Transects' represents statistics for all transects (i.e. overall mean); 'Transects P' represents statistics for transect where a species was recorded (present); 'All Stations' represents results of all stations (i.e. overall mean density for all stations); 'Stations P' represents results for stations where a species was recorded (present). Transect = 1 m x 40 m, station = six transects of 1 m x 40 m each.

Aitutaki reef benthos transect (RBT) assessment data summary

Species	All Transects			Transects P			All Stations			Stations P		
	Mean	SE	N	Mean	SE	N	Mean	SE	n	Mean	SE	n
A. mauritiana	1598.0	203.3	324	3779.2	414.3	137	1598.0	446.0	54	2538.0	659.7	34
H. atra	10,113.4	922.5	324	12,900.6	1115.2	254	10,113.4	2155.6	54	11,377.6	2364.0	48
H. atra (big)	1024.7	114.6	324	2000.0	195.8	166	1024.7	192.5	54	1383.3	235.0	40
H. cinerascens	2279.3	519.6	324	18,012.2	3184.6	41	2279.3	1110.8	54	10,256.9	4394.8	12
H. coluber	3.9	2.6	324	416.7	166.7	3	3.9	2.5	54	69.4	27.8	3
H. hilla	0.8	0.8	324	250.0		1	0.8	0.8	54	41.7		1
H. leucospilota	1416.7	257.9	324	7524.6	1065.9	61	1416.7	541.6	54	4026.3	1367.9	19
H. whitmaei	0.8	0.8	324	250.0		1	0.8	0.8	54	41.7		1
S. chloronotus	247.7	47.6	324	794.6	138.2	101	247.7	59.4	54	445.8	92.5	30
S. maculata	0.8	0.8	324	250.0		1	0.8	0.8	54	41.7		1

Mangaia reef benthos transect (RBT) assessment data summary

Species	All Transects			Transects P			All Stations			Stations P		
	Mean	SE	N	Mean	SE	N	Mean	SE	n	Mean	SE	n
A. mauritiana	542.7	55.8	240	986.7	83.6	132	542.7	106.3	40	620.2	115.8	35
H. atra	5522.9	1064.6	240	8778.1	1636.9	151	5522.9	2447.8	40	6903.6	3019.1	32
H. atra (big)	762.5	91.1	240	1619.5	158.8	113	762.5	173.6	40	1129.6	225.9	27
H. cinerascens	3658.3	608.1	240	8959.2	1319.6	98	3658.3	1131.2	40	6651.5	1836.4	22
H. leucospilota	370.8	79.5	240	2022.7	337.3	44	370.8	168.6	40	1141.0	459.5	13
H. whitmaei	3.1	1.8	240	250.0	0.0	3	3.1	1.8	40	41.7	0.0	3

→

Palmerston reef benthos transect (RBT) assessment data summary

Species	All Transects			Transects P			All Stations			Stations P		
	Mean	SE	N	Mean	SE	N	Mean	SE	n	Mean	SE	n
A. mauritiana	81.3	23.0	126	569.4	104.6	18	81.3	48.4	21	341.7	164.3	5
H. atra	1343.3	485.6	126	4977.9	1661.8	34	1343.3	1150.6	21	3526.0	2971.4	8
H. atra (big)	263.1	43.2	126	690.6	82.1	48	263.1	71.1	21	306.9	78.4	18
H. cinerascens	71.4	50.6	126	4500.0	500.0	2	71.4	71.4	21	1500.0		1
H. leucospilota	43.7	26.7	126	1100.0	522.0	5	43.7	37.7	21	305.6	243.4	3
S. chloronotus	1681.7	293.2	126	3071.0	475.1	69	1681.7	615.0	21	2354.4	802.0	15

Rarotonga reef benthos transect (RBT) assessment data summary

Species	All Transects			Transects P			All Stations			Stations P		
	Mean	SE	N	Mean	SE	N	Mean	SE	n	Mean	SE	n
A. mauritiana	580.9	101.6	360	1714.1	272.5	122	580.9	168.7	60	1124.3	296.6	31
H. atra	7016.3	741.9	360	9983.7	999.0	253	7016.3	1763.4	60	7795.9	1931.7	54
H. atra (big)	1520.8	289.2	360	2851.6	524.3	192	1520.8	449.4	60	2122.1	604.6	43
H. cinerascens	2875.3	572.0	360	15683.7	2601.3	66	2875.3	966.4	60	8626.0	2467.8	20
H. leucospilota	2107.6	225.5	360	4192.0	391.5	181	2107.6	469.0	60	3327.9	666.3	38
H. whitmaei	0.7	0.7	360	250.0		1	0.7	0.7	60	41.7		1
S. chloronotus	731.3	223.8	360	2309.2	685.7	114	731.3	355.8	60	1185.8	567.1	37

Appendix 4.

Main reef habitat types and surface areas for study sites.

Palmerston

Habitat	km²	ha
Deep lagoon	27.91	2791
Fore reef	5.88	588
Linear reef flat*	1.35	135
Inner slope	6.2	620
Lagoon pinnacle	0.27	27
Land on reef	5.22	522
Reef flat	19.12	1912

Mangaia

Habitat	km²	ha
Reef flat	3.59	359
Fore reef	4.77	477
Linear reef flat*	33.59	101

Aitutaki

Habitat	km²	ha
Deep lagoon	38.22	3822
Deep terrace	4.28	428
Fore reef	7.53	753
Land on reef	3.96	396
Linear reef flat*	2.63	263
Main land	14.87	1487
Reef flat	18.25	1825
Shallow terrace	19.04	1904
Subtidal reef flat	0.2	20

Rarotonga

Habitat	km²	ha
Channel	0.04	4
Diffuse fringing	0.17	17
Fore reef	9.88	988
Linear reef flat*	2.29	229
Land on reef	0.23	23
Main land	67.68	6768
Passages	0.11	11
Reef flat	7.63	763
Shallow terrace	3.44	344
Subtidal reef flat	0.03	3

* Linear reef flat: the distance (circumference) of the surf zone, multiplied by habitat width used to estimate biomass for surf redfish.

Appendix 5.

Price matrix for surf redfish and greenfish in Fiji.

Fiji price (NZD) matrix for surf redfish

Price (NZD)					
per piece (fresh)	per kg (300 g ind.)	per kg (400 g ind.)	per kg (500 g ind.)	per kg (600 g ind.)	per kg (700 g ind.)
2.59	8.64	6.48	5.19	4.32	3.70
3.89	12.97	9.73	7.78	6.48	5.56
5.19	17.29	12.97	10.37	8.64	7.41

Fiji price (NZD) matrix for greenfish

Price (NZD)				
per piece (fresh)	per kg (100 g ind.)	per kg (200 g ind.)	per kg (300 g ind.)	per kg (400 g ind.)
0.52	5.19	2.59	1.73	1.30
0.65	6.48	3.24	2.16	1.62
0.78	7.78	3.89	2.59	1.95
0.91	9.08	4.54	3.03	2.27

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