Survey of reef invertebrate resources in the Republic of Nauru

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by

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Summary

The people of Nauru are highly dependent on coastal resources for their food security, which has resulted in many invertebrate species being overharvested. Their decline is exacerbated by a lack of regulations to manage and control the impact of fishing. Local residents expressed the need for a status assessment and a request was made to the Pacific Community (SPC) to provide technical assistance. This report presents the findings of the resulting assessment, conducted in the Republic of Nauru in May 2015. The main objective of the work was to assess the population abundance and size structure of several key species, including turban snails (*Turbo setosus* and *T. argyrostomus*), belligerent rock shell (*Reishia armigera*), spiny rock lobster (*Panulirus penicillatus*) and species of interest to foreign markets, in particular sea cucumbers.

Six survey methods were applied to suit the different coastal habitats of Nauru. These were reef benthos transects, reef front timed walks at night, manta tow, reef front timed swims in the daytime, lobster night searches (reef front timed swims at night) and deep-water timed scuba searches. Where possible, information from this assessment was compared with that collected during the PROCFish survey in 2005, to explore changes in resource status over time.

The reef benthos transect survey showed densities of the sea cucumber surf redfish (*Actinopyga mauritiana*) on the reef flat to be well below the healthy reference density, while densities of the sea cucumber lollyfish (*Holothuria atra*) were well above the healthy reference density. The manta tow survey gave opposite results, with surf redfish exceeding healthy reference densities on the shallow reef front. However, the average density of surf redfish had declined significantly from 2005 to 2015. The deep-water timed scuba searches found six species of sea cucumbers, all in densities well below their healthy reference points. The blue-black urchin (*Echinothrix diadema*) occurred in the highest density during reef front timed swims on the shallow reef front, while the sea cucumber flowerfish (*Pearsonothuria graeffei*) and the turban snail *Turbo setosus* appeared to be recovering after an absence in the 2005 surveys, although both of these species were found at very low densities. The night reef front timed walk survey, like the reef front timed swims, showed *E. diadema* having the highest density on the reef crest followed by lollyfish and the gastropods *T. setosu*s and *Reishia armigera*.

Timed night swims and night walks were used to assess the status of lobster populations on the reef front and crest, respectively. On the reef front, counts of spiny rock lobsters (*Panulirus penicillatus*) were low, with less than one individual observed per hour (average = 0.83 ± 0.24). Counts of slipper lobsters (*Parribacus caledonicus*) were similarly low, with an average of 1.08 ± 0.38 individuals observed per hour. No spiny rock lobsters or slipper lobsters were observed during the night walks on the reef crest, contrasting with anecdotal reports of large numbers of lobsters being caught from these habitats in years past.

Length information was compiled for two sea cucumber species (*A. mauritiana and H. atra*) and three gastropod species (*R. armigera*, *Thais aculeata* and *Turbo setosus*) that were present in sufficient numbers. The average length of *A. mauritiana* was 203 mm. Only 16% of the *A. mauritiana* observed in this study were above the estimated total length of maturity (230 mm). The average length of lollyfish (*H. atra*) was 84 mm, which is well below average lengths recorded for this species elsewhere in the region.

The results of this survey and previous surveys on Nauru provide evidence of significant overexploitation of Nauru's coastal invertebrate resources, indicating a dire need to put management policies and practices in place. To promote recovery and long-term sustainability of harvest of Nauru's invertebrate resources we recommend the following management actions:

- Prohibit exports of all invertebrate resources
- Introduce a total ban on harvesting of giant clams
- Establish marine managed areas
- Impose restrictions on fishing gear
- Implement minimum harvest size limits
- Establish a monitoring programme and undertake regular monitoring of coastal resources
- Improve education and awareness.

1. Introduction

1.1. Background

The Republic of Nauru is a single raised limestone island situated in the centre of the Pacific Ocean (0°31′ S, 116°55′ E), approximately 60 km south of the equator (Figure 1). Nauru's nearest neighbouring island is Banaba, also known as Ocean Island, in the Republic of Kiribati, which is about 300 km to the east. The country has a total land area of 21.9 km^2 and an exclusive economic zone (EEZ) of approximately 310,000 km^2. Nauru mainly comprises a flat plateau that descends to a narrow coastline fringe where most of the population lives. The October 2011 census determined the population to be 10,084.

Nauru's economy has been largely based on phosphate mining, which began at the start of the 20th century. Income generated from royalties paid to local land owners supported a significant economy through to the 1990s. However, declining global prices for phosphate, high costs of maintaining associated infrastructure, decreasing phosphate reserves, declining profits and financial mismanagement combined to make the economy collapse in the late 1990s. The open-cast strip mines that now cover 80% of the nation's surface have left much of the land barren and uninhabitable, primarily at the centre of the island. This has resulted in the population migrating to the coastal fringe, and with the now rapidly increasing population, this has led to problems such as heightened land pressures and disputes in the coastal area, increased pressure on marine resources in the shallow reef flat, and potentially microclimate deterioration (ADB 2000).

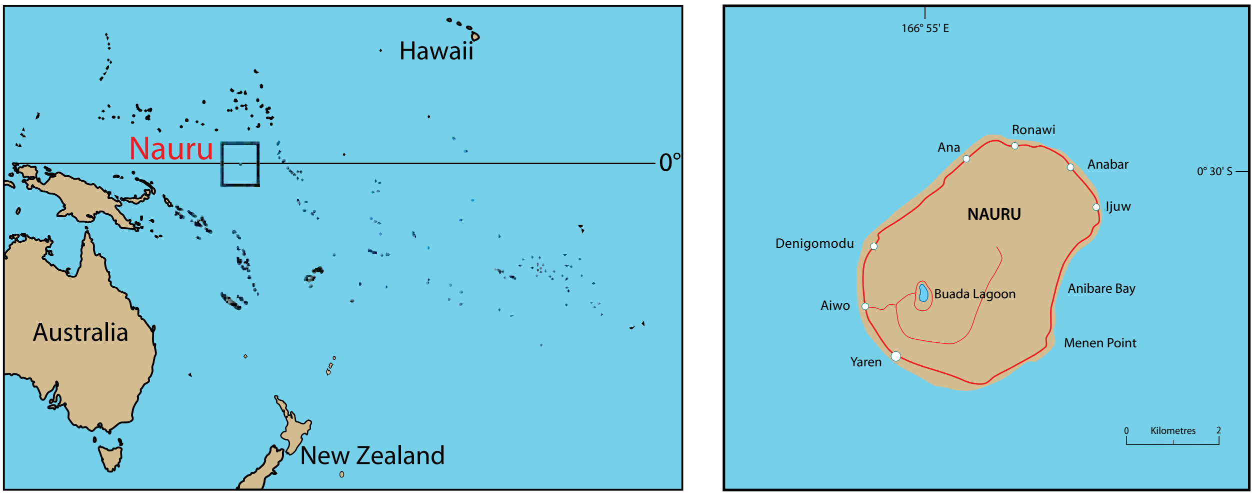

Figure 1. Map of Nauru.

The reef and shelf area around Nauru is very limited. The shallow intertidal fringing reef flat measures approximately 50–300 m from shore and has an area of approximately 3.4 km^2. Beyond this, the Nauru shelf descends to 1000 m between 1.2 and 1.7 km from shore. Bathymetric surveys in the early 1990s revealed that the 200 m isobath lies between 100 and 300 m from the shore, equating to a fishable slope area for bottom fish of 3.9 km^2 (Mead and Cusack 1990; Watt 1993).

Despite being limited to such a small area, fishing and fisheries resources play a major role in sustaining people's livelihoods, particularly since the recent economic downturn resulting from the degeneration of the phosphate mining industry. The fisheries sector comprises a large-scale industrial oceanic fishery targeting tuna and associate species, a small-scale tuna fishery which is active along the reef edge and around fish aggregating devices (FADs), and a coral reef fishery. The narrow coral reef surrounding the island supports a wide range of finfish (snappers, surgeonfish, parrot fish, groupers, mullet, trevally, scads etc.) and invertebrates (cephalopods, gastropods, bivalves, crustaceans, echinoderms etc.). Some of the common invertebrate food resources of Nauru include crabs, eels, octopus, lobsters, sea snails and sea urchins. Coastal resources are harvested using a variety of methods. Finfish are typically captured by handlines (including the local 'Christmas tree' rigs), cast nets, seine nets or by spearfishing (either by freediving or using scuba).

Invertebrate resources are typically gathered from the shallows or using snorkel or scuba. Lobsters are usually speared using scuba (Dalzell and Debao 1994).

The Fisheries Act 1997 is the primary legislation for the management, development, protection and conservation of fisheries and living marine resources of Nauru. The Fisheries Regulation 1998 regulates the registration and activities of boats; prohibits the use of explosives, poisons or noxious substance when fishing; regulates the placement and use of FADs; and regulates the exportation of live fish. At present there is no regulation to control the taking of coastal resources or the management of resources by communities. A review of the primary Fisheries Act 1997 is in process.

Dalzell and Debao (1994) characterised coastal and nearshore fishing activities and resulting seafood production in Nauru in 1994. Of the fishing trips they encountered, 90% focused on nearshore pelagic species and 10% on reef species (finfish and invertebrates). Jacob (2000) reported that the most harvested invertebrates were turban shells (*Turbo setosus* and *Turbo argyrostomus*), lobsters and a variety of crabs. According to Jacob (2000), many Nauruans ignored traditional knowledge for resource management at the beginning of mining operations, and the loss of this knowledge encouraged a 'free-for-all' attitude which led to unsustainable harvesting of resources.

Survey work by the Pacific Community (SPC) in Nauru in 2005 found the annual per capita consumption of invertebrates to be 1.6 kg, much lower than that for both fresh fish (46.5 kg) and canned fish (16 kg) (Vunisea et al. 2008). During in-water assessments six species of sea cucumber were recorded, generally in low densities. Vunisea et al. (2008) recommended that sea cucumber stocks be allowed to build before opportunities for commercial harvests are explored. No blacklip pearl oysters, trochus or giant clams were found during the survey, although Vunisea et al. (2008) considered the habitat to be suitable for giant clams and trochus. At the time of the 2005 SPC survey, commercial and anecdotal information suggested stocks of spiny rock lobsters were in decline (Vunisea et al. 2008).

A recent biodiversity study of marine non-cryptic macroinvertebrates of Nauru recorded the presence of 248 species (van Dijken 2015). During this assessment five species of sea cucumber were observed, generally in low densities: deepwater blackfish (*Actinopyga palauensis*), surf redfish (*Actinopyga mauritiana*), flowerfish (*Pearsonothuria graeffei*[1]), lollyfish (Holothuria atra), and prickly redfish (*Thelenota ananas*). Van Dijken (2015) noted very low densities of easily accessible gastropods (e.g. *Turbo* spp.) which he suggested was due to over-exploitation of these resources.

1.2. Objectives of the study

At the eighth Head of Fisheries meeting in Noumea in March 2013, Nauru requested technical assistance from SPC to assess the status of its coastal invertebrate resources, and to build the capacity of local staff in invertebrate assessment methodologies. The need for an assessment to clarify the status of key coastal resources was highlighted by members of the community during consultations undertaken as part of the ongoing Community Ecosystems Approach to Fisheries Management (CEAFM) programme. Furthermore, there has been foreign interest expressed in the harvest of sea cucumbers and lobsters for export.

The main objectives of this study were thus to conduct a comprehensive assessment of the population status of key harvested marine invertebrate species in Nauru, and to provide advice for management and potential for commercial export. The assessment focused on those species most commonly harvested for food purposes, including turban snails (*T. setosus* and *T. argyrostostomus*), drupe shell (*Reishia armigera*), lobster (*Panulirus penicillatus*), and species of interest to foreign importers, in particular sea cucumbers. Improved knowledge of the status of these key reef species is important to develop effective and realistic management approaches. At the same time this assessment aimed to build capacity of local fisheries officers to allow similar surveys of invertebrate stocks to be conducted in the future.

[1] Listed in van Dijken (2015) as *Bohadschia graeffei*; this species is now officially listed as *Pearsonothuria graeffei*.

2. Methods

2.1. Field surveys

Survey work in Nauru took place over a three-week period from 11 to 30 May 2015. Six survey methods were used to assess the status of invertebrate resources, with each method targeting a different habitat on the reef. Methods typically followed those outlined in Pakoa et al. (2014).

Modified fine-scale reef benthos transects (RBt) were conducted on reef flat habitats at low tide. A total of 19 RBt stations were surveyed (Figure 2), with each station consisting of six 40 x 1 m replicate transects spaced approximately 5 m apart. Two surveyors completed three transects at each station, by walking along the reef flat. Species and habitat data were recorded for each replicate transect and a GPS waypoint was logged for each station (to an accuracy of ± 5 m).

Invertebrates on the reef crest were assessed by reef front timed walks (RFw) at night-time during low tide. This involves two surveyors walking adjacent to each other at a distance of 8 m, counting all macroinvertebrates observed for a period of 10 minutes. Six 10-minute walks were completed at each station, with each surveyor completing three walks. A GPS point was recorded at the beginning and end of each 10-minute walk. A total of seven RFw stations were completed during the assessment (Figure 2).

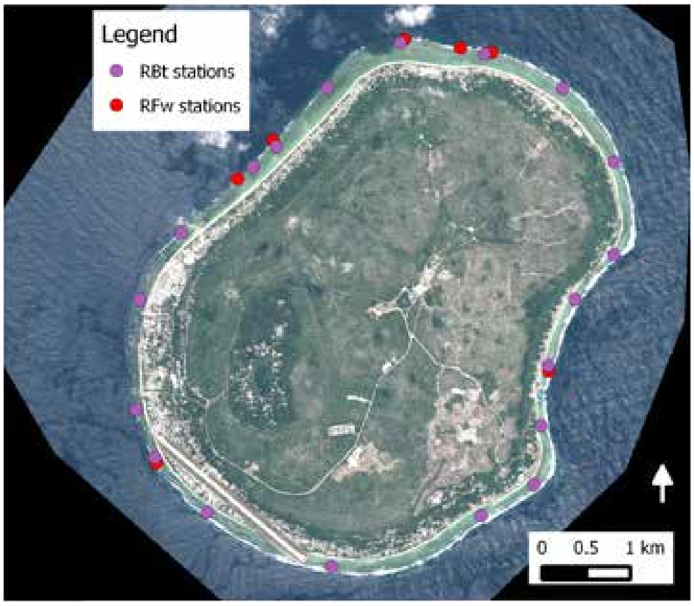

Figure 2. Locations of reef benthos transect (RBt) stations and reef front timed walk (RFw) stations established on Nauru, May 2015.

Invertebrates inhabiting the shallow outer reef front (1–5 m depth) were assessed using reef front timed swims (RFs). In this approach two surveyors snorkelled side by side, separated by approximately 5 m, counting the invertebrates observed for a period of 5 minutes. A total of six 5-minute swims were completed at each station, with each surveyor completing three swims. A GPS point was recorded at the beginning and end of each 5-minute swim. A total of 19 reef front timed swim stations were completed during the assessment (Figure 3), equating to a total search time of 9.5 hours search time (30 minutes per station).

Tropical rock and slipper lobster populations were assessed using reef front timed swims at night-time using underwater torches. This approach followed that for daytime RFs stations, with two surveyors snorkelling parallel to each other and each completing three timed searches. Each search lasted for 10 minutes. A total of 12 night-time lobster search stations were completed during the assessment (Figure 3), equating to a total search time of 12 hours (60 minutes per station).Manta tows were conducted to provide a broad-scale overview of the status of large, sedentary invertebrates living on the outer reef front in depths of 1–10 m. In this assessment, a snorkeler was towed behind a boat with a manta board at an average speed of approximately 4 km/hour. Each tow replicate was 300 m in length with a 2 m observation belt and was calibrated using the odometer function within the trip computer option of a Garmin 76Map GPS.

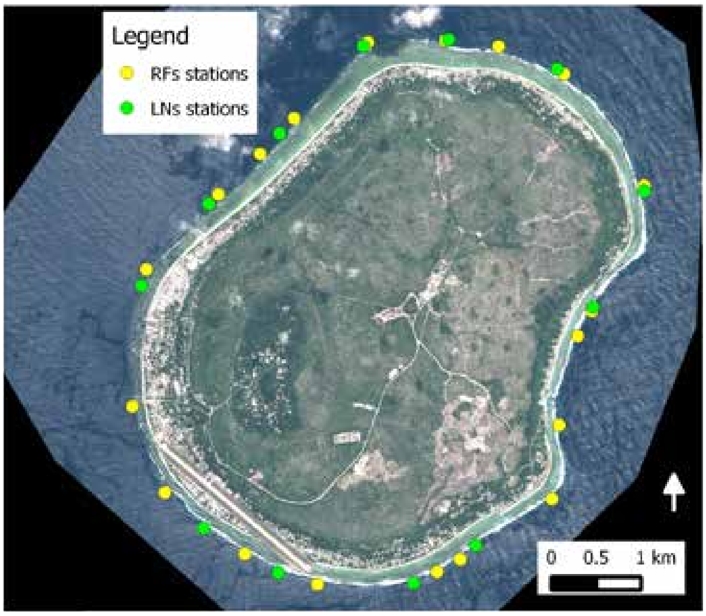

Figure 3. Locations of reef front timed swim (RFs) and lobster night search (LNs) stations established on Nauru, May 2015.

Six 300 x 2 m manta tow replicates were conducted at each station, with the start and end GPS positions of each tow recorded to an accuracy of < 5 m. A total of nine manta tow stations were completed during the assessment, covering a survey area of 32.4 km^2 (Figure 4).

Sea cucumber species inhabiting deep outer reef slopes (20–45 m) were assessed using deep-water timed scuba searches. Divers swam side by side, separated by approximately 5 m, and recorded all the sea cucumber species they observed in three 5-minute search periods. A total of seven deep-water timed scuba search stations were completed (Figure 4) equating to a total search period of 3.5 hours and covering a search area of approximately 31,668 m^2.

The survey methods and coverage are summarised in Table 1. Appendix 1 lists GPS waypoints for all locations surveyed.

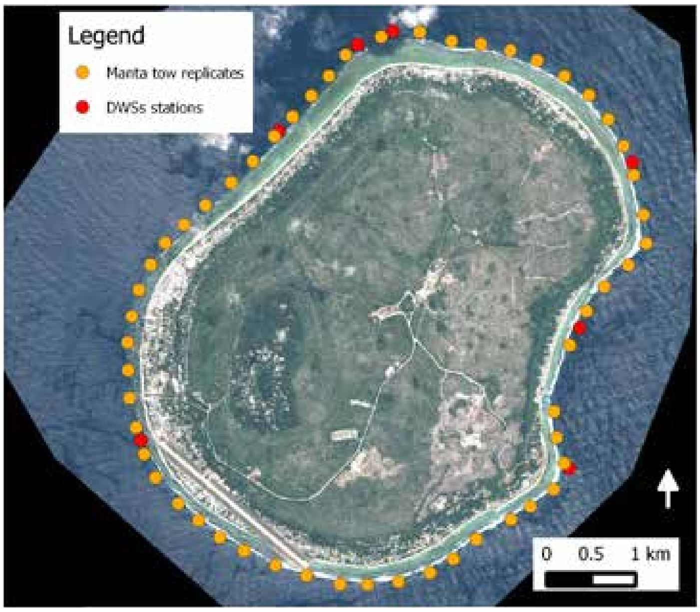

Figure 4. Location of manta tow replicate transects and deep-water scuba search stations established on Nauru, May 2015.

Table 1. Survey coverage during the invertebrate assessment in Nauru.

Method	Habitat	No. of stations	No. of transects/ search periods	Approximate area surveyed (m2)
Reef benthos transects	Intertidal/shallow subtidal reef flat	19	114	4,560
Reef front timed walk (night)	Reef crest on low tide	7	42	14,849[1]
Daytime reef front timed swim	Shallow outer reef (1–5 m)	19	114	54,663[2]
Lobster night search (night-time reef front timed swim)	Shallow outer reef (1–5 m)	12	72	34,524[3]
Manta tow	Shallow outer reef (1–10 m)	9	54	32,400
Deep-water timed scuba search	Deep outer reef (20–45 m)	7	42	31,752[4]

2.2. Data analysis

Data collected in Nauru during the survey were entered into the Reef Fisheries Integrated Database (RFID) at SPC in Noumea to provide information on species presence, densities, mean size and size frequency of the species of interest. The analysis of sea cucumber and other invertebrate species data follows fishery status indicators provided in Friedman et al. (2008) and Pakoa et al. (2014). Where possible, information derived from this assessment was compared with that collected in 2005 (Vunisea et al. 2008) to explore changes in resource status over time. In this report, species density information is summarised by survey method because species densities vary by habitat and the different methods targeted different habitats. Species mean size and length frequency data are analysed and presented for all methods/habitats combined.

3. Results and discussion

3.1. Species presence

A variety of invertebrate species were encountered during this assessment (Table 2). Nine species of sea cucumber were observed, exceeding the number observed during the Vunisea et al. (2008) survey when six species were encountered. During the current survey the sea cucumbers stonefish (*Actinopyga lecanora*), surf redfish (*Actinopyga mauritiana*) and lollyfish (*Holothuria atra*) were encountered on the reef flat during reef benthos transects. Surf redfish and flowerfish (*Pearsonothuria graeffei*) were encountered during reef front timed swims on the shallow reef front. Surf redfish and flowerfish were also encountered during manta tows, along with deepwater blackfish (*Actinopyga palauensis*) and prickly redfish (*Thelenota ananas*). Deepwater blackfish, prickly redfish, flowerfish, leopardfish (*Bohadschia argus*), black teatfish (*Holothuria whitmeai*) and amberfish (*Thelenota anax*) were all encountered during deep-water timed scuba searches on the outer reef slope (Table 2).

One individual of each of the elongate giant clam (*Tridacna maxima*) and Noah's giant clam (*Tridacna noae*) were encountered on the reef flat during the survey, while another two *T. maxima* were observed whilst walking to survey sites (Figure 5). While only a small number, this finding contrasts with Vunisea et al. (2008) who suggested *Tridacna* spp. were locally extinct on Nauru. Given the relatively small size of the encountered individuals, it is likely that they settled in their present locations after the survey of Vunisea et al. (2008). However it is not known whether these individuals originated from brood stock on Nauru itself or neighbouring islands.

While a large number of gastropods (sea snails) of importance for food and handicraft production were observed during the current survey (Table 2), no trochus (*Tectus niloticus*) were encountered. While it is within the geographical range of naturally distributed trochus stocks, Nauru is unlikely to receive recruits from neighbouring islands given the species' short planktonic larval duration (< 7 days) (Vunisea et al. 2008). Moreover, while Nauru's reefs provide suitable habitat for adult trochus, the uplifted reef platform on the coastline provides poor habitat for juvenile trochus, lacking shallow water rubble habitats.

Table 2. Species recorded during the 2015 survey, and survey method by which they were encountered.

Group	Common name	Scientific name	Manta tow	Reef benthos transect (RBt)	Other
Sea cucumber	Stonefish	*Actinopyga lecanora*		+	
	Surf redfish	*Actinopyga mauritiana*	+	+	+
	Deepwater blackfish	*Actinopyga palauensis*	+		+
	Leopardfish	*Bohadschia argus*			+
	Lollyfish	*Holothuria atra*		+	+
	Black teatfish	*Holothuria whitmeai*			+
	Flowerfish	*Pearsonothuria graeffei*	+		+
	Prickly redfish	*Thelenota ananas*	+		+
	Amberfish	*Thelenota anax*			+
Bivalve	Elongated giant clam	*Tridacna maxima*		+	
	Noah's giant clam	*Tridacna noae*		+	
Crustacean	Spotted reef crab	*Carpilius maculatus*			+
	Splendid reef crab	*Etisus splendidus*			+
	Spiny rock lobster	*Panulirus penicillatus*			+
	Slipper lobster	*Parribacus caledonicus*			+
	Decorator crab	*Camposcia retusa*			+
Gastropod	Lettered cone	*Conus litteratus*		+	
	Soldier cone	*Conus miles*		+	+
	Arabian cowrie	*Cypraea arabica*			+

Group	Common name	Scientific name	Manta tow	Reef benthos transect (RBt)	Other
	Serpent's head cowrie	*Cypraea caputserpensis*			+
	Humpback cowrie	*Cypraea mauritiana*		+	+
	Money cowrie	*Cypraea moneta*		+	+
	Tiger cowrie	*Cypraea tigris*		+	+
	Purple drupe	*Drupa morum*		+	+
	Belligerent rock shell	*Reishia armigera*		+	+
	Aculeate rock shell	*Thais aculeata*		+	+
	Intermediate drupe	*Thais intermedia*			+
	Silver mouthed turban	*Turbo argyrostomus*			+
	Rough turban	*Turbo setosus*		+	+
Star	Blue linckia	*Linckia laevigata*			+
	Brittle star	*Ophiomastrix* sp.		+	
	Brittle star	*Ophiothrix nereidina*		+	
Urchin	Rock boring urchin	*Echinometra mathaei*		+	+
	Banded sea urchin	*Echinothrix calamaris*			+
	Blue-black urchin	*Echinothrix diadema*	+	+	+
	Slate pencil urchin	*Heterocentrotus mammillatus*			+
	Collector urchin	*Tripneustes gratilla*		+	

Figure 5. Specimen of Noah's giant clam (*Tridacna noae*) (left, photo: Colette Wabnitz) and a specimen of the elongate giant clam (*Tridacna maxima*) (right, photo: Richard Story) for comparison. *Tridacna noae* can be identified by the presence of discrete teardrops bounded by white margins on the edge of the mantel while *Tridacna maxima* shows a row of eyes on the edge of the mantle.

3.2. Density

Reef benthos transect

The densities of the 19 species most commonly observed during reef benthos transects on the shallow reef flat are presented in Table 3. Comparison against the Pacific reference densities for healthy stocks (Pakoa et al. 2014) indicate that densities of stonefish (*Actinopyga lecanora*) and surf redfish (*A. mauritiana*) in 2015 were well below the healthy reference densities. Surf redfish is typically not abundant on emerged platforms (Vunisea et al. 2008). Densities of lollyfish (*Holothuria atra*) were well above the reference point for healthy stocks (Table 3). Stonefish was not encountered by Vunisea et al. (2008) suggesting it is a recovering stock. Densities of giant clams were similarly well below reference densities (Table 3).

Table 3. Densities of species recorded in reef benthos transects in the current study. Reference densities for healthy stocks (from Pakoa et al. 2014) are shown for comparison (where available).

Species group	Common name	Scientific name	Overall mean density ± SE (individuals/ha)	Pacific reference density (individuals/ ha)
Sea cucumber	Stonefish	*Actinopyga lecanora*	2.2 ± 2.2	10
	Surf redfish	*Actinopyga mauritiana*	26.3 ± 12.4	200
	Lollyfish	*Holothuria atra*	55,589.9 ± 12,141.1	5600
Bivalve	Elongated giant clam	*Tridacna maxima*	2.2 ± 2.2	750
	Noah's giant clam	*Tridacna noae*	2.2 ± 2.2	NA
Gastropod	Lettered cone	*Conus litteratus*	2.2 ± 2.2	NA
	Soldier cone	*Conus miles*	13.2 ± 9.0	NA
	Humpback cowrie	*Cypraea mauritiana*	8.8 ± 6.0	NA
	Money cowrie	*Cypraea moneta*	32.9 ± 12.2	NA
	Tiger cowrie	*Cypraea tigris*	17.5 ± 6.6	NA
	Purple drupe	*Drupa morum*	21.9 ± 19.7	NA
	Belligerent rock shell	*Reishia armigera*	15.4 ± 11.1	NA
	Aculeate rock shell	*Thais aculeata*	76.8 ± 31.1	NA
	Rough turban	*Turbo setosus*	100.9 ± 100.9	NA
Star	Brittle star	*Ophiomastrix* sp.	8.8 ± 8.8	NA
	Brittle star	*Ophiothrix nereidina*	92.1 ± 58.6	NA
Urchin	Rock boring urchin	*Echinometra mathaei*	103.1 ± 46.1	NA
	Blue-black urchin	*Echinothrix diadema*	155.7 ± 82.0	NA
	Collector urchin	*Tripneustes gratilla*	6.6 ± 6.6	NA

Reef front timed walk (night)

On the reef crest, the blue-black urchin (*Echinometra diadema*) occurred in the highest density, followed by the sea cucumber lollyfish (*Holothuria atra*) and the gastropods *Turbo setosus* and *Reishia armigera* (Table 4). Densities of surf redfish (*Actinopyga mauritiana*) were generally low (24.8 ± 6.0 individuals/ha; Table 4), and well below regional reference densities of 200 individuals/ha suggested by Pakoa et al. (2014). No spiny rock lobsters or slipper lobsters were sighted during the night-time reef front timed walks in the present survey. This contrasts with historical anecdotal reports of local fishers collecting large numbers of these species walking on the reef crest at night, suggesting that abundances of these species have declined severely over the years.

Table 4. Overall mean densities of invertebrate species observed during night-time reef front timed walks during the present survey.

Species group	Common name	Scientific name	Overall mean density ± SE (individuals/ha)
Sea cucumber	Surf redfish	*Actinopyga mauritiana*	24.8 ± 6.0
	Lollyfish	*Holothuria atra*	206.0 ± 66.6
Crustacean	Spotted reef crab	*Carpilius maculatus*	3.4 ± 1.3
Gastropod	Soldier cone	*Conus miles*	6.8 ± 4.7
	Arabian cowrie	*Cypraea arabica*	1.1 ± 0.7
	Serpent's head cowrie	*Cypraea caputserpensis*	3.9 ± 1.7
	Humpback cowrie	*Cypraea mauritiana*	10.1 ± 3.8
	Money cowrie	*Cypraea moneta*	5.1 ± 2.4
	Tiger cowrie	*Cypraea tigris*	2.3 ± 1.2

	Purple drupe	*Drupa morum*	6.2 ± 6.2
	Belligerent rock shell	*Reishia armigera*	62.5 ± 17.1
	Aculeate rock shell	*Thais aculeata*	23.1 ± 8.1
	Intermediate drupe	*Thais intermedia*	0.6 ± 0.6
	Rough turban	*Turbo setosus*	64.7 ± 33.4
Urchin	Rock boring urchin	*Echinometra mathaei*	3.9 ± 2.7
	Banded sea urchin	*Echinothrix calamaris*	9.6 ± 8.9
	Blue-black urchin	*Echinothrix diadema*	3517.4 ± 1297.2

Daytime reef front timed swim

Seven macro-invertebrate species from three species groups were observed during daytime reef front timed swims (Table 5). Overall mean densities were generally similar to those reported during the 2005 survey (Vunisea et al. 2008). Consistent with the findings of van Dijken (2015), densities of turban snails were very low in the current study, with averages of 2.2 ± 0.7 *Turbo argyrostomus* and 1.3 ± 1.1 *T. setosus* per hectare.

Table 5. Overall mean densities of invertebrates encountered on shallow reef front during the daytime reef front timed swim in the current survey, and densities reported from the 2005 survey for comparison (Vunisea et al. 2008).

Species group	Common name	Scientific name	Overall mean density ± SE (individuals/ha)	
			Current survey (2015)	2005 survey
Sea cucumber	Surf redfish	*Actinopyga mauritiana*	62 ± 13.8	77.1 ± 15.1
	Lollyfish	*Holothuria atra*	0.4 ± 0.4	0.2 ± 0.2
	Flowerfish	*Pearsonothuria graeffei*	0.7 ± 0.7	–
Urchin	Rock boring urchin	*Echinometra mathaei*	9.0 ± 8.6	4.1 ± 1.8
	Blue-black urchin	*Echinothrix diadema*	652.2 ± 57.4	686.7 ± 125.8
Gastropod	Silver mouthed turban	*Turbo argyrostomus*	2.2 ± 0.7	3.3 ± 1.03
	Rough turban	*Turbo setosus*	1.3 ± 1.1	–

Lobster night searches (Night-time reef front timed swim)

Five crustacean species were recorded at 12 stations during lobster night searches on the shallow reef front (Table 6 and Figure 6). Just over one slipper lobster (*Parribacus caledonicus*), and less than one spiny rock lobster (*Panulirus penicillatus*), were observed on average per hour of survey. While no reference information is available for healthy spiny rock lobster populations, the number observed in Nauru during the present study is well below that observed in previous surveys elsewhere in the Pacific region. For example, an average of 2.2 spiny rock lobsters (and a maximum of four) was observed per hour during free diving along the shallow reef front at Palmerston Atoll in the Cook Islands (Passfield 1988). Lobsters are considered to be one of the most overexploited invertebrates in Nauru, largely due to the restaurant trade and home consumption (Jacob 2000; Vunisea et al. 2008).

Table 6. Overall mean number of crustaceans per hour during lobster night searches.

Common name	Scientific name	Mean number/h ± SE
Spotted reef crab	*Carpilius maculatus*	0.3 ± 0.2
Splendid reef crab	*Etisus splendidus*	0.1 ± 0.1
Spiny rock lobster	*Panulirus penicillatus*	0.8 ± 0.2
Slipper lobster	*Parribacus caledonicus*	1.1 ± 0.4
Decorator crab	*Camposcia retusa*	0.1 ± 0.1

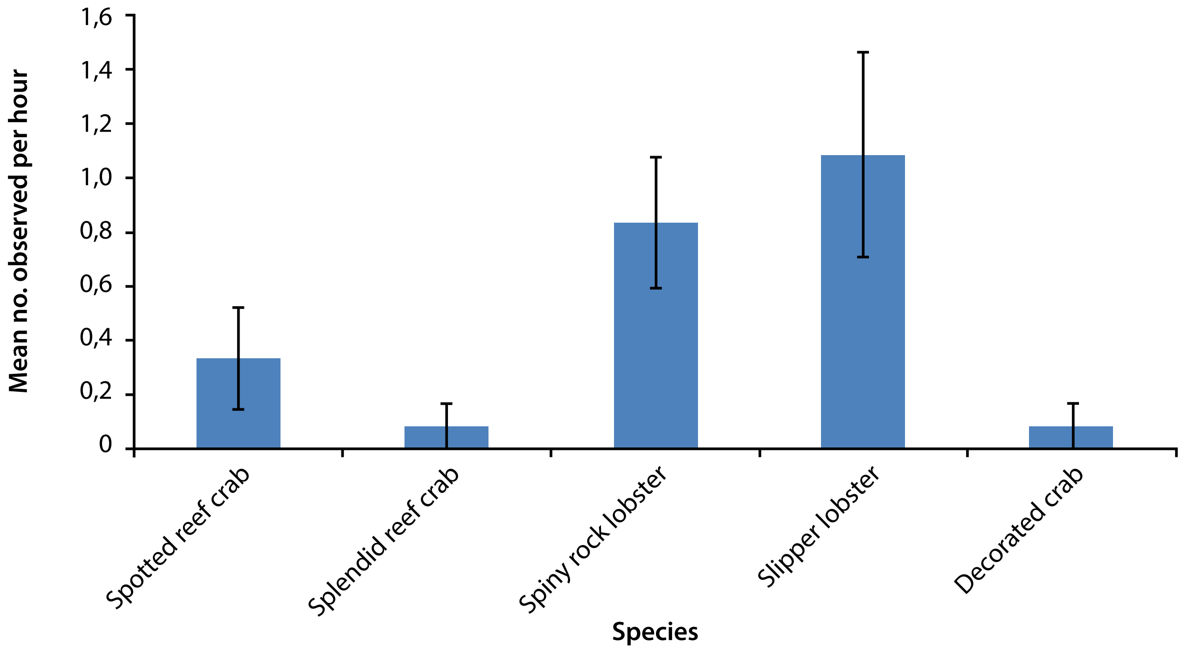

Figure 6. Mean number of crustaceans observed (± SE) during reef front timed swims at night in the present survey (2015).

Manta tow

During the manta tow surveys, four sea cucumber species were observed. Densities of three of these were below the reference densities indicative of healthy stocks (Table 7). Compared with the study by Vunisea et al. (2008), a considerable decline in the density of surf redfish was observed in 2015 relative to 2005 (Figure 7).

Table 7. Mean densities of sea cucumber species observed using manta tow in the current study, and the Pacific regional reference densities for healthy sea cucumber stocks (from Pakoa et al. 2014).

Common name	Scientific name	Overall mean density (individuals/ha)	Pacific reference density (individuals/ha)
Surf redfish	*Actinopyga mauritiana*	65.4	20
Deepwater blackfish	*Actinopyga palauensis*	0.3	NA
Lollyfish	*Holothuria atra*	0.0	2400
Flowerfish	*Pearsonothuria graeffei*	2.2	50
Prickly redfish	*Thelenota ananas*	0.9	10

Deep-water timed scuba searches

Six species of sea cucumber were observed during the deep-water timed scuba searches in the present study. Densities of all observed species were low (< 10 individuals/ha) (Table 8 and Figure 8), and well below reference densities for healthy stocks given by Pakoa et al. (2014). Few differences in density were observed between the results of the present study and those of Vunisea et al. (2008), with only the mean density of prickly redfish appearing much lower in 2015 relative to 2005 (Table 8 and Figure 8).

Table 8. Overall mean densities of sea cucumber species recorded during deep-water timed scuba in the current survey, and densities reported from the 2005 survey for comparison (Vunisea et al. 2008).

Common name	Scientific name	Overall mean density ± SE (individuals/ha)	
		2005 survey	Current survey (2015)
Deepwater blackfish	*Actinopyga palauensis*	–	0.6 ± 0.4
Leopardfish	*Bohadschia argus*	–	0.3 ± 0.3
Lollyfish	*Holothuria atra*	2.2 ± 1.0	–
Black teatfish	*Holothuria whitmeai*	0.7 ± 0.7	0.6 ± 0.6
Flowerfish	*Pearsonothuria graeffei*	3.2 ± 3.2	0.3 ± 0.3
Prickly redfish	*Thelenota ananas*	33.8 ± 28.1	5.4 ± 3.4
Amberfish	*Thelenota anax*	–	0.9 ± 0.9

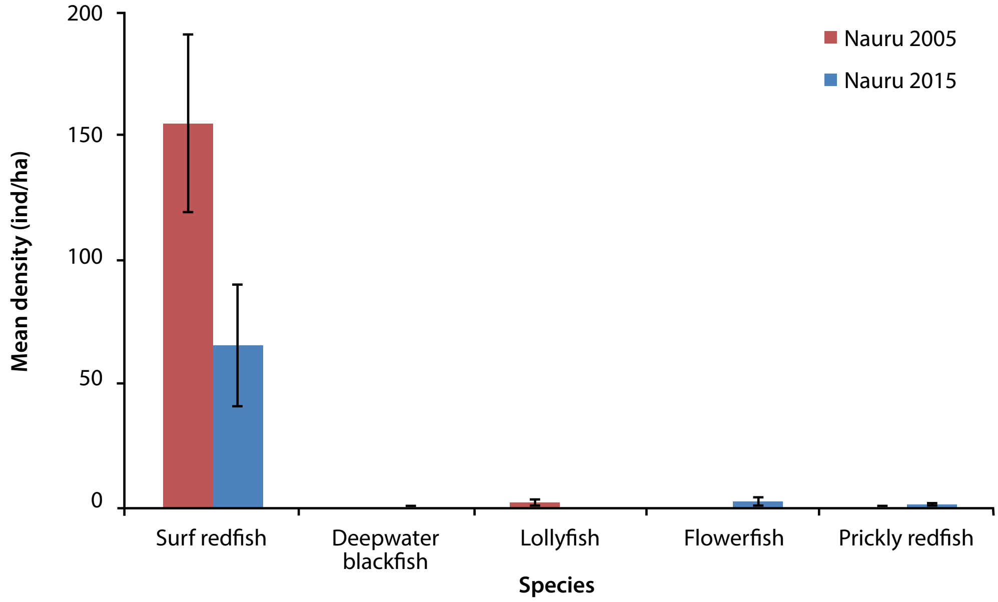

Figure 7. Overall mean densities (± SE) of sea cucumber species observed using manta tow in Nauru in 2005 (Vunisea et al. 2008) and in the present survey (2015).

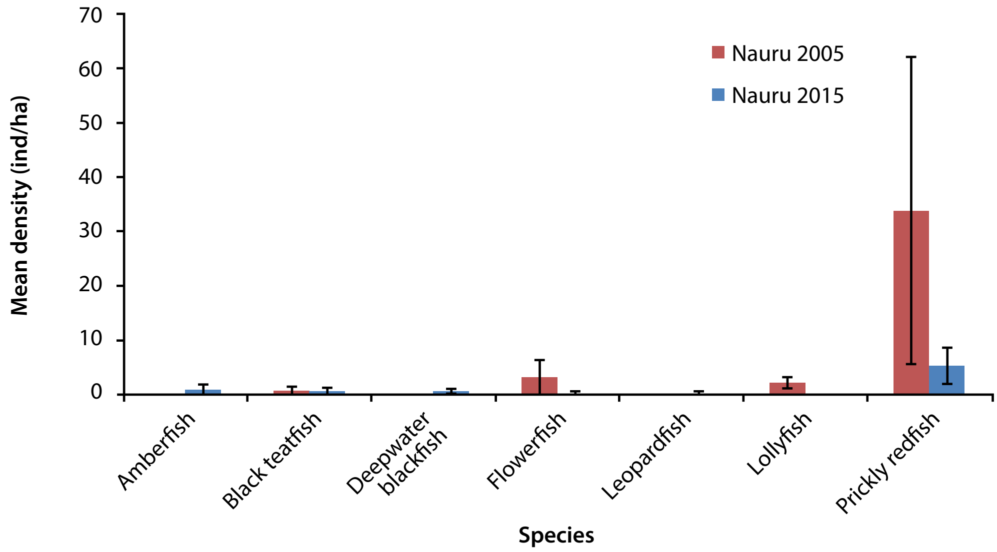

Figure 8. Overall mean densities (± SE) of sea cucumber species observed during deep-water timed scuba searches in Nauru in 2005 (Vunisea et al. 2008) and in the present survey (2015).

3.3. Species mean size and size frequency

Mean lengths for species with more than five individuals measured are presented in Table 9. For those species present in significant numbers (two sea cucumber species (*A. mauritiana and H. atra*) and three gastropod species (*R. armigera*, *Thais aculeata* and *Turbo setosus*)), the findings are discussed below.

Table 9. Mean lengths of species encountered.

Species group	Common name	Scientific name	Mean length ± SE ((mm	No. of specimens measured
Sea cucumber	Surf redfish	*Actinopyga mauritiana*	2.0 ± 203.4	290
	Lollyfish	*Holothuria atra*	0.8 ± 83.5	804
	Prickly redfish	*Thelenota ananas*	11.4 ± 450.8	6
Crustacean	Spotted reef crab	*Carpilius maculatus*	9.3 ± 104.1	7
	Slipper lobster	*Parribacus caledonicus*	7.6 ± 190.7	7
Gastropod	Soldier cone	*Conus miles*	1.5 ± 33.0	18
	Serpent's head cowrie	*Cypraea caputserpensis*	1.7 ± 29.4	7
	Humpback cowrie	*Cypraea mauritiana*	3.6 ± 67.0	23
	Money cowrie	*Cypraea moneta*	0.7 ± 20.8	24
	Tiger cowrie	*Cypraea tigris*	2.9 ± 69.0	12
	Purple drupe	*Drupa morum*	0.4 ± 23.1	15
	Belligerent rock shell	*Reishia armigera*	0.7 ± 62.2	188
	Aculeate rock shell	*Thais aculeata*	1.0 ± 44.4	108
	Silver mouthed turban	*Turbo argyrostomus*	2.5 ± 81.4	12
	Rough turban	*Turbo setosus*	1.7 ± 50.0	54

Surf redfish (Actinopyga mauritiana)

A total of 290 surf redfish were measured during the 2015 survey. The average size was 203 ± 2.0 mm. The most common length class was 201–210 mm (Figure 9). A total of 45 individuals were greater in length than the reported length of maturity (230 mm; Purcell et al. 2012) (Figure 9), equating to approximately 16% of the total number of surf redfish observed.

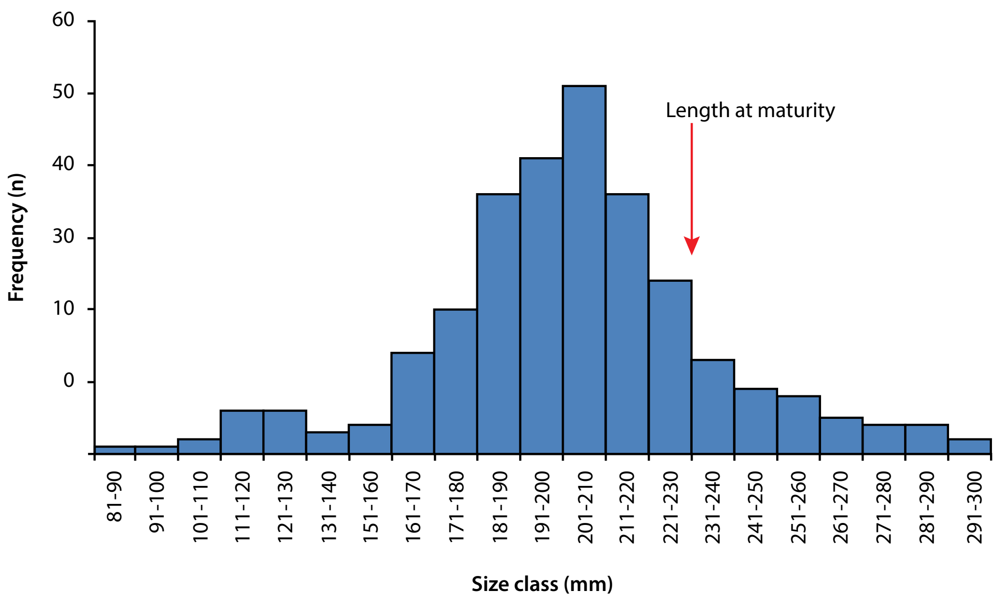

Figure 9. Size distribution of surf redfish (*Actinopyga mauritiana*).
The red arrow indicates reported length of maturity (from Purcell et al. 2012).

*Lollyfish (*Holothuria atra*)*

A total of 540 lollyfish were measured during the 2015 survey. The vast majority of these were small, with most individuals measuring less than 100 mm (Figure 10). The mean size was 83.5 ± 0.8 mm, while the most common length class was 81–90 mm (Figure 10).

To manage sea cucumber fisheries, many Pacific Island countries are imposing minimum legal harvest size limits. In Tonga for example, a minimum legal harvest size of 165 mm is in place. Approximately 1% of the lollyfish population in Nauru was over this size.

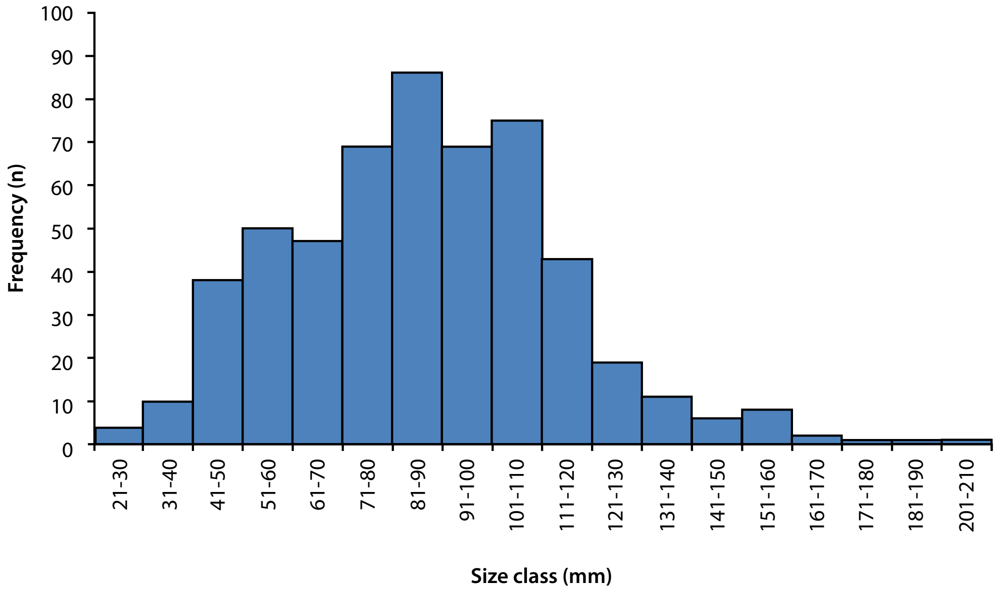

Figure 10. Size distribution of lollyfish (*Holothuria atra*).

*Belligerent rock shell (*Reishia amigera*)*

A total of 188 *Reishia amigera* were measured. The size ranged from a minimum 31 mm to a maximum 95 mm, with the most common size between 50 and 60 mm and mean size 62.2 ± 0.7 mm (Figure 11). At the time of writing there are no listed fishery status indicators for this species to enable comparison of the maximum length, size at maturity, or total count of sizes that are of mature age.

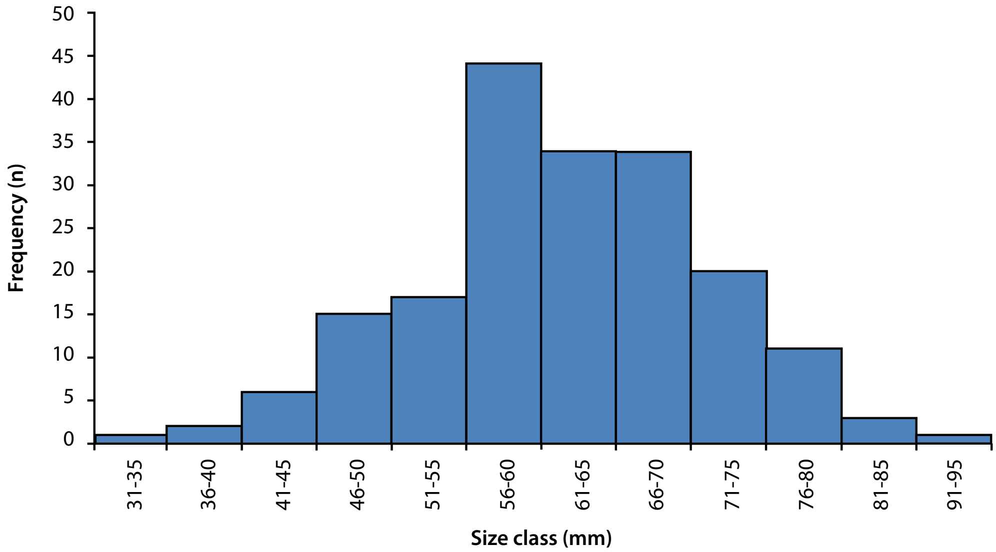

Figure 11. Size distribution of *Reishia amigera*.

*Aculeate rock shell (*Thais aculeata*)*

A total of 108 *Thais aculeata* were measured during the May 2015 surveys. The most common size encountered was within the 31–35 mm category, and the mean size was 44.4 ± 1 mm (Figure 12). Information on the species maximum length and size at maturity is not available to gauge the status of the population's size structure.

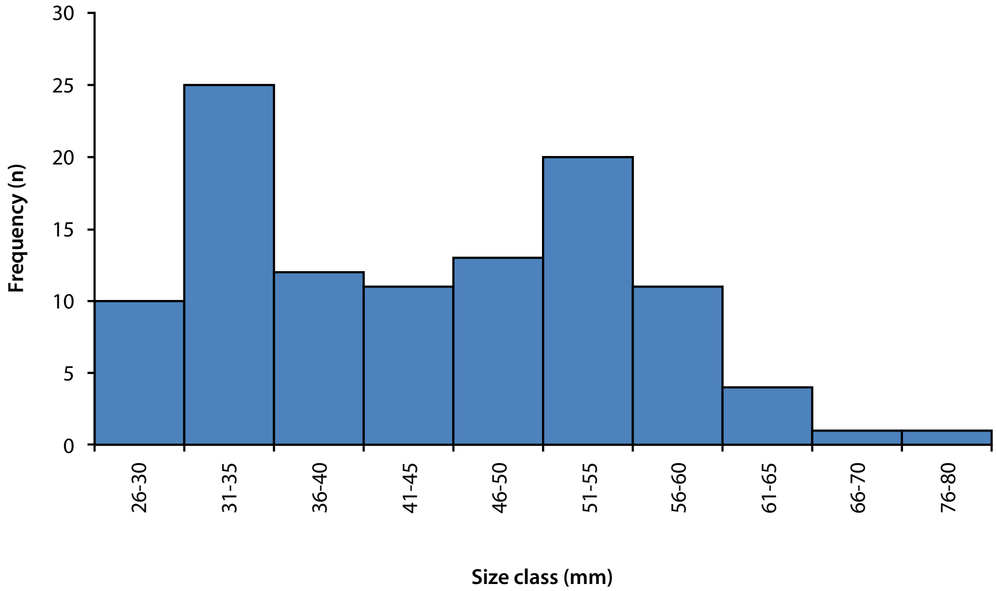

Figure 12. Size distribution of *Thais aculeata*.

*Rough turban snail (*Turbo setosus*)*

Turban snails are among the most targeted invertebrates found on the reef crest during low tide, which may be the cause for the depletion of the species. During the survey only 54 rough turban snails were measured, and the mean size was 50 ± 1.7 mm (Figure 13). This species can grow to a maximum length of 90 mm, which is significantly greater than the largest rough turban snails encountered in this study (71–75 mm).

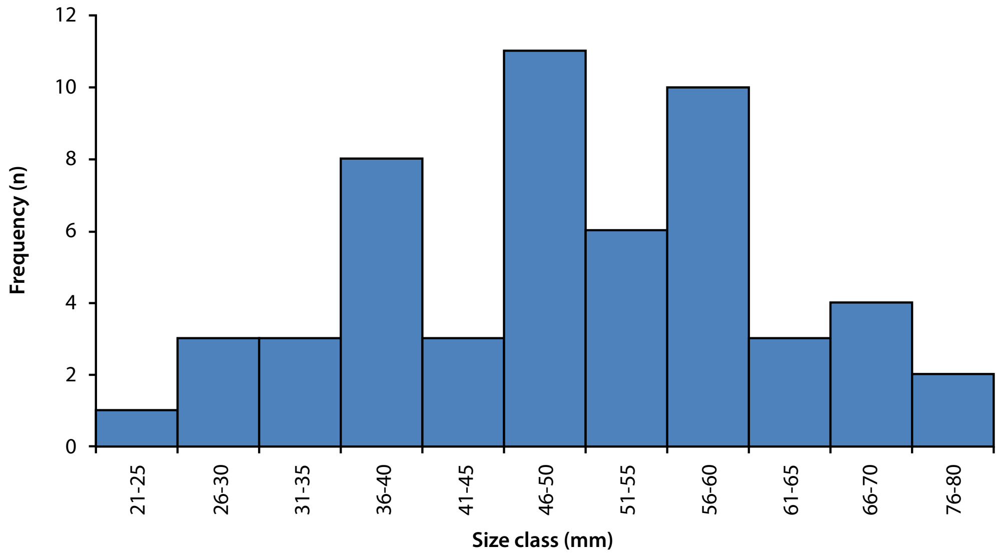

Figure 13. Size distribution of *Turbo setosus*.

4. Conclusions and recommendations

Coastal fisheries in Nauru have operated for many years with inadequate management. As a consequence, populations of coastal marine species, and particularly macroinvertebrates, have suffered.

The results of this assessment depict invertebrate stocks that are characterised by low population densities (low abundance) and small sizes. Accordingly, as a matter of priority and in the best interest of coastal communities, there is an urgency to develop a legal framework and introduce fisheries management initiatives (including community-based approaches) for the sustainable management of the fishery. Below are some recommendations for improved management of Nauru's reef invertebrate resources that could be developed into enforceable legal instruments or as actions in community resource management initiatives.

1. Prohibit exports of all invertebrate resources. Due to very low numbers of reef invertebrates and the small sizes (average lengths) observed, it is recommended that these limited resources be used for domestic purposes only rather than exporting overseas for commercial gain or for gifts.

2. Introduce a total ban on harvesting of giant clams. In the 2005 nationwide assessment, no giant clams were found. During the current study only three *Tridacna maxima* and one *Tridacna noae* were encountered. This group of bivalves is extremely vulnerable to extinction in Nauru, thus very tight measures are critical to ensure their survival.

3. Establish marine managed areas. By establishing and enforcing no-fishing areas, marine resources and habitats are protected from pressures of fishing. As a guide, it is recommended that networks or pockets of suitable reef habitat totalling 15–30% of the reef area are designated as no-fishing areas. The reserves provide refuge for over-harvested species and protection for mature and breeding populations whose recruits may settle in nearby reefs. No-fishing areas should comprise habitats with healthy densities of several marine species and be positioned where enforcement is effective. These areas should be clearly marked (signposted) and known to communities.

4. Impose restrictions on fishing gear. Harvesting or collecting of reef invertebrate should be restricted to hand picking, collecting by wading (reef walking) and free diving. All other methods of harvesting (e.g. using underwater breathing apparatus such as scuba) should be prohibited. Deeper areas inaccessible to wading or routine snorkelling (breath-hold diving) hold essential reservoirs of adult breeding stocks of some invertebrate species that are in danger of being over-harvested, and this measure will greatly reduce the fishing pressure on these species.

5. Implement minimum harvest sizes. To sustain populations, it is crucial to allow young and non-reproductive animals to reach sexual maturity and spawn for several seasons before they are caught. The recommended minimum harvest sizes are:

- turban snail (*T. setosus and T. argyrostomus)*: 60 mm shell length
- spiny rock lobster (*Panulirus penicillatus*): 100 mm carapace length
- slipper lobster (*Parribacus caledonicus*): 150 mm in total length when laid flat (from front edge of carapace to rear edge of telson (tail)).

6. Establish a monitoring programme and undertake regular monitoring of coastal resources. The quantity and sizes of coastal species caught should be monitored to assess the catch trends over time. Monitoring catch could be accomplished through creel or landing surveys. At minimum a survey could be done one day per week over a year. These sampling days should be randomly selected and should include both week and weekend days. To conduct population surveys we recommend a small selection of RBt stations (six), manta tow stations (six) and deep-water timed scuba search stations (six) be established around the fringing reef for permanent monitoring purposes and assessed every two years. This would allow follow-up surveys to be completed in less than one week. A large-scale assessment of the whole island could then be conducted every five years.

7. Improve education and awareness. Education and awareness programmes should explain the management approaches, why certain management measures are needed, and how to implement them. A public well informed on such information as coastal marine resources biology, life cycle, vulnerability, trends in catches, population status etc. are more likely to comply with management measures. The programmes should target all levels of society, from children to adults.

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Appendix 1. List of GPS waypoints for locations surveyed in this assessment

Station type	Station name	Replicate	Latitude (S)	Longitude (W)
Deep-water scuba search	Dive_1	NA	−0.52962	166.95433
Deep-water scuba search	Dive_5	NA	−0.51278	166.959692
Deep-water scuba search	Dive_2	NA	−0.543899	166.953246
Deep-water scuba search	Dive_3	NA	−0.541064	166.909948
Deep-water scuba search	Dive_4	NA	−0.500808	166.931876
Deep-water scuba search	Dive_6	NA	−0.49942	166.935456
Deep-water scuba search	Dive_7	NA	−0.509596	166.923897
Lobster night search	Lobster_1	1 start	−0.551383	166.943423
Lobster night search	Lobster_1	2 start	−0.55272	166.941948
Lobster night search	Lobster_1	3 start	−0.553858	166.940297
Lobster night search	Lobster_2	1 start	−0.555189	166.937176
Lobster night search	Lobster_2	2 start	−0.555646	166.935266
Lobster night search	Lobster_2	3 start	−0.55568	166.93375
Lobster night search	Lobster_3	1 start	−0.554122	166.923597
Lobster night search	Lobster_3	2 start	−0.553333	166.922045
Lobster night search	Lobster_3	3 start	−0.552518	166.920552
Lobster night search	Lobster_4	1 start	−0.549617	166.916114
Lobster night search	Lobster_4	2 start	−0.548729	166.914914
Lobster night search	Lobster_4	3 start	−0.547595	166.913871
Lobster night search	Lobster_5	1 start	−0.52511	166.909893
Lobster night search	Lobster_5	2 start	−0.524379	166.910272
Lobster night search	Lobster_5	3 start	−0.523276	166.910621
Lobster night search	Lobster_6	1 start	−0.516854	166.916647
Lobster night search	Lobster_6	2 start	−0.516181	166.917339
Lobster night search	Lobster_6	3 start	−0.515353	166.918095
Lobster night search	Lobster_7	1 start	−0.509744	166.923762
Lobster night search	Lobster_7	2 start	−0.508798	166.924485
Lobster night search	Lobster_7	3 start	−0.507896	166.925491
Lobster night search	Lobster_8	1 start	−0.500906	166.932128
Lobster night search	Lobster_8	2 start	−0.500138	166.93345
Lobster night search	Lobster_8	3 start	−0.499564	166.936133
Lobster night search	Lobster_9	1 start	−0.50027	166.940727
Lobster night search	Lobster_9	2 start	−0.500533	166.941948
Lobster night search	Lobster_9	3 start	−0.50058	166.944648
Lobster night search	Lobster_10	1 start	−0.503225	166.951624
Lobster night search	Lobster_10	2 start	−0.504088	166.953094
Lobster night search	Lobster_10	3 start	−0.504611	166.954013
Lobster night search	Lobster_11	1 start	−0.515571	166.960331
Lobster night search	Lobster_11	2 start	−0.517448	166.960716
Lobster night search	Lobster_11	3 start	−0.518865	166.960798
Lobster night search	Lobster_12	1 start	−0.527316	166.955212
Lobster night search	Lobster_12	2 start	−0.528682	166.95455
Lobster night search	Lobster_12	3 start	−0.529914	166.953766
Manta tow	Manta_1	1 start	−0.538133	166.951761

Station type	Station name	Replicate	Latitude (S)	Longitude (W)
Manta tow	Manta_1	2 start	–0.54079	166.95198
Manta tow	Manta_1	3 start	–0.543402	166.952801
Manta tow	Manta_1	4 start	–0.546063	166.951694
Manta tow	Manta_1	5 start	–0.547797	166.949346
Manta tow	Manta_1	6 start	–0.54915	166.947381
Manta tow	Manta_2	1 start	–0.551129	166.943851
Manta tow	Manta_2	2 start	–0.553135	166.941522
Manta tow	Manta_2	3 start	–0.554506	166.939185
Manta tow	Manta_2	4 start	–0.555463	166.936002
Manta tow	Manta_2	5 start	–0.555726	166.932872
Manta tow	Manta_2	6 start	–0.555676	166.930104
Manta tow	Manta_3	1 start	–0.554814	166.926708
Manta tow	Manta_3	2 start	–0.553759	166.923544
Manta tow	Manta_3	3 start	–0.552281	166.920368
Manta tow	Manta_3	4 start	–0.550926	166.917906
Manta tow	Manta_3	5 start	–0.54919	166.91576
Manta tow	Manta_3	6 start	–0.547456	166.913733
Manta tow	Manta_4	1 start	–0.544821	166.911411
Manta tow	Manta_4	2 start	–0.542433	166.910295
Manta tow	Manta_4	3 start	–0.539754	166.909444
Manta tow	Manta_4	4 start	–0.536731	166.908806
Manta tow	Manta_4	5 start	–0.533928	166.908659
Manta tow	Manta_4	6 start	–0.531066	166.90859
Manta tow	Manta_5	1 start	–0.528419	166.909037
Manta tow	Manta_5	2 start	–0.525759	166.909765
Manta tow	Manta_5	3 start	–0.523174	166.910927
Manta tow	Manta_5	4 start	–0.520966	166.912434
Manta tow	Manta_5	5 start	–0.519095	166.914307
Manta tow	Manta_5	6 start	–0.517121	166.916482
Manta tow	Manta_6	1 start	–0.514816	166.919087
Manta tow	Manta_6	2 start	–0.512664	166.921283
Manta tow	Manta_6	3 start	–0.510095	166.923455
Manta tow	Manta_6	4 start	–0.50814	166.925314
Manta tow	Manta_6	5 start	–0.505999	166.927205
Manta tow	Manta_6	6 start	–0.503969	166.929005
Manta tow	Manta_7	1 start	–0.501837	166.930691
Manta tow	Manta_7	2 start	–0.500018	166.934276
Manta tow	Manta_7	3 start	–0.499532	166.938189
Manta tow	Manta_7	4 start	–0.50045	166.941398
Manta tow	Manta_7	5 start	–0.500734	166.944396
Manta tow	Manta_7	6 start	–0.501398	166.947347
Manta tow	Manta_8	1 start	–0.502425	166.950084
Manta tow	Manta_8	2 start	–0.504024	166.952838
Manta tow	Manta_8	3 start	–0.505949	166.955322
Manta tow	Manta_8	4 start	–0.508423	166.957285

Station type	Station name	Replicate	Latitude (S)	Longitude (W)
Manta tow	Manta_8	5 start	−0.511129	166.958807
Manta tow	Manta_8	6 start	−0.514105	166.959832
Manta tow	Manta_9	1 start	−0.518123	166.960846
Manta tow	Manta_9	2 start	−0.521059	166.961108
Manta tow	Manta_9	3 start	−0.523249	166.959272
Manta tow	Manta_9	4 start	−0.525423	166.956834
Manta tow	Manta_9	5 start	−0.527951	166.95505
Manta tow	Manta_9	6 start	−0.531389	166.953341
Reef benthos transect	RBt_1	NA	−0.53391	166.95162
Reef benthos transect	RBt_2	NA	−0.54608	166.9502
Reef benthos transect	RBt_3	NA	−0.549321	166.944768
Reef benthos transect	RBt_4	NA	−0.55451	166.929497
Reef benthos transect	RBt_5	NA	−0.548976	166.916777
Reef benthos transect	RBt_6	NA	−0.538408	166.909589
Reef benthos transect	RBt_7	NA	−0.527112	166.909944
Reef benthos transect	RBt_8	NA	−0.520236	166.914218
Reef benthos transect	RBt_9	NA	−0.513519	166.921522
Reef benthos transect	RBt_10	NA	−0.505375	166.929133
Reef benthos transect	RBt_11	NA	−0.500799	166.936579
Reef benthos transect	RBt_12	NA	−0.501901	166.945172
Reef benthos transect	RBt_13	NA	−0.505482	166.953103
Reef benthos transect	RBt_14	NA	−0.512985	166.958375
Reef benthos transect	RBt_15	NA	−0.522521	166.958361
Reef benthos transect	RBt_16	NA	−0.527129	166.954348
Reef benthos transect	RBt_17	NA	−0.540105	166.950926
Reef benthos transect	RBt_18	NA	−0.543313	166.911514
Reef benthos transect	RBt_19	NA	−0.511416	166.923904
Reef front timed swim	RFs_1	1 start	−0.527692	166.955119
Reef front timed swim	RFs_1	2 start	−0.527761	166.954921
Reef front timed swim	RFs_1	3 start	−0.528154	166.954679
Reef front timed swim	RFs_2	1 start	−0.530219	166.953681
Reef front timed swim	RFs_2	2 start	−0.530817	166.953594
Reef front timed swim	RFs_2	3 start	−0.531556	166.953365
Reef front timed swim	RFs_3	1 start	−0.546702	166.951062
Reef front timed swim	RFs_3	2 start	−0.547178	166.950857
Reef front timed swim	RFs_3	3 start	−0.547423	166.950408
Reef front timed swim	RFs_4	1 start	−0.552791	166.941868
Reef front timed swim	RFs_4	2 start	−0.55331	166.94104
Reef front timed swim	RFs_4	3 start	−0.55365	166.94037
Reef front timed swim	RFs_5	1 start	−0.55406	166.93955
Reef front timed swim	RFs_5	2 start	−0.554442	166.938839
Reef front timed swim	RFs_5	3 start	−0.554788	166.937886
Reef front timed swim	RFs_6	1 start	−0.5553	166.92753
Reef front timed swim	RFs_6	2 start	−0.55503	166.92682
Reef front timed swim	RFs_6	3 start	−0.554831	166.925991

Station type	Station name	Replicate	Latitude (S)	Longitude (W)
Reef front timed swim	RFs_7	1 start	–0.55223	166.92023
Reef front timed swim	RFs_7	2 start	–0.551491	166.918552
Reef front timed swim	RFs_7	3 start	–0.550771	166.917737
Reef front timed swim	RFs_8	1 start	–0.546003	166.912233
Reef front timed swim	RFs_8	2 start	–0.5447	166.911373
Reef front timed swim	RFs_8	3 start	–0.543695	166.910818
Reef front timed swim	RFs_9	1 start	–0.537309	166.908985
Reef front timed swim	RFs_9	2 start	–0.535438	166.908607
Reef front timed swim	RFs_9	3 start	–0.534674	166.908551
Reef front timed swim	RFs_10	1 start	–0.523484	166.910384
Reef front timed swim	RFs_10	2 start	–0.521786	166.911359
Reef front timed swim	RFs_10	3 start	–0.520938	166.912277
Reef front timed swim	RFs_11	1 start	–0.515904	166.91762
Reef front timed swim	RFs_11	2 start	–0.515216	166.918522
Reef front timed swim	RFs_11	3 start	–0.514446	166.919436
Reef front timed swim	RFs_12	1 start	–0.511783	166.921816
Reef front timed swim	RFs_12	2 start	–0.510942	166.922611
Reef front timed swim	RFs_12	3 start	–0.510081	166.923446
Reef front timed swim	RFs_13	1 start	–0.508203	166.925215
Reef front timed swim	RFs_13	2 start	–0.507351	166.925893
Reef front timed swim	RFs_13	3 start	–0.506384	166.926805
Reef front timed swim	RFs_14	1 start	–0.500528	166.932636
Reef front timed swim	RFs_14	2 start	–0.500093	166.933859
Reef front timed swim	RFs_14	3 start	–0.500031	166.934081
Reef front timed swim	RFs_15	1 start	–0.500364	166.940405
Reef front timed swim	RFs_15	2 start	–0.500396	166.941256
Reef front timed swim	RFs_15	3 start	–0.500558	166.941844
Reef front timed swim	RFs_16	1 start	–0.500953	166.945751
Reef front timed swim	RFs_16	2 start	–0.501107	166.946646
Reef front timed swim	RFs_16	3 start	–0.501343	166.94746
Reef front timed swim	RFs_17	1 start	–0.503744	166.952295
Reef front timed swim	RFs_17	2 start	–0.504191	166.952989
Reef front timed swim	RFs_17	3 start	–0.50513	166.954285
Reef front timed swim	RFs_18	1 start	–0.515043	166.960336
Reef front timed swim	RFs_18	2 start	–0.515777	166.960489
Reef front timed swim	RFs_18	3 start	–0.516596	166.960665
Reef front timed swim	RFs_19	1 start	–0.539247	166.951802
Reef front timed swim	RFs_19	2 start	–0.540072	166.951895
Reef front timed swim	RFs_19	3 start	–0.540772	166.95192
Reef front timed walk	RFw_1	1 start	–0.535362	166.951429
Reef front timed walk	RFw_1	2 start	–0.53439	166.951641
Reef front timed walk	RFw_1	3 start	–0.533413	166.951942
Reef front timed walk	RFw_2	1 start	–0.543044	166.91121
Reef front timed walk	RFw_2	2 start	–0.543954	166.911658
Reef front timed walk	RFw_2	3 start	–0.544717	166.912038

Station type	Station name	Replicate	Latitude (S)	Longitude (W)
Reef front timed walk	RFw_3	1 start	−0.50208	166.94677
Reef front timed walk	RFw_3	2 start	−0.50173	166.94584
Reef front timed walk	RFw_3	3 start	−0.50144	166.94497
Reef front timed walk	RFw_4	1 start	−0.50137	166.94359
Reef front timed walk	RFw_4	2 start	−0.50131	166.94267
Reef front timed walk	RFw_4	3 start	−0.50119	166.94166
Reef front timed walk	RFw_5	1 start	−0.500295	166.938186
Reef front timed walk	RFw_5	2 start	−0.500402	166.936946
Reef front timed walk	RFw_5	3 start	−0.50035	166.936079
Reef front timed walk	RFw_6	1 start	−0.510115	166.924392
Reef front timed walk	RFw_6	2 start	−0.510807	166.923522
Reef front timed walk	RFw_6	3 start	−0.511576	166.922863
Reef front timed walk	RFw_7	1 start	−0.513779	166.920854
Reef front timed walk	RFw_7	2 start	−0.51478	166.919928
Reef front timed walk	RFw_7	3 start	−0.515831	166.918781

[1] Calculated using an estimated search area of 141 m × 2.5 m (from Pakoa et al. 2014).

[2] Calculated using an estimated search area of 137 m × 3.5 m (from Pakoa et al. 2014).

[3] Calculated using an estimated search area of 137 m × 3.5 m (from Pakoa et al. 2014).

[4] Calculated using an estimated search area of 126 m × 6 m (from Pakoa et al. 2014).

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