Status of the coconut crab *Birgus latro* in Niue

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Status of the coconut crab *Birgus latro* in Niue

by

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Contents

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Acronyms

CL	cephalothoracic length
CPUE	catch per unit of effort
DAFF	Department of Agriculture, Forestry and Fisheries
DNA	desoxyribonucleic acid
GPS	Global Positioning System
ha	hectare(s)
kg	kilogram(s)
km	kilometre(s)
km^2	square kilometre(s)
m	metre(s)
m^2	square metres
mm	millimetre(s)
P	a statistical value that indicates the strength of evidence for and against a parameter
PCF	primary coastal forest
PERMANOVA	permutational analysis of variance
PIF	primary interior forest
QGIS	Quantum Global Information System
R^2	a statistical value that indicates the strength of the relationship between variables
SCF	secondary coastal forest
SciCOFish	Scientific Support for the Management of Coastal and Oceanic Fisheries in the Pacific Islands region
SE	standard error
SIF	secondary interior forest
SPC	Pacific Community
STDEV	standard deviation
TL	thoracic length

Summary

The vulnerability of coconut crabs (*Birgus latro*) to predation by humans and animals, their slow population growth rates and their ease of capture by hunting, as well as reductions of coastal habitats, have contributed to the decline and disappearance of coconut crabs in many islands in the Pacific region. The coconut crab is an iconic species to Niue; it is hunted for local consumption and sale; it is used in celebrations; it is exported to Niuean's living abroad; and it supports a growing eco-tourism sector.

This report presents the results of coconut crab resource assessments in Niue in November 2014; it provides management recommendations, suggestions for further research and resource monitoring protocols for future assessments. In addition, it presents experiences and perceptions of coconut crab hunters shared by community members and estimates coconut crab exports for 2014. The main objective of the assessment was to gather information to determine relative abundance, size structure and distribution of the coconut crab population in Niue.

In total, 30 stations were assessed in three forest regions, 0–1 km coastal, 1–2 km coastal and the interior region (>2 km from the coastline) using baited coconut trails. In Niue, during the pre-summer period, (September to November) coconut crab catch per unit of effort (CPUE) progressively decreases by 77% from the 0–1 km coastal region to the 1–2 km region and to the interior region. Key findings indicate that there was a greater abundance of coconut crabs in 2014 compared to previous studies, but the coconut crab population size structure has remained reasonably stable over the past two decades, with small average and maximum sizes for female and male coconut crabs. For the 0–1 km coastal region the current study estimated 1.51 crabs per coconut bait, in 1990 the catch per unit of effort was 0.38 for the coastal forest region. Similarly, for the 1–2 km region, the current CPUE estimate of 0.36 is around four times greater than the 1990 study.

There is a general absence of large crabs, with only 4.3% of measured crabs larger than 45 mm thoracic length (TL) and 1.9% larger than 50 mm TL. Seventeen per cent of crabs recorded (both male and female) were larger than the current minimum harvest size limit of 36 mm TL, but only 2% of females recorded were above the minimum harvest size. There is a slight decrease in the average size of male and female crabs recorded in this study compared to 1990. Small average sizes and the lack of large crabs in a population is consistent with heavy harvesting pressure.

In an effort to quantify coconut crab exports, departing aircraft passengers and their baggage/cargos were monitored for some flights between March 2014 to January 2015. From this monitoring we estimate that around 9,350–9,850 crabs were sent abroad over the sampling period. The study was not able to quantify domestic sale and consumption of coconut crabs.

Schiller (1991) made sound recommendations for the management of coconut crabs in Niue; most of the recommendations are still valid. To improve the management of this important resource, a series of management actions are outlined in Section 5 of this report and summarised as follows:

- improve education and awareness;
- establish seasonal and area closures when crabs are reproductively active;
- establish coconut crab reserves;
- ban or control coconut crab exports;
- increase minimum size limit or protect female crabs from harvest;
- control predators; and
- establish a monitoring programme.

1. Introduction

1.1 Biology

The coconut crab, *Birgus latro*, is a terrestrial crustacean related to the hermit crab. It belongs to the family Coenobitidae (Fletcher 1993). It is the largest of all land crabs and is slow growing, living in excess of 40 years and attaining weights of up to 4 kg (Fletcher et al. 1991). Coconut crabs are found on tropical islands from the Seychelles in the Indian Ocean to the Tuamotu Archipelago in the Pacific Ocean (Fletcher 1993) (Fig. 1). The colour of coconut crabs varies from light violet to deep blue, black, brown to red / orange.

Figure 1. Distribution of coconut crab (re-drawn from Fletcher 1993).

Coconut crabs have separate sexes. During mating, the male transfers sperm packets (spermatophores) to the underside of a female. A few weeks later, the female releases her eggs, which are fertilised as they pass over the spermatophores and form a spongy, orange to dull grey / brown egg mass under the female's body. Helfman (1973) reports that females carry between 51,000 to 138,000 eggs. This range is dependent on the size of the females; larger females carry more eggs than smaller females. Schiller et al. (1991) suggest that females produce one batch of eggs a year. The egg-bearing females migrate towards the shore-line and release the fertilised eggs into the sea at night during high tides. The fertilised eggs hatch into tiny larvae, which settle on shore after about one to two months at sea (Fig. 2). The settled juveniles enter an empty sea-snail (gastropod) shell which they discard around a year later (Hams [1932] and Reese [1968], cited in Brown and Fielder 1991). Of the many eggs released, only a very small proportion (>0.1%) grow to reproductive maturity (SPC 2011).

Coconut crabs shed their hard exoskeleton (moult) in order to grow. Prior to each moult, they burrow underground. It takes between one and four months for a new shell to harden (Fletcher et al. 1991). During this period, the crab is vulnerable so it stays hidden underground for protection. On Niue, local hunters report that crabs burrow to moult throughout the year, with burrowing more frequent during the dry winter months (May–August). Very little is known about the behaviour of juvenile crabs due to their cryptic nature after they have settled along coastlines. Adult coconut crabs shelter alone in burrows, under ledges, rock crevices and holes in rocks or logs in coastal forest regions (Schiller 1992). Coconut crabs generally remain hidden during the day and come out at night to forage for food. They are omnivorous, eating leaves, fallen fruits, berries and nuts, as well as other crabs and small animals (SPC 2011).

Coconut crabs are capable of reproducing at approximately five or six years of age (Schiller et al. 1991). They are very slow growing; with males attaining larger sizes than females. It takes around eight or nine years for a male crab to reach the Niue minimum harvest size of 36 mm thoracic length, while females take around 13–14 years to reach the minimum harvest size.

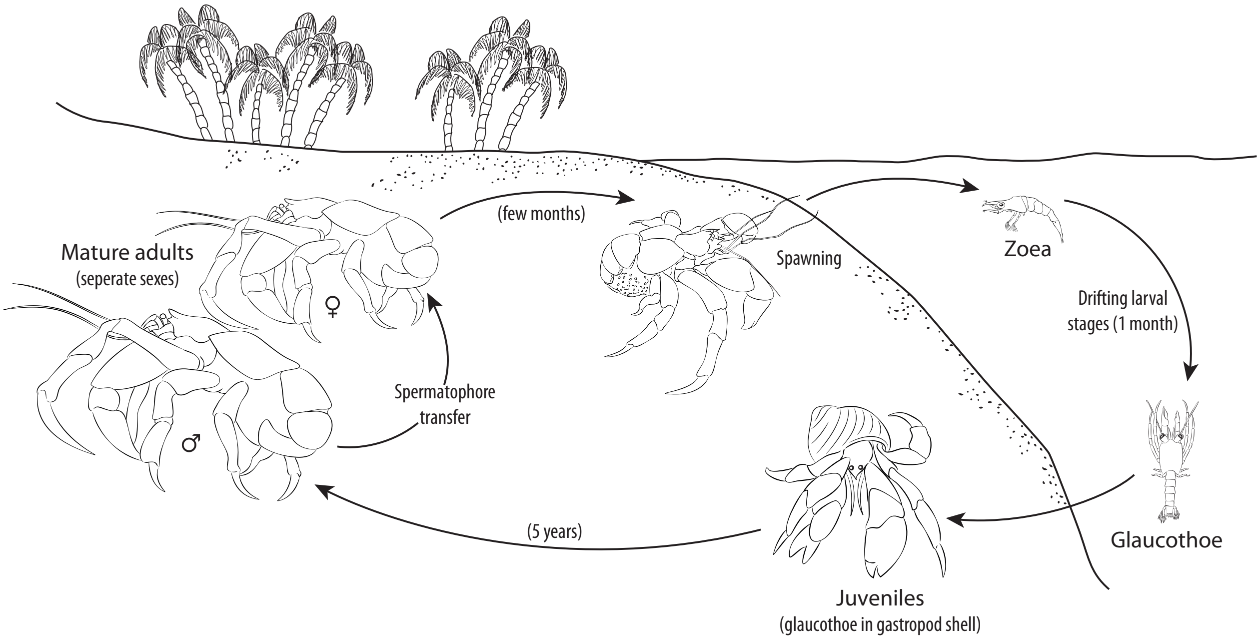


Figure 2. Life cycle of coconut crab (Source: SPC 2011).

1.2 Cultural and socioeconomic importance of coconut crabs to Niue

Niue is situated at 19.00°S–169.00°W and is a remote, uplifted coral island with a narrow fringing reef at the foot of rugged cliffs. The island has two terraces, the lower being 28 m and the upper 70 m above sea level. Niue has many caves and rocky coves. Much of the coastal region is covered in primary and light/scattered forest, and the interior is dominated by forest and fern land. Its land area is 259 km^2 and its exclusive economic zone is 350,000 km^2. Being a self-governing state in free association with New Zealand, Niuean nationals are New Zealand citizens, able to travel freely between the two countries. In 2011 the Niue population was approxcimately 1,600 (Government of Niue 2011).

The coconut crab is an iconic species in Niue and a local delicacy, eaten regularly and used in celebrations. It is hunted for domestic sale and for export to Niueans living abroad, and supports a growing eco-tourism sector, where visitors take guided tours to view crabs in natural habitats. To catch coconut crabs, hunters set baits of coconuts split in half or a whole coconut with a small wedge cut out. This bait is fastened to a tree root or limestone coral. Half coconuts are generally used when crabs are needed at short notice. Whole coconut with a small wedge removed are set and revisited regularly for up to three weeks. Hunters revisit baits at various times of the night with torches or head lamps. In general, they prefer to search baited trails in the forest during periods of light rain and wind conditions, due to perceived higher catches at these times. Crabs are also dug directly from burrows, although locating crabs underground requires considerable experience. Hunters may use dogs to assist them in searching for crabs and vehicles are now also being used to search for crabs at night on and alongside roads.

The vulnerability of coconut crabs to predation by animals such as feral pigs, their ease of capture and their slow population growth rate, as well as the reduction of coastal habitats, have contributed to the decline and disappearance of coconut crabs in many islands (SPC 2011).

1.3 Previous studies

Estimates of coconut crab populations using the mark and recapture method have been made on a number of small islands, but on large islands (such as Niue) recapture rates are too low for reasonable estimates to be made (Schiller 1992). Quadrats and transects of known sizes have been used to estimate coconut crab density and abundance on small islands (e.g. Christmas Island in the Indian Ocean and Tokelau in the Pacific) (Schiller 1992; Pasilio et al. 2013). However, this method is not appropriate for assessing crabs on large islands with a rugged, forested landscape, such as Niue. To overcome the problem of assessing coconut crabs on large islands, Fletcher and Amos (1994) quantified the relationship between the relative abundance (number of crabs caught per bait set) and the density through the calculation of a catchability coefficient in the form of a conversion factor. The conversion factor was determined from experiments in Venua Island, Vanuatu, where a catch per unit of effort (CPUE) of one crab per bait corresponded to a population density of 12,000 crabs per square kilometre. This conversion factor relates to CPUE data collected during the wet season, using baits set at locations where crabs are likely to be found. This method has been used to estimate coconut crab stocks in various parts of Vanuatu and previously in Niue, and it is likely that it could be applied equally, but with caution, to crab stocks in areas with a coastal landscape similar to that of Venua Island (Schiller 1992; Fletcher and Amos 1994; Pakoa et al. 2014).

A search of literature located three previous studies of Niue's coconut crab population. Schiller (1992) reports studies on Niue coconut crab in 1988 and 1990. Data from an unpublished coconut crab study in the Huvalu Forest Conservation Area in 1997[1] was provided by the Niue Department of Environment and a draft report of a study into the Niue coconut crab population in 2008 was also located (Barnett et al. 2008[2]).

The 1990, 1997 and 2008 surveys each used baited stations to estimate catch per unit of effort (CPUE), i.e. the number of crabs per coconut bait. CPUE estimates from surveys in the early 1990s ranged from 0.01 crabs per bait in the interior region to 0.38 crabs per bait in the coastal forest region (Schiller 1992). In 1997 CPUE ranged from 0.15 to 1.47 with an average of 0.71 from 11 baited stations within the Huvalu conservation area (unpublished data). In 2008 the average CPUE was 0.25 coconut crabs per bait for all transect and forest types (calculated from Barnett et al. 2008). To obtain density and abundance estimates, Schiller (1992) applied the Vanuatu conversion factor to CPUE estimates determined from surveys in Niue during1990, while Barnett et al. (2008) applied half the Vanuatu conversion factor to CPUE estimates derived from the assessment in Niue in 2008. Schiller (1992) estimated a population size of 181,440 individuals, while Barnett et al. (2008) estimated a population size of 213,680 individuals, but cautioned an uncertainty value of 50% in this estimate. If Barnett et al. (2008) had used the Vanuatu conversion factor of CPUE of one coconut crab per bait equals 12,000 crabs per square kilometre, the population estimate would have been 427,360.

Gathering data on hunting practices, landings and exports provides useful information for assessing catch and production trends. We were unable to locate any reliable time series information on the quantity of coconut crabs caught or consumed in Niue. However, from sporadic assessments on export quantities during June 1987 to March 1988 and September/October 2008, estimates of annual coconut crab exports were 3,200–5,900 and 13,500 respectively (Schiller 1992; Barnett et al. 2008).

[1] A survey of coconut crabs was done in 1997 for the Niue Environment Department but the findings of the survey were not published. They are, nonetheless, an important source of information.

[2] Unfortunately, the draft report was never published, but the authors of this current study feel justified in citing the findings of Barnett et al. (2008).

The coconut crab population in Niue during the early 1990s was small, dominated by small crabs (<32 mm thoracic length) (Schiller 1992). Schiller assumed that this small coconut crab population in the early 1990s was due to the export of large numbers of coconut crabs overseas. Barnett et al. (2008) reported improvements in the relative abundance and size structure of Niue's coconut crab population, which they attributed to greater public awareness and the introduction of conservation and management measures after the assessment in the early 1990s.

1.4 Management

Recruitment of juvenile coconut crabs is dependent on having healthy spawning biomass (i.e. good numbers of crabs capable of spawning) and favourable habitats for recruitment and foraging. Coconut crab larval survival and recruitment to the Niue population depend on the mercy of oceanic currents and this is beyond the control of humans. The species' slow growth, extended longevity, erratic recruitment, and dependence on suitable habitats make coconut crabs highly susceptible to over exploitation, even at light to moderate levels of exploitation. It is therefore important to ensure that coconut crabs remain abundant in Niue; their collapse would have negative consequences to biodiversity, crab population distribution and, most importantly, traditional and socioeconomic aspects of life in Niue.

Minimum harvest sizes have been used to control coconut crab exploitation in many Pacific Islands, with minimum size limits varying by country. Solomon Islands and Vanuatu have minimum cephalothoracic lengths (CL) of 90 mm, while Wallis and Futuna and Niue impose a minimum size limit of 36 mm thoracic length (TL) (SPC 2005). Vanuatu also uses no taking of egg-bearing females, open and closed hunting seasons and annual harvest quotas. In Vanuatu, quotas are determined for a province and this annual quota is subdivided by council areas/islands within a province. In Tokelau, coconut crabs from Nukunonu and Fakaofo are prohibited from export and harvesting is prohibited on some reef islets (*motu*), feral pigs are also eradicated (Pasilio et al. 2013). Export permits are required in Solomon Islands to export crabs (SPC 2005). In Manihiki (Cook Islands), coconut crabs can only be consumed on the island; it is prohibited to export coconut crabs.

The Niue Fishing Regulations 1996 prohibits the export of coconut crabs in any form without the written approval of Cabinet during the period 1 December to 28 February each year. This regulation was amended in February 2015, prohibiting the export of coconut crabs from Niue during any period unless there is written approval of Cabinet. Section 4 (2) of the 1996 regulations prohibits the interference, taking or killing of coconut crabs with a thoracic length of less than 36 mm. The Niue Fisheries Act 1996 reinforces this regulation by prohibiting the interference, taking or killing of individuals in berry, and/or with soft shell. Unfortunately, enforcement is difficult so management has focused largely on education through the coconut crab life cycle poster, handing out thoracic length measuring tools, and sporadic monitoring at the market and during village show days. The Huvalu forest conservation area has a section of it protected as a sacred (*tapu*) area where no person can enter.

1.5 Purpose of assessment

The main objective of this assessment was to gather information on the population size structure and distribution and to provide a relative estimate of abundance of coconut crabs on Niue. This study endeavoured to determine if any changes in population structure had occurred since the first surveys of coconut crabs in Niue during the late 1980s and early 1990s and the unpublished results of the survey in the late 1990s and the one in 2008. Secondary objectives were to train local staff of the Department of Agriculture, Forestry and Fisheries (DAFF) in coconut crab assessment methods and to develop survey protocols so that DAFF would be able to conduct future assessments of the coconut crab population on Niue. The information gathered will also be used for informing coconut crab resource management in Niue.

2. Methods

2.1 Population survey

Sampling design

Surveys of Niue's coconut crab population took place in November 2014. The timing of the survey coincided with the dark phase of the moon and was conducted during the summer wet season, as this is the period when coconut crabs emerge from under the ground to begin foraging and migration towards the coastline. Based on local knowledge and findings by Schiller (1992), the distribution of coconut crabs on Niue is not random. It is a function of the distance from coastline and vegetation. For these reasons the Niue land area was divided into the following regions:

- coastal region 1: the area within one kilometre of the coastline;
- coastal region 2: the area between one and two kilometres from the coastline; and
- interior region: the area two kilometres or more from the coastline.

These three regions were further divided into two vegetation categories:

- primary forest; and
- light/scattered forest.

This produced six habitat categories where assessments were completed.

1. 1 km from coastline, primary forest
2. 1 km from coastline, light/scattered forest
3. 1–2 km from coastline, primary forest
4. 1–2 km from coastline, light/scattered forest
5. Interior, primary forest
6. Interior, light/scattered forest

To avoid unnecessary disruption to local communities, residential areas were not assessed. Neither were coastal and interior fern-lands, where the environment is hot with low humidity, as this vegetation category provides very poor habitat requirements for coconut crabs. The limestone pinnacle areas (particularly on the eastern portion of the island) were also not assessed due to the very rugged terrain, a habitat rather hostile to surveyors. And the *tapu* areas were not sampled out of respect for traditional cultures.

The areas for the six habitat categories assessed and the habitats that were not assessed were determined using Quantum Global Information System (QGIS) software by Richard Siataga of the Niue Justice Department.

The number of baited stations assessed in each zone and vegetation category was based on:

- the relative size of the zone and vegetation category, in relation to the total area of Niue; and
- the high likelihood of crabs being found.

Greater sampling effort was applied to the regions where coconut crabs were most likely to be encountered (i.e. the region within one kilometre from the coastline). Some bait stations were placed within the general location assessed by Schiller (1992) and Barnett et al. (2008) and other bait stations were redistributed so that there was a spread of sample areas over the regions and vegetation categories.

Bait stations and assessing coconut crabs

The survey method was the same as that used by Schiller (1992), Barnett et al. (2008) and other assessments in Vanuatu. Unhusked coconuts were split in half and each half formed a bait. During bait station preparation, a path of relative least resistance within the forest was selected. Ten baits (half coconuts) were positioned on each bait station within the 0–1 and 0–2 km coastal regions and 15 baits for each baited station in the interior region. However, on some bait trails, additional baits were added by some surveyors. At each bait station, baits were spaced between 20 and 40 metres apart and tethered securely to trees, strong roots or limestone coral. Brightly coloured ribbons were tied to fixtures near baits to assist in relocating baits at night (Fig. 3). Various bait station patterns were set, but generally in a horse shoe or U-shaped configuration (Fig. 4). Three bait trails were cleared and baits set each afternoon of the survey. Each bait station was baited between 12:00 p.m. and 2:30 p.m. and GPS positions were taken at the start and end of each bait trail. All bait stations were checked approximately one hour after sunset on the day the bait was set (Table 1). When revisiting baited trails to search for crabs, crabs encountered either at the bait or on the trail were measured.

Figure 3. Half coconut baits tethered to secure forest structures (indicated by dashed grey circle) with bright coloured ribbon to assist in relocating baits at night (A). Crab on coconut bait (B).

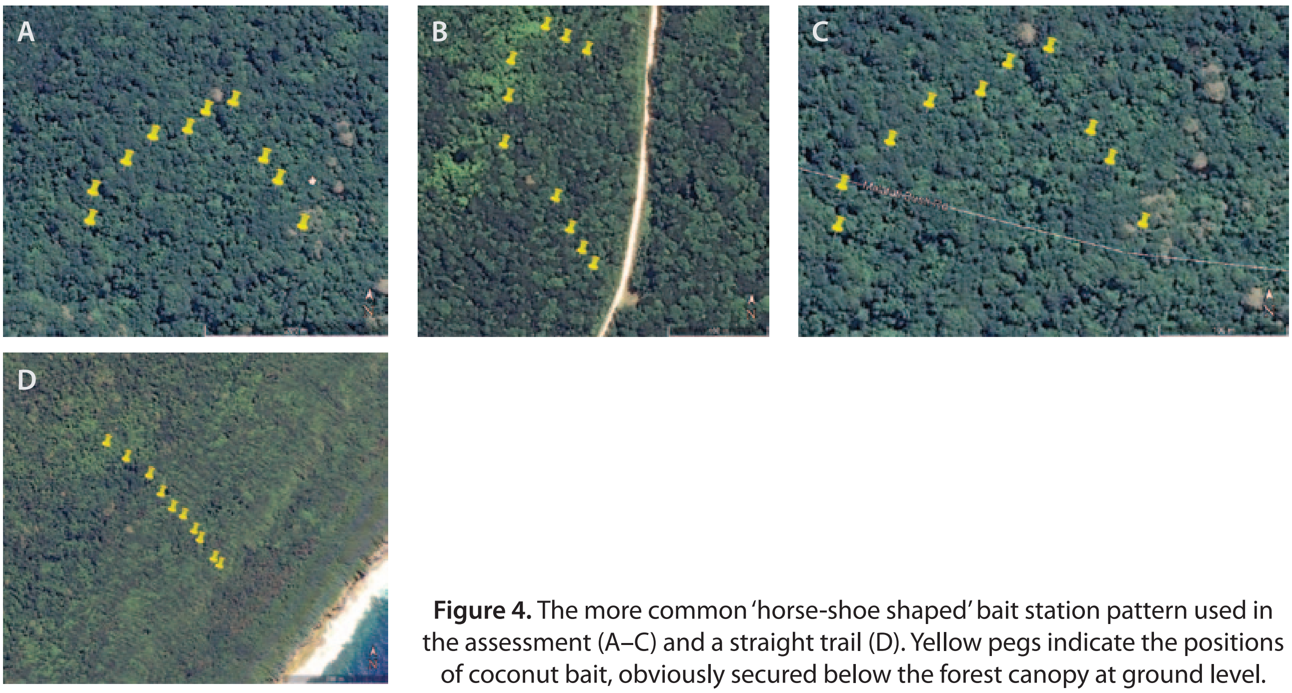


Figure 4. The more common 'horse-shoe shaped' bait station pattern used in the assessment (A–C) and a straight trail (D). Yellow pegs indicate the positions of coconut bait, obviously secured below the forest canopy at ground level.

In addition, two hunters' hypotheses regarding CPUE were tested. The first examined whether more crabs are found on a bait the evening after baits are set than on the evening they are set. For this, six bait stations were surveyed twice to determine if there was a difference in the CPUE (Table 1).

The second test examined the hypothesis that more crabs and larger crabs are found on baits in the early morning (before daylight) the day after baits are set compared to the evening when baits are set (Table 1).

Table 1. Time of searching bait stations.

Time of searching bait stations	Reason	Bait stations
Revisiting and searching baited stations an hour after dark on the evening of setting baits	General assessment – to examine CPUE and collect information for morphometric analyses	All (bait stations 1–30)
Revisiting and searching baited stations an hour after dark a day after baits were set	To test hunters' theory: more crabs are found on baits when bait trails are revisited a day after placing baits	6 (bait stations 1, 2, 3, 4, 5, 6)
Revisiting and searching baited stations at 3 a.m. the morning after the baits were set	To test hunters' theory: more and larger crabs are found on baits when bait trails are revisited during early morning	6 (bait stations 10, 11, 12, 13, 14, 30)

Three teams of three surveyors set baits during afternoons and conducted night searches for coconut crabs with torches, head lamps, and measuring and recording instruments. A lead crab searcher would scan up to four metres each side of the baited trail and collect coconut crabs, a second surveyor measured thoracic (TL) and cephalothoracic (CL) lengths and determine sex and dominant colour, and a third person was dedicated to weighing the crabs and recording all morphological information (Figs 5, 6 and 7). Crabs were released after the morphological information was recorded. Lengths were recorded by callipers to the nearest millimetre and weights were recorded by digital scale to the nearest ten grammes. The crabs were placed in a bucket during weighing. Female crabs were identified by the egg-carrying appendages beneath the abdomen (Fig. 6). The following colour variations, blue (*uga lanu*), brown (*uga kaki*), purple (*uga lanu uhiuhi*), black (*uga uli*) and red (*uga pomea*) were recorded, based on the dominant colour of a crab (Fig. 7). GPS positions and the number of baits at each station were also recorded.

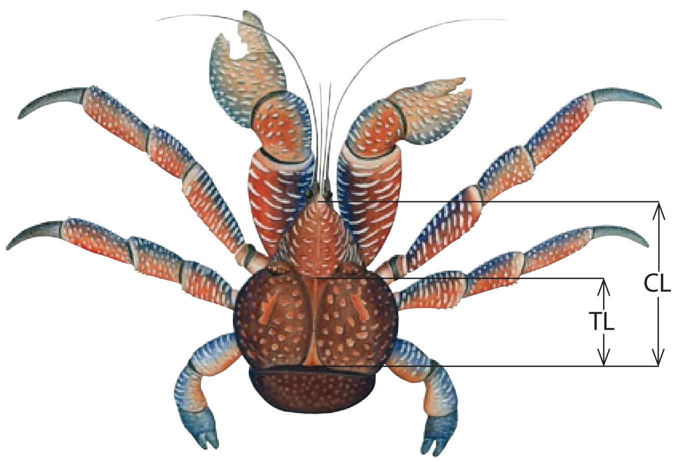
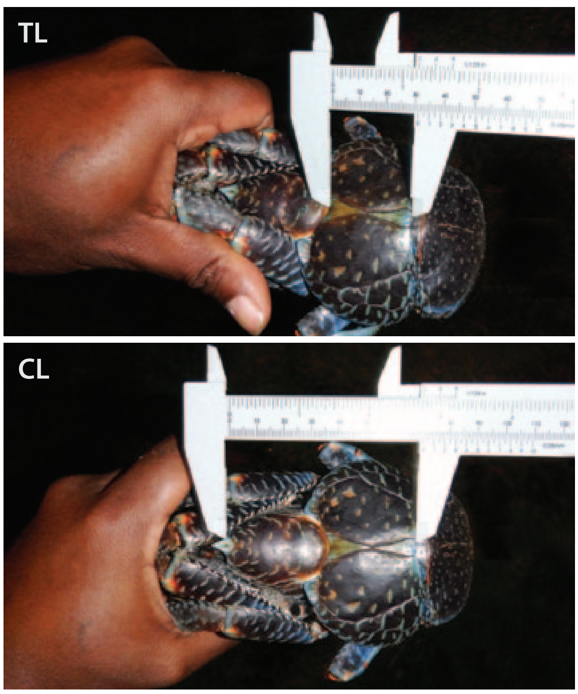


Figure 5. Coconut crab thoracic (TL) and cephalothoracic (CL) length measures.



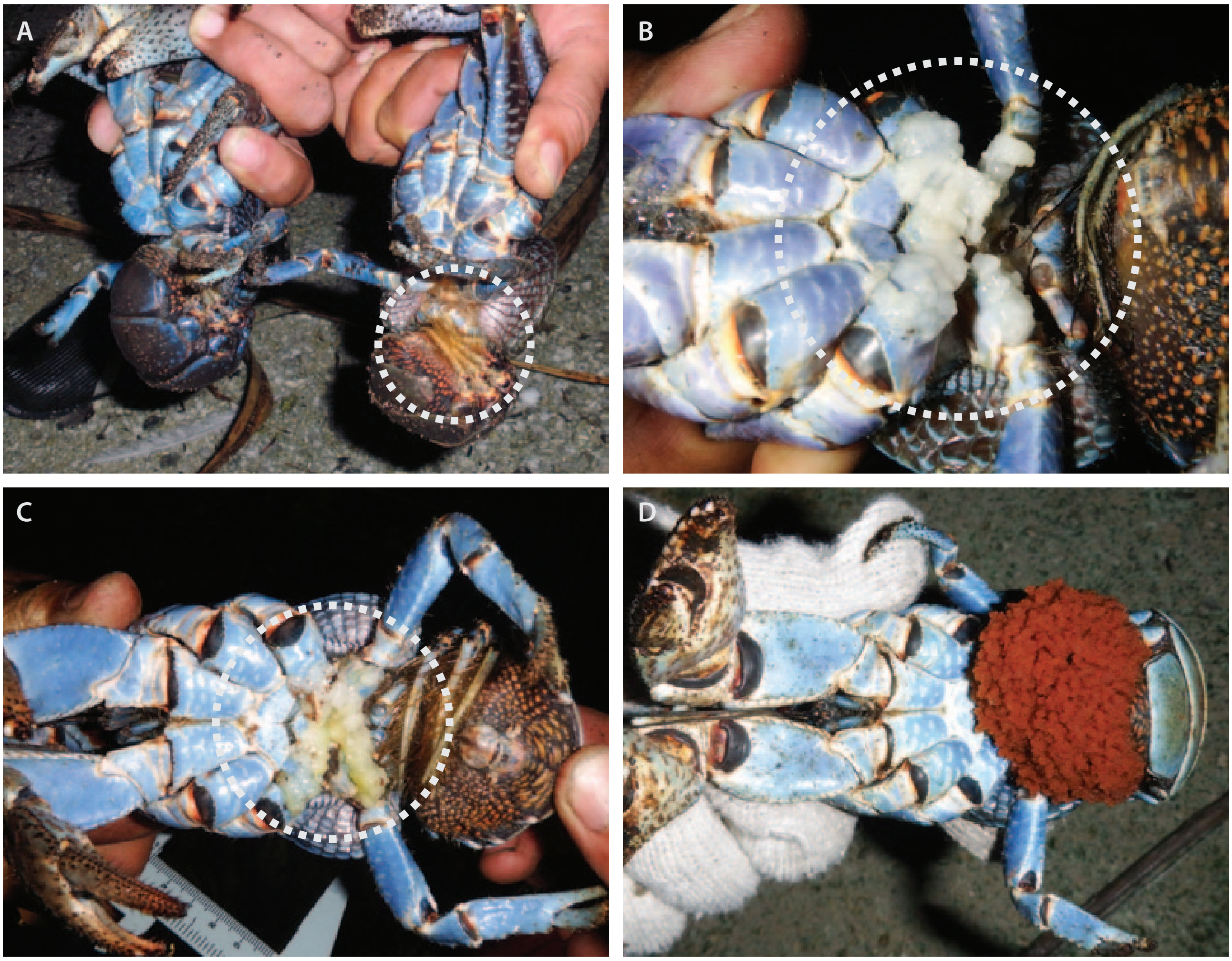


Figure 6. Male crab (A: left) and female crab with three feathery pleopods indicated in grey circle (A: right). Spermatophore on and around female oviducts after copulation (grey circle, B–C), and gravid female captured on her migration to the coastline (D).

Data analysis

The survey yielded three types of data:

- morphological information to determine size (lengths/weight) and colour relationships from all size and colour information recorded in the population survey, hunter hypotheses surveys and random crab measurements;
- count information in the form of CPUE values (number of crabs per bait) to allow for estimation of distribution, and relative abundance from population and hunter hypotheses surveys; and
- information of sex to allow for determining sex ratio and sex-specific population size structures, from population and hunter hypotheses surveys.

CPUE values were determined for all bait stations within each region-vegetation category as follows:

Region/vegetation CPUE = total number of crabs found at all bait stations within a region/vegetation category / total number of baits set in that region/vegetation category

Differences in CPUE among regions and vegetation categories were assessed by permutational analysis of variance (PERMANOVA) at $P = 0.05$, using PRIMER 6.1.13. Region and vegetation category were fixed factors in the analysis. PERMANOVA analyses were based on Euclidean distances and unlimited

Figure 7. Five dominant colour variations observed for coconut crabs in Niue: A) black (*uga uli*); B) blue (*uga lanu*); C) brown (*uga kaki*); D) purple (*uga lanu uhiuhi*); and E) red/orange (*uga pomea*).

permutations of the data. Tests of hunters' hypotheses were also examined by PERMANOVA using the parameters described and the time of bait setting as a fixed factor in the analysis.

Sex-specific length frequency distributions were constructed based on numbers of individuals grouped in 2 mm length classes. Chi-squared tests were used to compare sex-specific length frequency distributions amongst the current survey and the 1990 survey. For these tests, data for lengths of <20 mm TL and >50 mm TL were pooled into <20 and >50 mm length classes due to low frequencies in the tails of the length distributions and to ensure that the same range of length classes was compared across all surveys.

2.2 Coconut crab exports

In an effort to quantify coconut crab exports, DAFF conducted surveys of aircraft cargo from 7 March 2014 to 24 January 2015. The survey involved visual inspection of aircraft cargo and of passenger baggage at the Hanan International Airport baggage x-ray security check point, where the number of coconut crabs seen in cargo was recorded. Passengers were also interviewed to determine the number of crabs they had packed for the flight to New Zealand. Responses to interviews were voluntary.

2.3 Hunter interviews

Interviews with long-time hunters were conducted to glean information on past and present hunting practices, hunters' knowledge and perceptions of coconut crab behaviour, migration, catch rates, stock trends and management status. The interviews used a casual non-structured approach.

3. Results

The weather pattern during the period of assessment was dominated by the prevailing easterly winds, average temperature of 26.4°C and total rainfall of 170 mm that fell over 15 days in November.

For this assessment, 30 stations were assessed and all stations were relatively close to roads or walking tracks. The assessment of baited trails occurred from 17–21 November and 24–28 November 2014. Including travelling time, each station took approximately three hours to bait, search for crabs and record information. Of the 30 stations assessed, 14 were within the general areas previously assessed by Schiller (1992) and Barnett et al. (2008) (Fig. 8). Table 2 lists the stations within each region and vegetation category and total land area (km^2); GPS waypoints for each station are in Appendix 1.

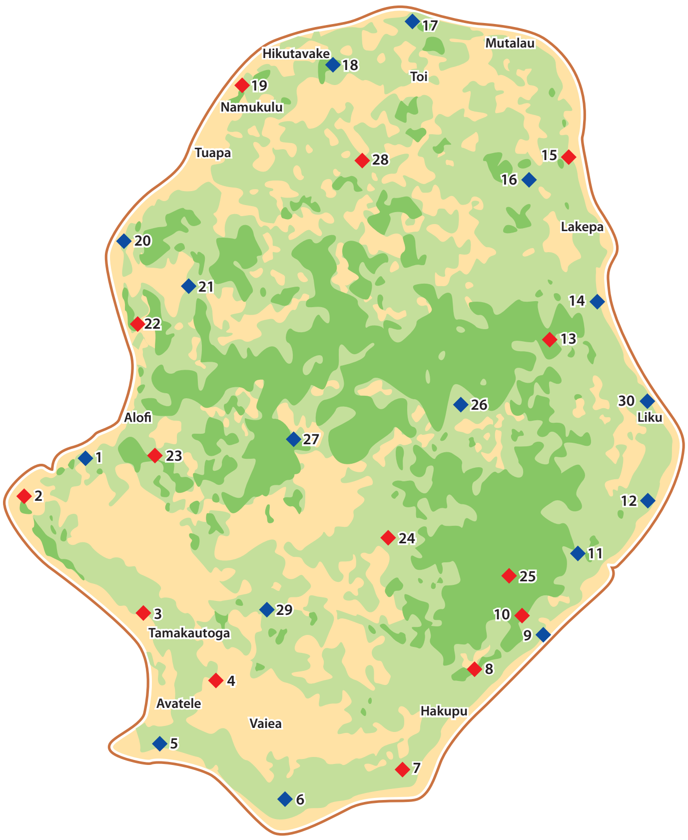


Figure 8. Map of Niue indicating baited stations (blue and red diamonds), the regions and vegetation categories. Red diamonds are stations within the general location assessed by Schiller (1992) and Barnett et al. (2008).

Table 2. Total area (km^2) of each vegetation category and the stations within each category.

Region and vegetation category	Area (km^2)	Station number
Coastal – 1 km primary forest	4.1	1, 2, 8, 19, 22
Coastal – 1 km secondary forest	37.1	3, 5, 6, 7, 9, 12, 14, 15, 17, 20, 30
Coastal – 1–2 km primary forest	80.1	10, 11, 13, 23
Coastal – 1–2 km secondary forest	7.1	4, 16, 18, 21
Interior primary forest	47.7	24, 25, 27
Interior secondary forest	66.1	26, 28, 29
Fern-land, residential and coastal rugged pinnacles	74.3	Not assessed
Total	**159.5**	**30**

3.1 Hunter hypotheses

Hunters hypothesised that the catch rates and the size of crabs caught vary depending on the time baits are visited. This variance would have an impact on CPUE and average size information in our results. To better understand potential bias, hypotheses relating to the timing of revisiting baited trails were examined.

Hunter hypothesis 1: More crabs visit baits the evening after setting baits than in the evening of setting baits.

There appears to be a slight difference in catch rates, depending on when the bait was checked (Fig. 9). However, after further examination of the data we found no difference observed in CPUE among stations surveyed on the evening of setting the bait versus those surveyed the evening after (PERMANOVA, $P = 0.368$).

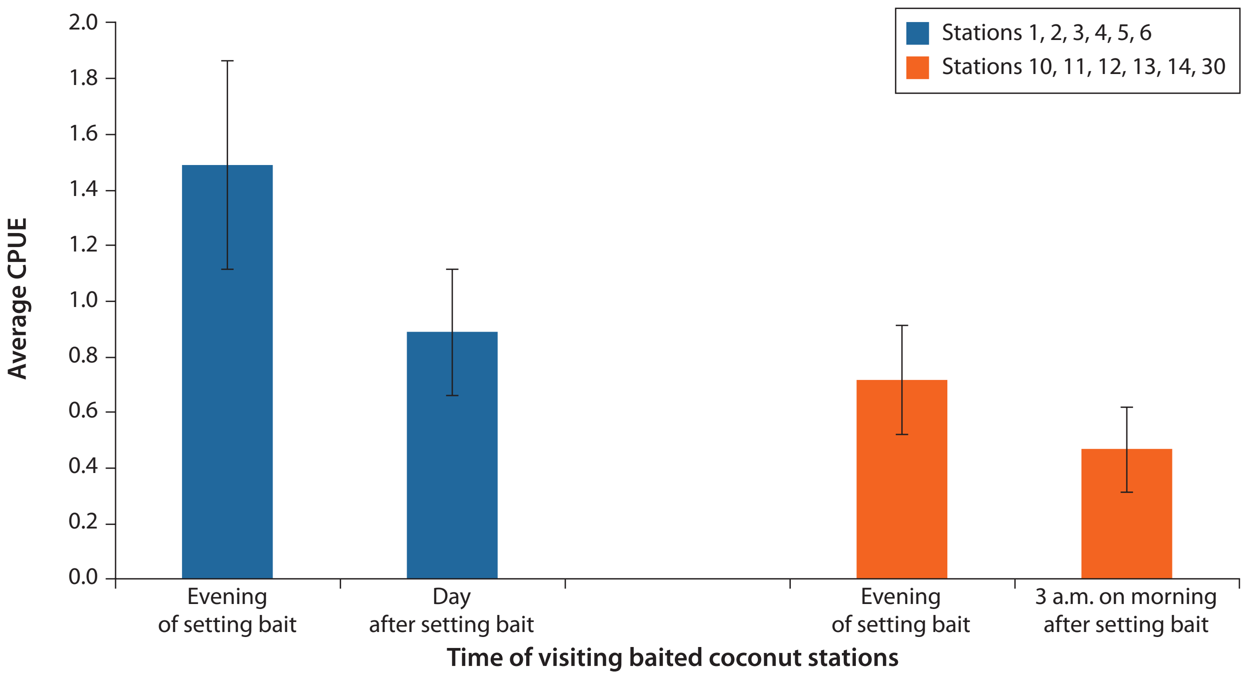


Figure 9. Average CPUE at bait stations surveyed at different times.

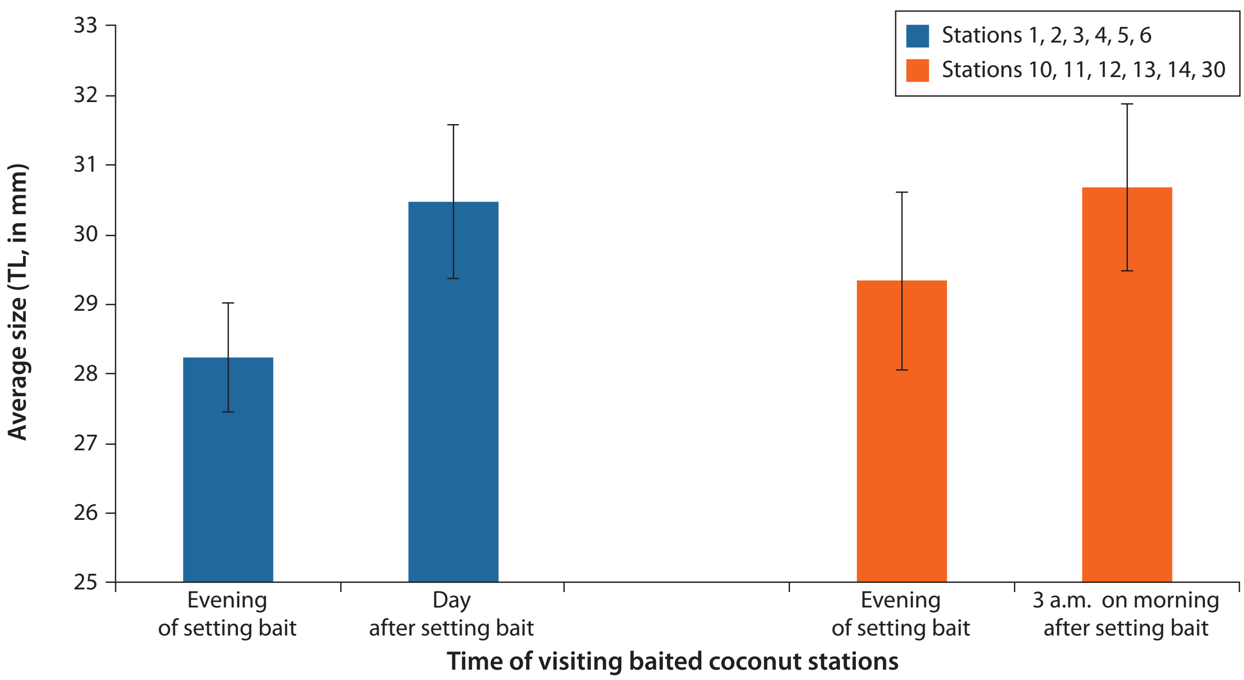


Figure10. Average size (TL) of coconut crabs at bait stations surveyed at different times.

Hunter hypothesis 2: More crabs and larger crabs visit baits in the early morning after setting baits than the evening of setting baits.

Again, no significant difference was observed in CPUE of baits checked the evening of being set and in the morning after being set (Fig. 9) (PERMANOVA; $P = 0.361$). Similarly, no difference in size was observed between bait checking times: means = 29.3 ±1.3 and 30.9 ±1.2 mm TL for crabs encountered one hour after dark and 3 a.m. the following morning, respectively (Fig. 10).

3.2 Relative abundance

Results in this section relate to baited stations visited only once, between 7 and 9 p.m. on the evening when the baits were set. Relative abundance of crabs is a function of distance from the coastline and declines from the coastal zone towards the interior region (Figs 11, 12 and 13). The furthest crab was found 5 km inland.

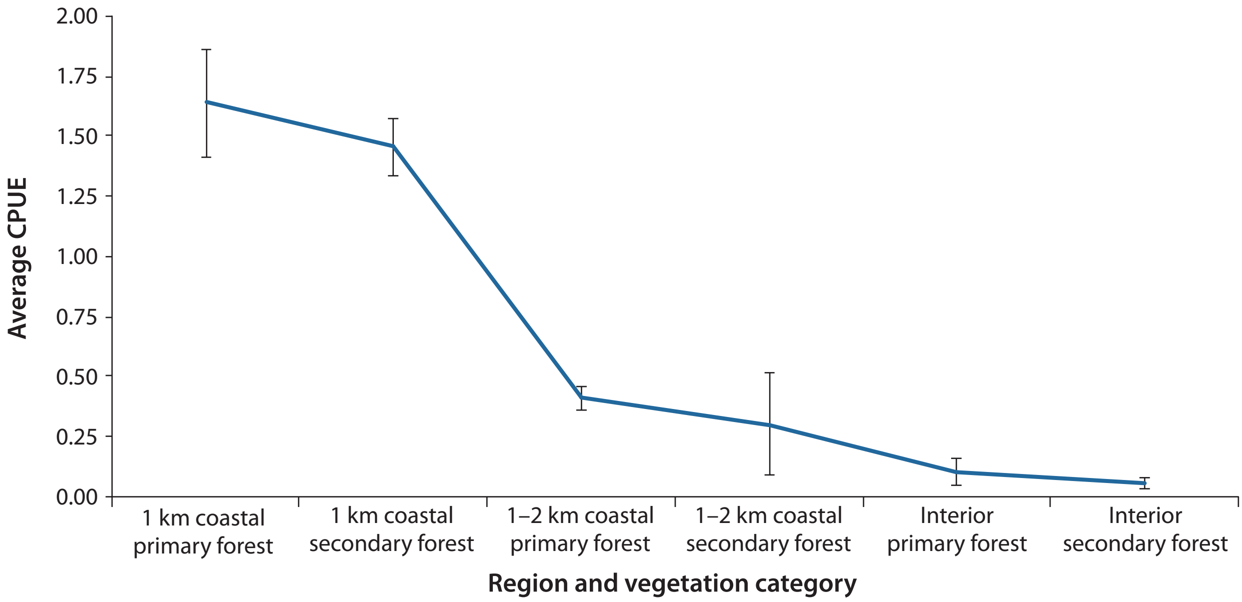


Figure 11. Average CPUE for all stations in each region and vegetation types in Niue.

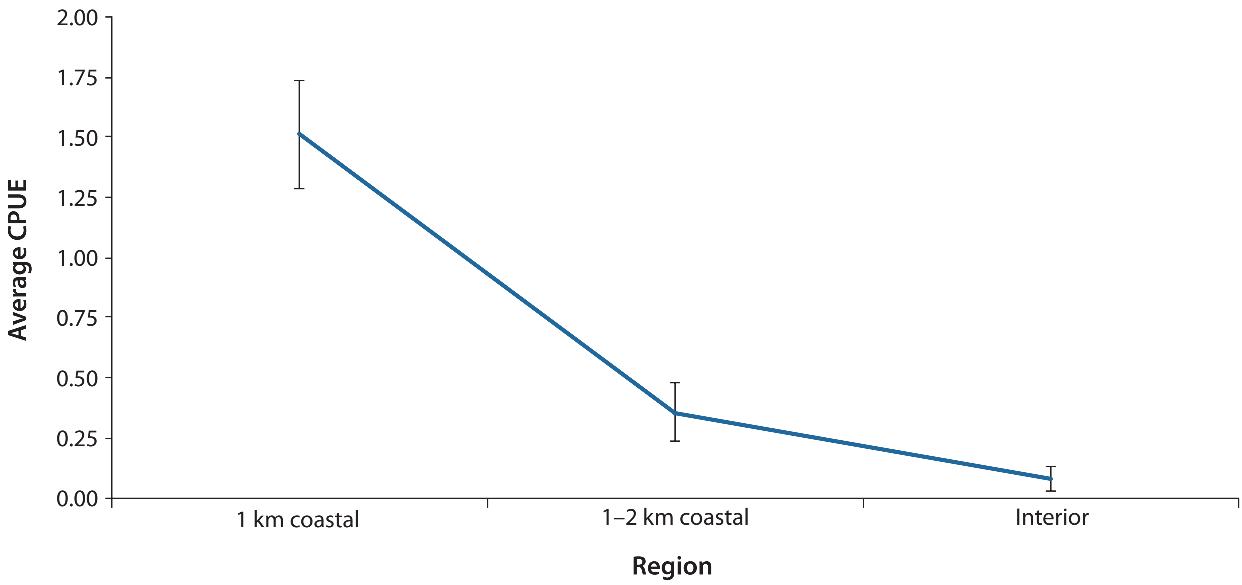


Figure 12. Aggregated (primary and secondary forests) average CPUE values for each region.

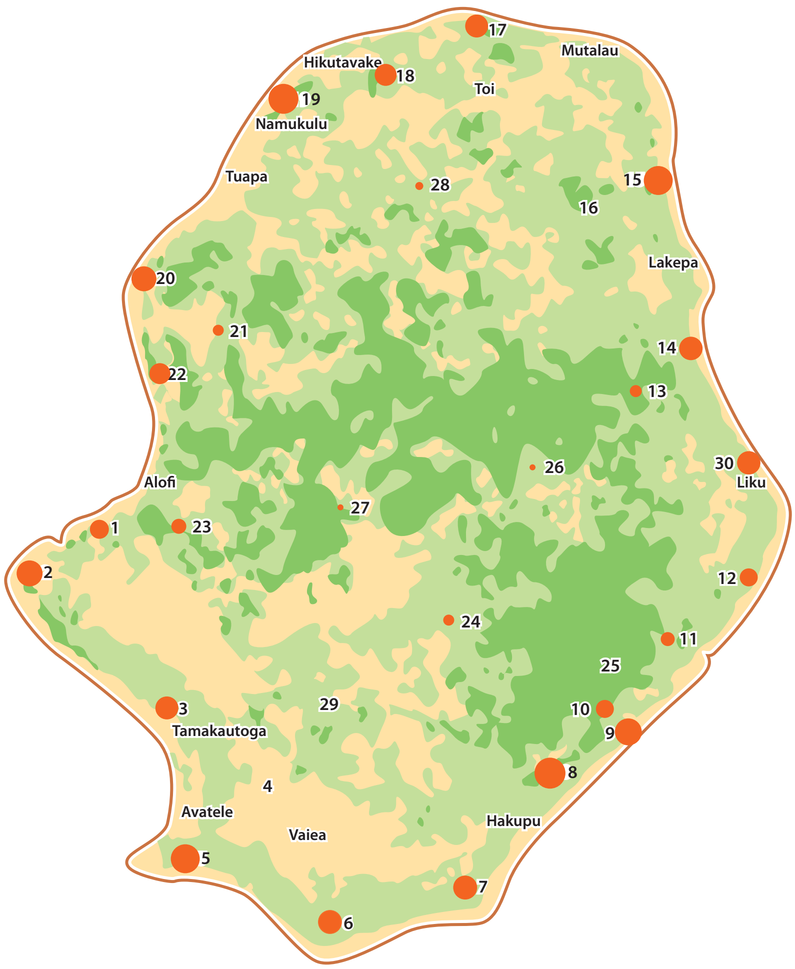


Figure 13. Coconut crab survey stations in Niue. Bubbles indicate relative abundance as CPUE; The larger the bubble the higher the relative abundance.

Two hundred and ninety-nine crabs were recorded at 26 of the 30 stations (no crabs were observed at stations 4 and 16 within the secondary coastal forest and stations 25 and 29 within the interior region). CPUE varied by region and vegetation type from 0.06 (±0.02 SE) crabs per bait in the interior secondary forest region to 1.64 (±0.23 SE) crabs per bait in the 1 km primary forest region (Appendix 2). No significant differences in CPUE were observed among vegetation categories within a region (Table 3). Accordingly, CPUE values for primary and secondary forest types were aggregated for each of the three regions (Fig. 12, Appendix 2). Similarly, no differences were observed among stations considered to be in the west (Stations 1–6 and 18–23) and those in the east (Stations 7–17 and 30) ($P = 0.92$). No differences were observed in CPUE at stations within the Huvalu Forest Conservation Area and sites open to harvest ($P = 0.69$). CPUE estimates for stations within the Huvalu Forest Conservation Area in 2014 were not significantly different from those in the Conservation Area in 1997 for either 1 km coastal sites ($P = 0.21$) or all sites examined ($P = 0.96$).

Table 3. Results of PERMANOVA test comparing vegetation categories within each region.

Comparison	*P*
0–1 km coastal primary forest versus 0–1 km coastal secondary forest	0.475
1–2 km coastal primary forest versus 1–2 km coastal secondary forest	0.465
Interior primary forest versus interior secondary forest	0.489

3.3 Lengths and weight relationships

Thoracic length is most commonly used to describe the size structure of coconut crab populations in Vanuatu (Fletcher 1993), Niue (Schiller 1992), French Polynesia (Chauvet and Kadiri-Jan 1999), Palau and Marshall Islands (Helfman 1973). Pasilio et al. 2013 used cephalothoracic length in a study in Tokelau. American Samoa and Vanuatu use cephalothoracic length and Niue, Wallis and Futuna uses thoracic length minimum sizes in national legislation. To allow comparisons with other studies or minimum size regulations, a TL to CL regression was developed for crabs measured in this study.

The regression has a strong linear correlation with an R^2 value of 0.96 (Fig. 14) and is explained by the formula:

$$CL = 1.917 \times TL + 6.906 \textit{ or}$$

$$TL = CL - 6.906 \ / \ 1.9176$$

These equations can be used to determine thoracic length or cephalothoracic length when only one measurement is available. For example, this equation is used to transform the Niue coconut crab TL minimum harvest size of 36 mm to its corresponding CL which is 76 mm and the Vanuatu minimum harvest size CL of 90 mm to its corresponding TL which is 43.5 mm.

To enable conversions from lengths to weight, regressions were developed for crabs measured in this study.

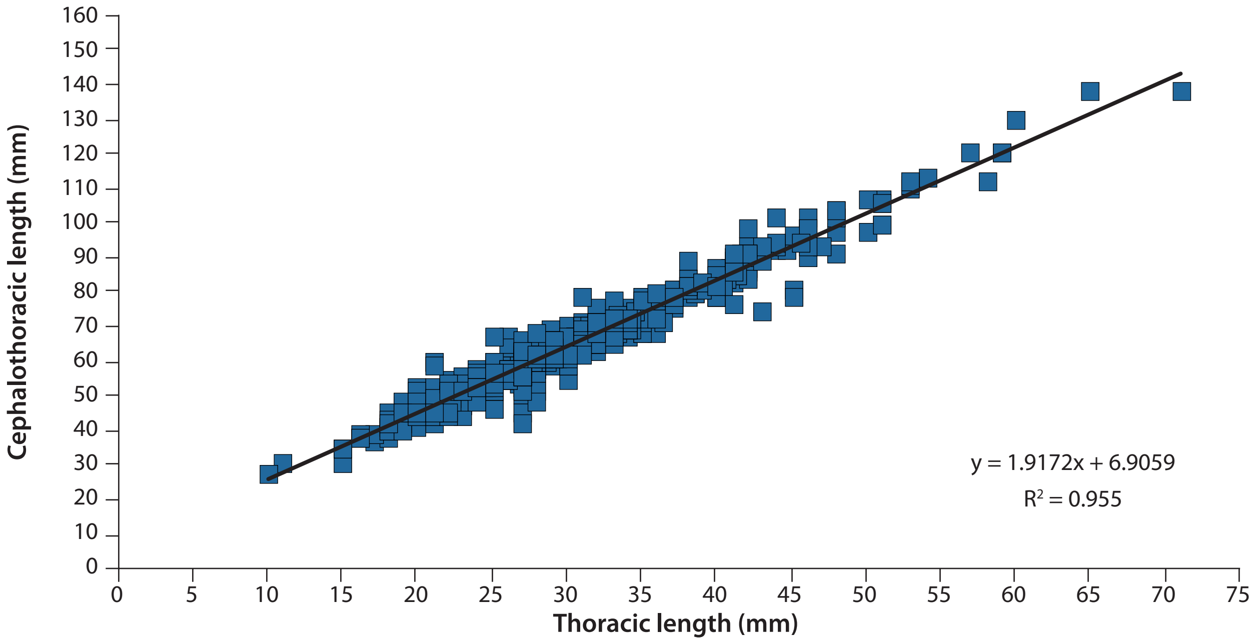


Figure 14. Linear regression for thoracic and cephalothoracic lengths for coconut crab in Niue. Sample size (n) = 502.

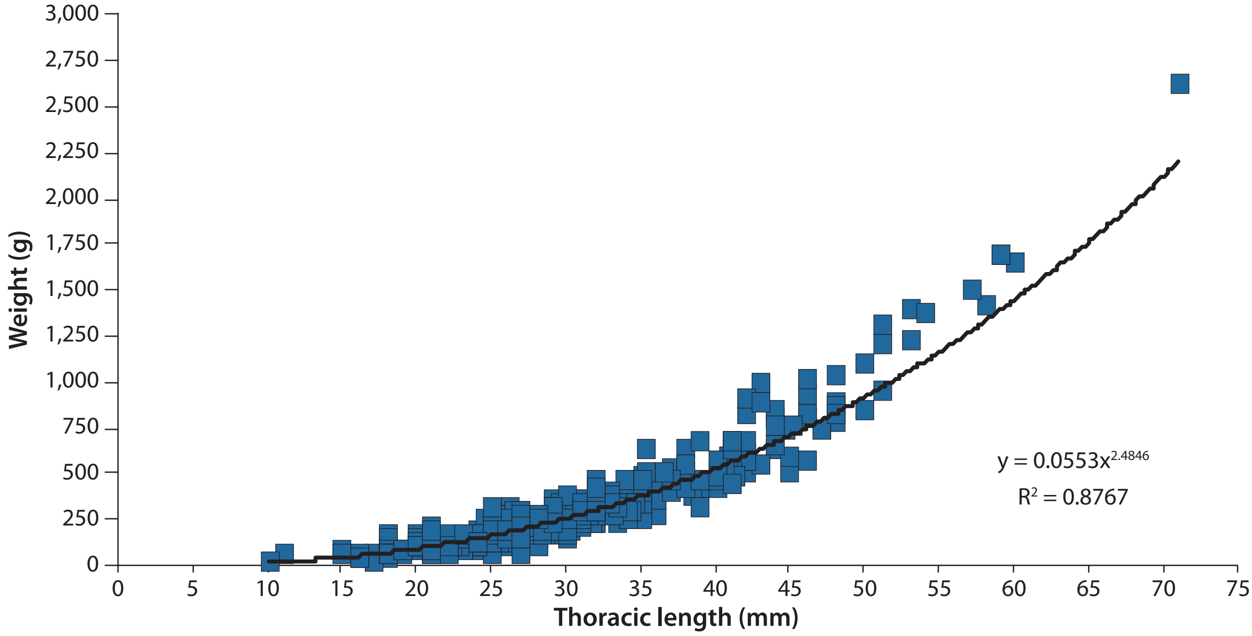
Both TL to weight and CL to weight regressions had good correlation (Fig. 15).

The TL (mm) to weight (g) relationship is explained by the formula:

$$Weight = 0.0553 \times TL^{2.4846} \ (R^2 = 0.88)$$

The CL (mm) to weight (g) relationship is explained by the formula:

$$Weight = 0.0023 \times CL^{2.7918} \ (R^2 = 0.90)$$



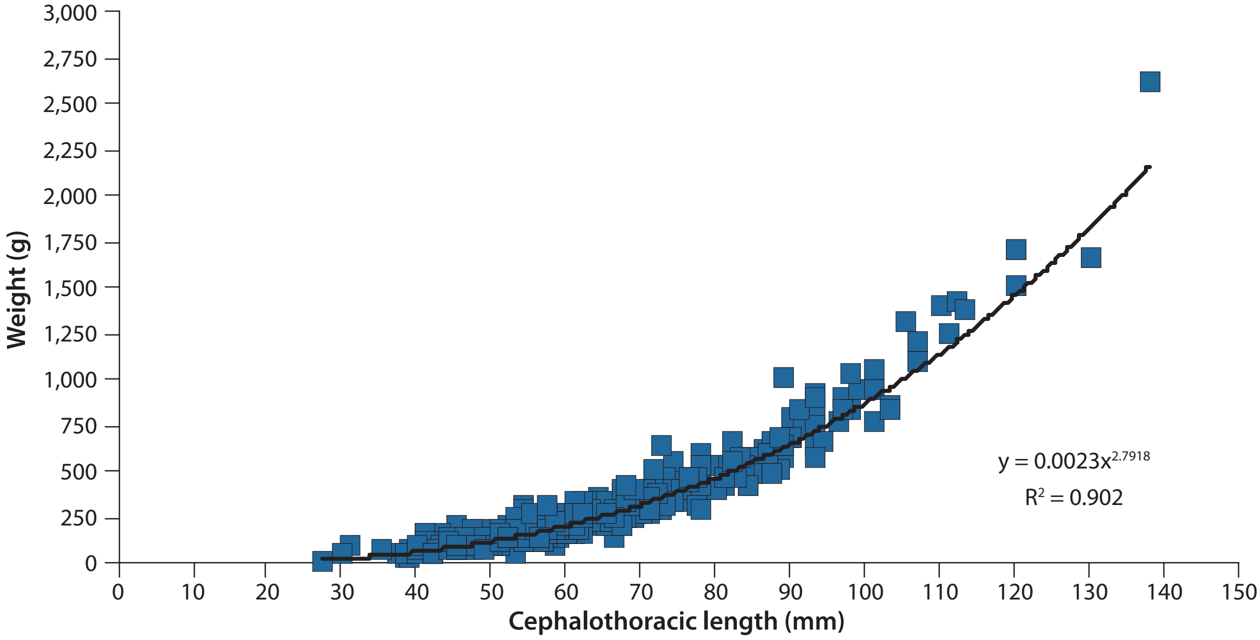


Figure 15. Thoracic length to weight (top graph) and cephalothoracic length to weight (bottom graph) relationships for coconut crabs in Niue, November/December 2014. Sample size (n) = 457.

3.4 Population sizes structures

Of the 422 coconut crabs measured during baited trail surveys, 161 (38%) were females and 261 (62%) were males. The female to male sex ratio is around one female to one male at 25 mm TL, but diminishes rapidly with increasing size in favour of males. At 35 mm (TL) the ratio is one female to three males and at 43 mm it is one female to 31 males (Table 4).

Table 4. Sex ratio (female:male) by size of coconut crabs on Niue.

Size TL (mm)	Female	Male
15	1	1
17	1	1
19	1	1
21	1	1
23	1	1
25	1	1
27	1	1
29	1	1
31	1	1
33	1	2
35	1	3
37	1	5
39	1	17
41	1	18
43	1	31

Coconut crabs exhibit clear sex / size differences; the mean body size of females is smaller than that of males (Table 5 and Fig. 16). The maximum size recorded for males is greater than the maximum size recorded for females; this is a common occurrence in all coconut crab studies reviewed (Appendix 3). In this study, the mean size of female coconut crabs is 16% smaller than that of males. In the Vanuatu study, the mean size of females was 20–25% smaller than that of males (Fletcher et al. 1991) and in Tokelau (Nukunonu) the mean size of females was 10% smaller than that of males (Pasilio et al. 2013; Appendix 3).

In this study the mean size of female crabs is TL 26 mm (±0.38 SE) while the mean size of males is TL 31 mm (±0.54 SE). In comparison, the mean size of female crabs in Niue in the early 1990s and in 2008 was TL 27 mm and the mean size for males was TL 32 mm and TL 33 mm respectively (Table 5). These low mean sizes and the general lack of larger female and male coconut crabs are attributed to high exploitation. In a recent coconut crab study in Tokelau (Nukunonu) the average TL for females was 34.5 mm (±1.07 SE) and for males 39.0 mm (±1.15 SE) (Pasilio et al. 2013). Appendix 3 provides mean sizes for male and female coconut crabs from various studies reviewed.

Table 5. Comparison of sex specific size information (TL in mm) with previous studies in Niue. Length frequency data from each study are in Appendix 4.

Statistic	Niue early 1990s		Niue 1997		Niue 2008		Niue 2014	
	Female	Male	Female	Male	Female	Male	Female	Male
Smallest crab measured	17	13	17	21	21	15	11	10
Largest crab measured	35	53	41	55	39	55	43	61
Average	27	32	28	33	27	33	26	31
Sample size (number)	123	161	66	98	26	64	161	261
Proportion >36 mm TL*	0%	24%	10%	38%	4%	33%	2%	25%
Proportion >25 mm TL**	86%	85%	83%	91%	77%	86%	72%	80%

* Niue minimum harvest size; ** Reported size at maturity.

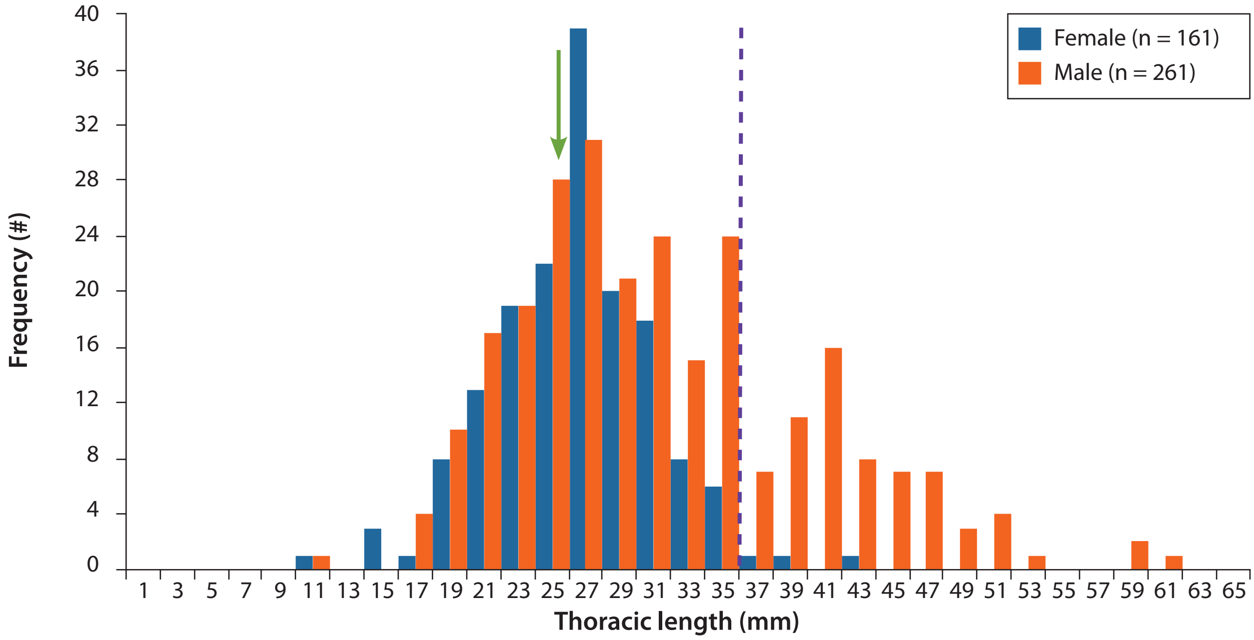


Figure 16. Thoracic length frequency distribution of male and female crabs recorded at all baited stations. The figure also illustrates size at maturity of 25 mm TL reported in literature (green arrow) and minimum harvest size in Niue of 36 mm TL (purple dashed line). Note: Only three females recorded a TL greater than the minimum harvest size.

Chi-squared tests revealed little difference in length frequency distribution among the 1990 and current surveys of coconut crabs on Niue for either sex ($\chi^2 = 15.926$, $P = 0.45$ and $\chi^2 = 15.651$, $P = 0.07$ for males and females, respectively). However, when comparing size structure between Niue and Tokelau crabs, the length frequency distributions of both sexes during the current study were both significantly different from those of Tokelau ($\chi^2 = 80.574$, $P<0.001$ and $\chi^2 = 44.022$, $P<0.001$ for males and females, respectively), with the population on Niue consisting of larger numbers of smaller crabs and fewer large crabs relative to Nukunonu-Tokelau (Fig. 17).

The smallest crab found was a 10 mm TL male. One very small coconut crab (10–15 mm TL) was found in the interior region (site 26) just over four kilometres from the coastline. It crawled into a rock crevice and was not captured or measured.

Sixteen per cent of all crabs (male and female) measured in our baited station surveys within the 0–1 km coastal region were above the minimum legal harvest size of 36 mm, and 22% of all crabs measured within the 1–2 km coastal region were above that limit.

One of the survey teams observed a pair of crabs copulating; the male was on top of the female, which was upside down. The male was 51 mm TL and the female was 27 mm TL. During the assessment, we encountered two females that had concluded copulation; these female crabs had white, jelly-like spermatophore attached to their thorax (Fig. 6). Of all (161) female crabs recorded, 4.3% were egg-bearing. These finding suggest that the beginning of their reproductive active season in Niue could be around October/November. The smallest egg-bearing female had a TL of 19 mm, consistent with Schiller's findings in the early 1990s. The average size for egg-bearing females was 27.1 ±1.5 but this information should be considered with caution, as the sample size of egg-bearing females was small (n = 7).

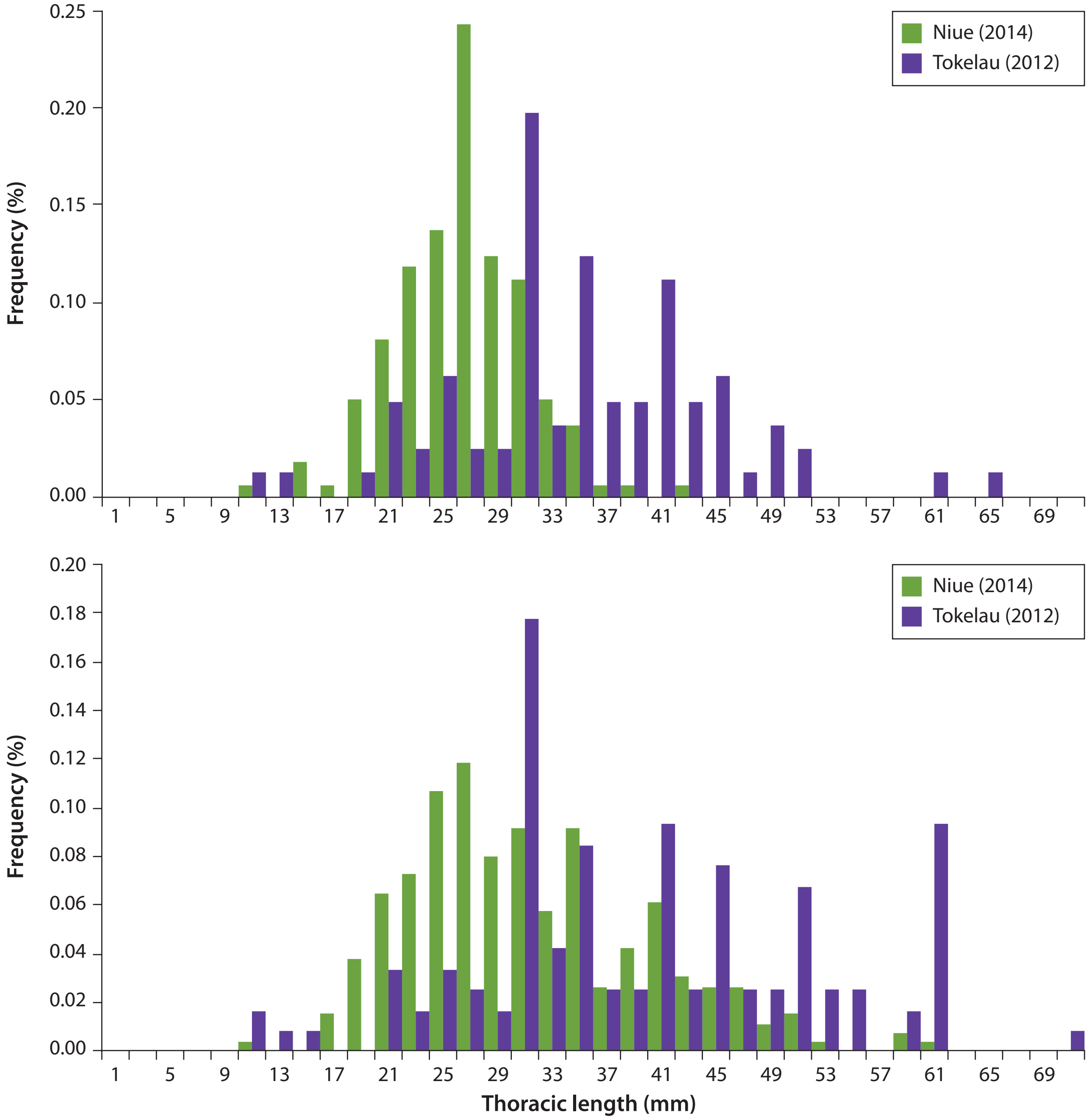


Figure 17. Comparison of thoracic length frequency distributions for female and male crabs in Niue and Tokelau. The top graph shows that the female population in Niue consists of larger numbers of smaller crabs and fewer large crabs relative to the Nukunonu-Tokelau population.

3.5 Colour differences

We found no relationship between colour, size or sex of coconut crabs, nor was there any pattern in colour dominance and coastal regions. The proportions of crabs with varying colour patterns were identical for both sexes. The most dominate colour pattern was brown (57%) followed by blue (33%), with black crabs comprising a very small proportion of the population (Fig. 18).

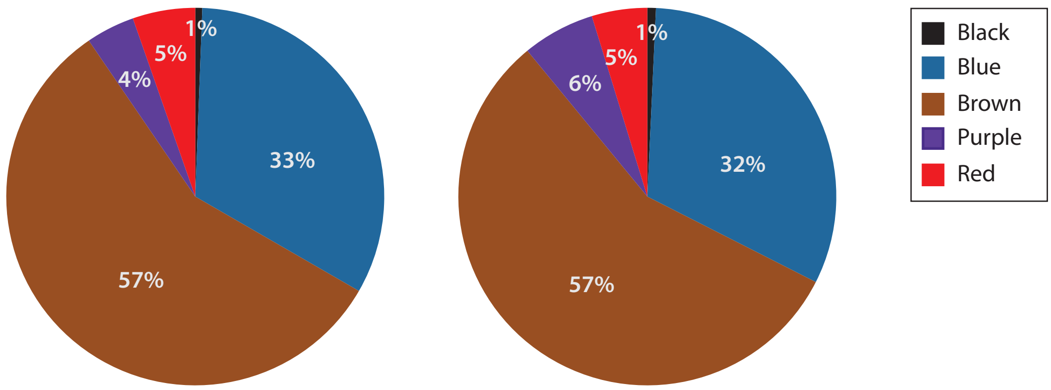


Figure 18. Proportion of crabs with colour. Female n = 168, Male n = 274.

3.6 Exports

Of the 80 Air New Zealand flights that departed Niue from March 2014 to January 2015, passenger baggage/cargo for 18 flights was sampled via x-ray (Table 6). Of these 18 flights, the data from three flights sampled were excluded because only a sample of the total cargo exported were inspected. Departing passengers were also interviewed when in the departure lounge for eight flights (10% of all flights) to determine the number of crabs that were taken abroad and to compare this information with that obtained by x-ray (Table 6 and Appendix 5).

Table 6. Coconut crab export data collected by x-ray inspections and interviews with departing passengers.

Date of flight	Number of crabs	
	X-ray	Interview
07-Mar-14	139	153
18-Apr-14	80	98
02-May-14	52	55
23-May-14	76	97
03-Jun-14	100	-
06-Jun-14	~	131
04-Jul-14	104	-
22-Jul-14	176	163
26-Aug-14	154	-
29-Aug-14	~	-
19-Sep-14	107	165
14-Oct-14	280	-
11-Nov-14	35	-
15-Nov-14	62	-
29-Nov-14	~	-
06-Dec-14	138	-
13-Dec-14	166	120
24-Jan-15	80	-
Average	**117**	**123**

~ information excluded from analysis; - no interviews conducted.

With regard to the average number of crabs per flight over the sample period, both survey methods (x-ray inspection and interviews) gave more or less the same result for five of the seven flights where both survey methods were conducted concurrently (Table 6). However, when further investigating both data sets it was difficult to quantify the exact number of crabs taken abroad for each passenger who were taking crabs abroad. Some passengers reported that they were carrying coconut crabs on behalf of other passengers, or that they had been given a box of goods (including crabs) to take for relatives overseas. This may have resulted in double counting, hence the large discrepancies in the number of crabs sampled by both methods on 19 September and 13 December. Inspectors were able to fairly accurately quantify the number of whole crabs in the cargo as it passed through security x-ray screening (Fig. 19) and this method of monitoring is thus preferred because the equipment is available, so it is a more efficient method of monitoring exports.

From x-ray inspections, numbers of crabs in passenger cargo(s) ranged from 1 to 36, with some passengers taking multiple parcels and from interviews the number of crabs taken abroad ranged from 1 to 40 (Appendix 5). From x-ray inspection, the numbers of crabs taken abroad ranged from 35 to 280 per flight with an estimate average of 117 and from interviews with departing passengers the range was 55–165 per flight with an average of 123 for all flights sampled. Extrapolating the averages from both monitoring methods we estimate around 9,350 to 9,850 crabs were sent abroad during the period March 2014 to January 2015 (11 months).

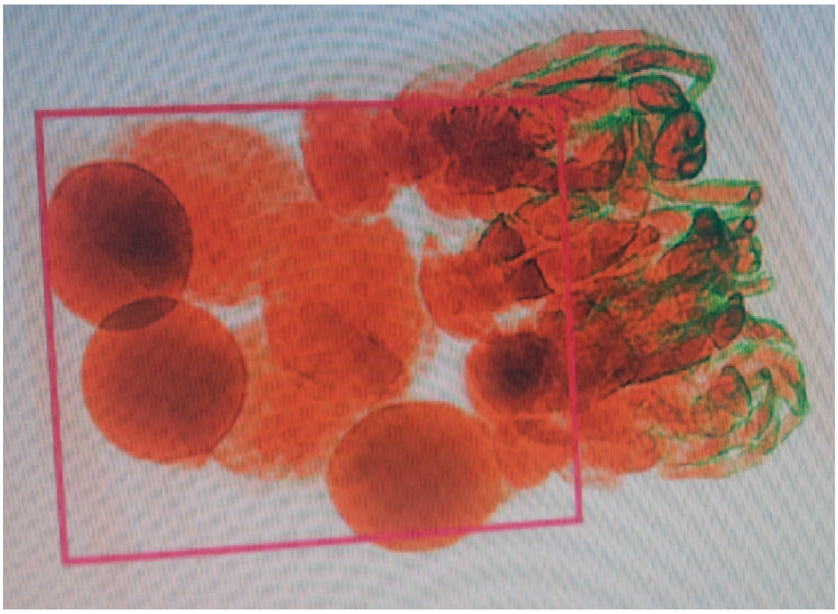


Figure 19. Coconut crabs are easily recognised through security x-ray. The image shows four crabs, packed with other items.

3.7 Local knowledge and perceptions

Experienced long-time local hunters (male and female) provided qualitative information ranging from historical and current hunting practices, to coconut crab behaviour and migration, to views on the status of stock and management of coconut crabs. The experiences, views and accounts from eight hunters interviewed ranged from 10 to 45 years are summarised below.

Hunting

In the past, crab hunting was primarily for family food needs or customary feasting. Men, women or the whole family would take part in crab hunting. During the 1970s and 1980s, barefoot hunters would search for crabs at night in the forest, using the inner sheath of the coconut tree flower (*toume*) as a flame torch; this was hard work. A flaming torch illuminates a relatively limited area and the torch would only burn for five to ten minutes before a second sheath needed to be lit. The coconut flame torch was later replaced by lanterns, followed by hand held torches, and hunters enjoyed the comfort of sandals by around the late 1980s. Today, vehicles are used to travel to distant hunting grounds, and hand torches, headlamps and sturdy shoes are necessary when hunting for coconut crabs.

Coconut crab behaviour and migration

Responses to questions relating to coconut crab migration were generally consistent. During the cool winter months (May–August) coconut crabs burrow. However, not all crabs seem to burrow, as hunters still encounter free-roaming crabs during this period. During this burrowing season, some hunters dig for crabs. By around September/October many male and female crabs start migrating towards forest areas along the coastline and between December and March large numbers of crabs are found along the coastal area and cliff face, although some remain in the interior regions. Egg-shedding normally occurs around January/February but in some years it occurs a month earlier or later. During egg-shedding, male crabs can be found along the cliff face. After egg-shedding, crabs disperse and migrate away from the coastline.

Most respondents reported egg-shedding (spawning) to occur during the night high tide (springtide). However, three hunters reported that it occurred during the night low tide; at these times it is quite easy to pick crabs off the cliff face either by hand or with sticks. Witnessing coconut crab spawning is fascinating; you see them walking down the cliff backwards with the abdomen (*ulu uga*) stretched out. They shake the abdomen when a wave splashes on it, and then walk up the cliff and disappear into the forest.

While published literature has juvenile crabs sheltering in gastropod shells, none of the interviewees had seen this. They said the crabs in the gastropod shells were hermit crabs. This is in contrast to published literature. Small coconut crabs are found along coastal areas and in the interior regions. Interestingly, two female hunters interviewed, who regularly collect sea shells along the intertidal coastal zone for traditional craft work, reported that very small coconut crabs look exactly like larger coconut crabs, except that the tiny ones lack pigment and are a translucent off-white/blue colour. During bush clearing operations, it is common to find juvenile crabs.

Catch rates

The hunters interviewed said that catch rates varied and that forest type, distance from the coast and weather conditions are considered to have the most influence on catch rates (Fig. 20). Catch rates are best during periods of light rain or rainless but damp periods and when there is slight to moderate breeze. Catch rates are poor during periods of heavy rain. Hunters suggested that under the right weather conditions more and larger crabs are caught in the early morning as opposed to evening. Some respondents said catch rates are better during the dark moon phase. All hunters interviewed said they have dedicated bait trails that they have used for years; they also on occasion hunt along random trails. Some hunters reported that large crabs live in burrows/dens (caves/holes) and if these crabs are removed it is best to rest the area for some time. The number of baits these hunters used vary from a low of five to as high as 150 baits per trail. The number of crabs caught also varied. From the interviews, we estimate a CPUE for crabs of moderate to large size of 0.29 (±0.02 SE) or three or four baits needed to catch one good sized crab (presumably over the legal size limit).

From the results of the population assessment survey (Section 3.2) we estimate a CPUE of 0.24 for crabs above the minimum harvest size in the 0–1 km coastal region, that is, four or five baits are needed to catch one crab >36 mm TL. This is remarkably similar to the CPUE calculated from the hunters' responses.

Figure 20. A coconut crab catch in Niue (Image: courtesy of Ioane Mamaia).

Status and management of coconut crab

Responses to questions on the status of crab population varied. One of the eight hunters interviewed said the population is increasing, three said they did not notice any difference from 20 plus years ago, two said that there were many more smaller crabs today then years ago and two were not sure but stated that it is harder to catch big crabs today; their catches were mainly medium size crabs.

With regard to coconut crab management, two interviewees said they were unaware of the minimum size limit, the remaining six said the minimum size was too small and all respondents felt that all small crabs should be left alone. At a meeting open to the public to present preliminary results of the survey work, many in attendance also said the minimum size was too small. Four of the hunters interviewed said that trespassing on people's properties to go crab hunting was a problem. Wild pigs are a problem that needs to be controlled; dogs also prey on coconut crabs and have been seen to go hunting for coconut crabs themselves.

One respondent said that a protected area dedicated to coconut crabs would help protect stocks and could be used for education and awareness. With regard to exports, there were mixed opinions. These include:

- a short season when exports are permitted;
- permits to be issued for all crabs exported; and
- a set number of crabs can be exported each year and families are allocated a portion of this annual export quota.

All interviewees said that it would be difficult for the people if there was a total ban on coconut crab exports.

All interviewees emphasised that there should be more awareness and education on coconut crab biology, hunting, catch quantities, resource management and status of stocks.

4. Discussion and key findings

Coconut crabs are principally terrestrial animals but they have a brief marine larval phase (Schiller et al. 1991). The number of viable larvae released into the ocean depends on the quantity and size of reproductively mature crabs. Recruitment back to Niue is largely dependent on the number of eggs released and ocean currents. Many larvae die because of starvation, predation, disease, and severe weather conditions.

Once the coconut crabs recruit on Niue, they still have a number of predators; people, pigs and dogs prey on larger crabs while rats and birds prey on small juveniles. Other forms of mortality include disease or road kill. Habitat modification, including road construction, fences, or land clearing for agriculture or residential areas can also threaten coconut crab survival. Many of these factors are influenced by actions of people.

Lavery and Fielder (1991) examined the population structure of coconut crabs from Christmas Island (Indian Ocean), Solomon Islands, Vanuatu, Niue and Cook Islands based on mitochondrial DNA. The findings indicate that crabs on Niue constitute a separate population from the other locations sampled. This implies that the coconut crab recruits to Niue originate from mature crabs that have shed their eggs along the Niue coastline and are not from other islands sampled. Therefore, the Niue stock forms a separate/isolated population, independent of crab populations on other islands.

Many studies are one-off and few have investigated coconut crab populations through time, but the coconut crab population in Niue has been studied several times: in 1988 and 1990 (Schiller 1992), 1997 (un-published data), 2008 (Barnett et al. 2008) and in 2014 (this study). The current findings indicate that there are more coconut crabs than previous studies in Niue, but the coconut crab population size structure has remained reasonably stable, with small average and maximum sizes for females and male crabs.

This 2014 study was able to determine estimates of relative abundance, population size structure, and exports of coconut crabs on Niue. The lack of information on the quantity and size of crabs caught for domestic consumption and on the amount of hunting makes it is difficult to estimate harvest pressure. However, harvesting pressure can be inferred by patterns in relative abundance and size structure of a population.

Previous studies into unexploited coconut crab populations using coconut baited trails have recorded an average CPUE of 2.10 on Diego Garcia in the Indian Ocean (Vogt 2004), 5.00 on the Hiu Islands in Vanuatu (Fletcher et al. 1991), and 4.20 on the lightly exploited Tegua Islands (Vanuatu) (Fletcher et al. 1991). However, these CPUE estimates are for crab populations on atolls and may not be appropriate as reference for populations on up-raised islands. We were unable to locate studies on coconut crab CPUE from unexploited up-raised islands that could act as a reference point to compare with the current state of the crab population on Niue. On light to moderately-exploited up-raised islands, average CPUE levels range from 1.00 at the Kole Coast to 0.4 at Kole Cliff, Vanuatu (Fletcher et al. 1991) and for heavily exploited stocks, the average CPUE was 0.24 at Saipan in the Northern Marianas (Kessler 2006) and 0.25 at Hog Harbour, Vanuatu (Fletcher et al. 1991; Appendix 3). The average CPUE estimates from this study on Niue were 0.08 for the interior region, 0.36 for the 1–2 km coastal region, and 1.51 for the 0–1 km coastal region, i.e. the CPUE decreases progressively by 77%, the further away from the sea the crabs are. The CPUE derived estimates in the current assessment for the 0–1 km and 1–2 km region compared to those from previous studies in Niue reflect a greater relative abundance of crabs on Niue (Appendix 2).

Size frequency information is useful for interpreting the status of stocks. The size frequency distribution of crabs in this study showed a lack of large crabs, with only 4.3% of measured crabs greater than 45 mm TL and 1.9% greater than 50 mm TL. The general lack of large crabs in the surveys could be due to these large crabs remaining hidden in dens or they could result from harvesting for local consumption and export. Radio-telemetry studies have indicated that smaller crabs disperse more than larger crabs (Fletcher et al. 1991); these smaller crabs are continually moving, looking for better dens in a more suitable area. For this reason, smaller crabs are likely to be encountered more frequently during surveys than larger crabs. Some studies (e.g. Fletcher at al. 1991; Helfman 1973; Amesbury 1980), suggest that large crabs might have an established den; this suggestion is supported by interviews with local hunters. From the literature reviewed, there is no documented evidence that large crabs take pieces of food to dens and remain hidden for a few days. However, if this were the case then some large crabs could have remained in dens during our population survey, and thus be under-represented in the size structures. This is an area worth further investigation.

From the results of this study, we conclude that the lack of large crabs is a result of heavy harvesting pressure. Larger coconut crabs are preferred by hunters for special dishes, functions and as luxury food. Because of this, the larger crabs in the population are exposed to higher hunting pressure than the moderate size and smaller crabs. The maximum sizes of male and female crabs in the four studies in Niue (i.e. Schiller 1992; unpublished data 1997; Barnett et al. 2008; and this study) were smaller than those recorded elsewhere in the Pacific between the 1970s and 2012 (Appendix 3). The average sizes for male and female crabs from the four studies in Niue are similar to those in other studies on heavily exploited crab populations in upraised islands (Fletcher et al. 1991; Kessler 2006; Appendix 3), supporting the conclusion that the lack of large crabs in the population is a result of heavy harvesting pressure.

When compared with Schiller (1992) and Barnett et al. (2008), our study found an increase in relative abundance, small increases in maximum sizes and a slight decrease in the average size over time. The period of the population survey could have affected abundance estimates. The 1990 surveys occurred over 7 ½ months (May–December), the 1997 survey occurred in March, the 2008 survey occurred in October and the present study started on 17 November and was completed by 28 November. Local hunters reported that crabs burrow and are underground during the cooler winter months (May–July/August) and around September/October they begin migrating towards coastal areas. The current survey took place when most crabs had started migrating towards the coast and this may have inflated abundance estimates when compared with Schiller (1991).

Helfman (1973) suggested that female and male coconut crab partners need to be of similar size for successful mating. He further suggested that males that are larger than females within a population are reproductively inactive. In the present survey, one of the survey teams observed a pair of crabs copulating; the male was on top of the female, which was held upside down. The male was 51 mm TL and female was 27 mm TL. This observation suggests that males are capable of reproducing with females of much smaller size.

We found no published information to confirm or suggest that females mate with multiple males. Our study found that the female to male sex ratio is low for the reproductively mature portion of the population; very low numbers of reproductively active females within the population could result in males having greater difficulty finding females for the purpose of mating.

Although limited, our observation indicated that the mating season begins around October/November. Local hunters report egg-shedding to occur around December/March and Fletcher (1993) indicates a pelagic larval phase of around one month in the ocean before returning to shore. Depending on the number of eggs released, survival during the larval phase depends largely on factors such as food, predation, currents and tides, and the survival of new recruits depends on factors such as food, predation, habitat and humidity. Recruitment of coconut crabs to Niue is thought to occur around February to May. This study did not investigate recruitment patterns but, given the independence of the Niue stock and factors affecting larval and juvenile survival, as well as the absence of small individuals in our survey and previous surveys, the timing, location/s and frequency of recruitment is worth investigation.

5. Management recommendations

The coconut crab is an important iconic species and has been used by Niueans as a source of protein for centuries. However, due to its slow growth, low survival, erratic recruitment, advances in hunting technology, increasing demand and uncontrolled export, coconut crabs can be exploited faster than they can reproduce and grow. In order to safeguard this important resource for current and future generations, current management approaches must be improved and formalised as management actions and regulations. Schiller (1992) made sound recommendations for the management of coconut crabs in Niue; most of the recommendations are still valid today. To achieve the objectives of sustainable management of coconut crab stock, we recommended the development and implementation of a management plan through participatory and consultative processes. The management recommendations outlined below do not only aim to safeguard stocks, but also to ensure that there are sufficient crabs for food, for their cultural uses, for stock replenishment and for aesthetic reasons.

The management recommendations as follows.

1. **Improve education and public awareness** about coconut crab biology, the life cycle, vulnerability, trends in catch, stock status, and unsustainable and sustainable exploitation practices. Education and awareness programmes should emphasise the types of management approaches and where/when in the life cycle these measures should be applied for the most impact on population sustainability. These programmes should also describe why and how certain management approaches are needed. A well-informed public is more likely to accept appropriate resource management approaches and may assist with compliance with management measures. Education and awareness should be targeted at various levels, (children/adults) and can be in various forms (e.g. posters, pamphlets, videos, radio).

2. **Establish seasonal and area closures when crabs are reproductively active** to ensure that females are protected during the time of greatest reproductive activity, from October/November to March. This protection allows them to mate, brood and release eggs into the ocean undisturbed. Closed areas should encompass coastal zones, areas of high crab abundance, known crab migration paths and spawning sites. The goal is to ensure that as many healthy eggs as possible are released to increase the chances of new recruits coming back to the Niue coconut crab population. Land in Niue belongs to people so when proposing coconut crab closed hunting areas, consultation with land owners and relevant parties such as government departments and village councils is required. Closed areas should be marked with signs and the public informed of them and of closed seasons.

3. **Establish coconut crab reserves** where the environment is kept in as natural a state as possible, and coconut crabs are undisturbed by human harvesting (i.e. harvesting is prohibited) and predation by animals is minimised or eliminated. Where possible reserves should be placed:

   a. where crab densities are high;

   b. where there is sufficient suitable coconut crab habitat (i.e. coastal zone, forest areas);

   c. to encompasses known coconut crab migration paths to the coastline (corridors) and spawning areas (cliffs/sites); and

   d. where it is relatively easy to enforce.

   Communities need to collaborate to identify the most preferred migration corridors and egg release areas. Reserve areas should be reasonably large (several square kilometres). Reserves allow coconut crabs to exist in a near natural state and can be used for educational purposes. As with recommendation 2, when proposing coconut crabs reserves, consultation with land owners is required. Reserved areas should be adequately marked and the public should be informed of them.

4. **Ban or control coconut crab exports.** The relative abundance of coconut crabs has increased but the proportion of large coconut crabs in the population has not increased in Niue since the studies in the

late 1980s and early 1990s. The lack of large crabs is attributed to harvest pressure. Exports of coconut crabs contribute significantly to harvest pressure and should be closely monitored or controlled. Banning exports would help reduce hunting pressure and rebuild stocks so that larger crabs become more common, thus contributing significantly to reproductive output. During interviews with local hunters, all interviewees said that a total ban on exports of coconut crabs would be difficult for Niuean people. If a total ban on exports is unacceptable to the community, then an export quota could be determined annually and allocated amongst residents. This quota would require controls through the issuing of export permits and inspections at Hanan international airport and Sir Robert Rex wharf.

5. **Increase minimum size limit or protect female crabs from being harvested** to allow crabs (particularly females) a better chance to increase in size and contribute to reproductive output. The purpose of a minimum size is to allow coconut crabs to reproduce before capture. The larger the female crab, the greater number of eggs. A 25 mm TL female produces around 100,000 eggs, a female at 35 mm TL can produce around 250,000 eggs and a female 45 mm TL produces around 350,000 eggs (calculated from Helfman 1973). Increasing the minimum size to 40 mm TL would effectively protect 99% of the female population, and increasing it to 45 mm TL would protect 100% of the female population (see Table 7). A 36 mm TL female crab is around 14–15 years old and a 36 mm TL male crab is around 9–10 years old. The proportion of edible flesh from a coconut crab is around 45%; a 36 mm TL crab weighing 400 grams has around 180 grams of edible flesh – a rather small portion of edible protein for an animal of such age. Having a greater number of larger females in the population contributes significantly to reproductive output and subsequent recruitment, thus building the Niue stock to a healthy self-replenishing state. At a meeting open to the public to present preliminary results of the survey work, many in attendance said the current minimum size was too small.When discussing minimum size adjustments, we advise managers to have actual crabs of the current and proposed size limits on display. It is also recommended that minimum size measuring tools be made available for the coconut crab hunting public.

Table 7. Proportion of population protected from adjustments in minimum harvest size.

Size (mm TL)	Female	Male	All	Total weight (g)
>36	98%	74%	83%	400
>40	99%	81%	88%	520
>45	100%	93%	96%	730

6. **Control predators.** Coconut crabs are a key food resource for Niuean people. Uncontrolled predation by feral pigs or domestic dogs causes additional mortality on crabs and should be minimised. Feral pigs should be reduced by regular culling programmes and by supporting improvements in the current project to control feral pigs in Niue. Alternatively, responsible persons could be hired to cull / control feral pig populations. Dogs are not a problem but as 'crab hunting dogs' they may perhaps associate coconut crabs with food, particularly when dog owners do not feed their dogs. Dog owners should be encouraged to improve the care of their dogs to prevent them from hunting crabs at will for food.

7. **Establish a monitoring programme** to monitor the quantity and size of crabs caught and to assess the population status over time. This could be accomplished through creel or log form surveys. Population surveys to determine population abundance, sex ratio and size structure can be done every three to five years. Analysis of the information gathered would measure the success or otherwise of management actions. Monitoring of current regulations governing natural resources should be improved to ensure better compliance and to determine the effectiveness or otherwise of management intervention. Appropriate authorities such as village councils and / or the Department of Agriculture, Forestry and Fisheries should establish monitoring and surveillance activities to deal with non-compliance of rules or regulations for resource management.

6. Further research

This and past surveys provide useful snapshot information on coconut crab stocks in Niue. Our study revealed substantial differences in the abundance of coconut crabs in Niue from previous studies. The survey method has remained the same, with some adjustments to sampling locations to provide a more even spread of sample stations throughout the coastal regions.

To improve the information, regular monitoring of catches (quantity, size, sex) and effort (number of hunters, baits, hunting area) should be collected over time (seasons, years). For understanding spatial patterns of exploitation, monitoring should collect data by region (e.g. village, coastal zone). In addition to this, information on the disposal of catch (e.g. subsistence, gifts, local sale or export) will provide valuable insights into coconut crab exploitation and utilisation. The information can be collected through hunter surveys or log books. It is important to present results of monitoring to stakeholders in a format that is easily understood. Reporting should be on a regular basis (e.g. quarterly or annual summaries).

Follow-up surveys to determine population status can be performed every 3 to 5 years (refer to example of survey design in Figure 21). For consistency and comparison with previous surveys, follow-up population studies should use the same assessment methods (i.e. baited coconut trails) as in previous studies. Future assessments should aim to cover the general area of previous survey stations (Fig. 8; Appendix 1 provides GPS waypoints for baited stations in this 2014 assessment). There should be consistency in the period / season when follow-up surveys are conducted. Due to the behaviour of crabs (foraging, moulting, migration, egg-release, etc.) we recommend follow-up surveys be performed around the dark moon phase during September to late November. This survey assessed 30 stations in three regions and two forest types within each region, and it was completed by nine people in ten days. If capacity and resources (staff, funds, time) hinders large scale follow-up surveys, we recommend that, at a minimum, the following can be done.

- Survey stations[3] in the 0–1 km and 1–2 km coastal regions. (Due to very low encounters of crabs in the interior region, this subset of the population would require considerable effort to sample adequately.)
- Combine forest types (primary and secondary) within each region when deciding on the number of stations to survey. Our results (Section 3.2) showed no significant differences in relative abundance (CPUE) among the two vegetation categories within each region.
- The number of stations to survey in each region to provide CPUE information with reasonable precision depends on many factors. Assuming follow-up surveys are conducted between September and November and are based on CPUE data from this (2014) survey, we suggest a minimum of ten stations be surveyed within the 0–1 km region and a minimum of 16 stations within the 1–2 km region.
- Use 10–15 baits (unhusked, ½ coconuts) per baited trail. Set the baits about 20–40 m apart at stations in the afternoon (around 2 p.m.). Revisit the baited trails to record coconut crabs about an hour after sunset and aim to complete night surveys by 10 p.m.
- Search a baited station once, then move to the next station. If the distance between stations is not too great, a survey team can search two stations in an evening.
- A survey team should comprise a minimum of two people, a team leader (crab searcher) and an assistant to record thoracic length, sex information and the number of baits per station.
- Two survey teams (of two people in each team), surveying two stations each evening, should be able to complete four stations in one afternoon / evening.
- Record one length measure (thoracic length) and sex information (for females record if berried or not berried). This study collected sufficient information to convert thoracic to cephalothoracic lengths and length(s) to weight. There is little need to keep repeating this.

[3] A station is a trail of baited coconuts.

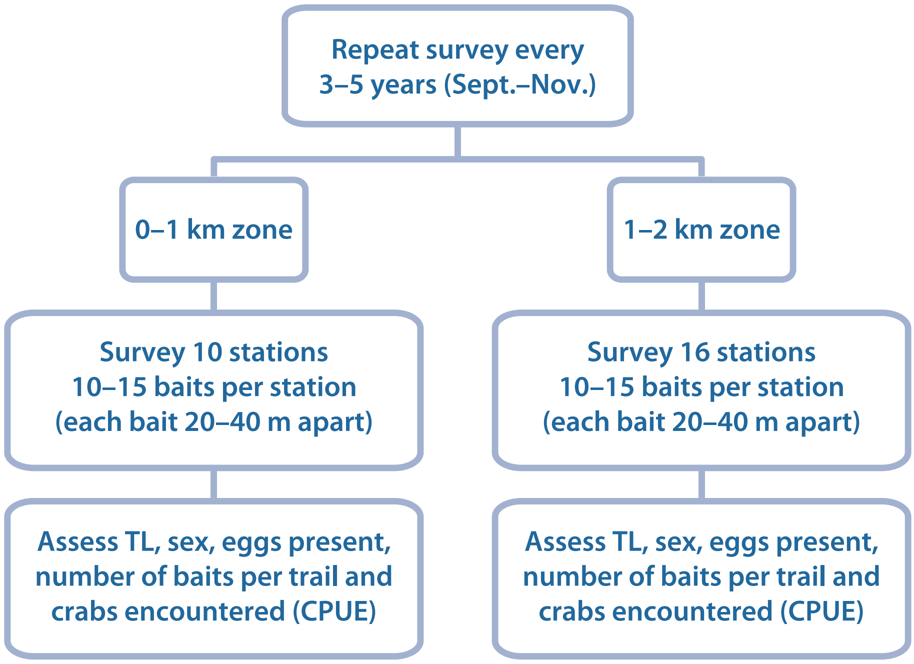


Figure 21. Representation of survey design for repeated coconut crab assessment.

We did not attempt to estimate the population of crabs in the three regions assessed due to uncertainty in the application of the conversion factor (i.e. a CPUE of one coconut crab per bait = 12,000 coconut crabs per kilometre squared) across the three regions of Niue. To estimate population abundance (i.e. how many crabs in the 0–2 km zone in Niue) we suggest that the relationship between CPUE and abundance for the 0–1 and 1–2 km zones be determined. This study is important, particularly for calculating sustainable yields. This requires considerable effort and time and is more suitably addressed through tertiary studies. Quantifying the CPUE and population abundance conversion factor for Niue could be accomplished using a number of different survey methods conducted at the same time and site, e.g. CPUE, mark recapture, transect or quadrats studies.

More comprehensive study into the genetics of the Niue coconut crab population and those of neighbouring countries would improve the understanding of sources of recruitment. Further studies should investigate recruitment patterns to provide a more comprehensive knowledge on the timing, location/s and frequency of juvenile coconut crab recruitment on Niue. These studies are demanding and best accomplished through tertiary education.

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Appendix 1.

Coconut crab survey stations summary information and survey effort and records

Baited trail surveys were conducted 17 to 28 November 2014.

Station information						Survey effort and catch		
Station	Region*	Latitude E	Longitude S	Local names	Forest classification**	Number of baits	Crabs observed	CPUE (crabs bait^{-1})
1	1	169°55.794'	19°03.812'	Tapeu	PCF	10	11	1.10
2	1	169°56.773'	19°04.381'	Anono	PCF	10	18	1.80
3	1	169°54.891'	19°06.083'	Tamakau Toga	SCF	10	14	1.40
4	2	169°53.705'	19°07.077'	Talamaitoga	SCF	10	0	0.00
5	1	169°54.606'	19°08.053'	Sekena Avasele	SCF	12	25	2.08
6	1	169°52.62'	19°08.839'	Vaiea	SCF	10	14	1.40
7	1	169°50.842'	19°08.419'	Mata	SCF	13	16	1.23
8	1	169°49.721'	19°06.923'	Ana	PCF	10	21	2.10
9	1	169°48.592'	19°06.396'	Togo	SCF	12	22	1.83
10	2	169°48.961'	19°06.084'	Togo	PCF	11	6	0.55
11	2	169°48.102'	19°05.175'	Tuafutu	PCF	10	4	0.40
12	1	169°47.035'	19°04.406'	Vailikulu	SCF	20	14	0.70
13	2	169°48.598'	19°02.011'	Malafasi	PCF	10	3	0.30
14	1	169°47.816'	19°01.433'	Motu	SCF	11	14	1.27
15	1	169°48.301'	18°59.345'	Vaitahe	SCF	10	19	1.90
16	2	169°48.894'	18°59.663'	Vatahe	SCF	10	0	0.00
17	1	169°50.76'	18°057.31'	Toi sea track	SCF	10	11	1.10
18	2	169°51.983'	18°57.981'	Tapaki	SCF	10	9	0.90
19	1	169°53.477'	18°58.277'	Makatutaha	PCF	10	21	2.10
20	1	169°55.25'	19°00.574'	Hiku Tavake	SCF	10	17	1.70
21	2	169°54.18'	19°01.272'	Seikena	SCF	10	3	0.30
22	1	169°55.032'	19°01.832'	Alofi north	PCF	10	11	1.10
23	2	169°54.682'	19°03.785'	Tuila	PCF	10	4	0.40
24	3	169°51.063'	19°04.974'	Pagopago	PIF	15	3	0.20
25	3	169°49.148'	19°05.517'	Tuafutu	PIF	15	0	0.00
26	3	169°49.949'	19°03.008'	Utuhina	SIF	20	2	0.10
27	3	169°52.547'	19°03.509'	Togatiti/Paluki	PIF	17	2	0.12
28	3	169°51.496'	18°059.36'	Fupalatao	SIF	15	1	0.07
29	3	169°52.957'	19°06.052'	Tegamoho	SIF	15	0	0.00
30	1	169°46.98'	19°02.956'	Tautu	SCF	10	14	1.40

* 1 = 1 km from coastline; 2 = from 1 km and up to 2 km from coastline; and 3 = more than 2 km from coastline (i.e. the interior region).
** PCF = primary coastal forest; SCF = secondary coastal forest; PIF = primary interior forest; and SIF = secondary interior forest.

Appendix 2.

Niue coconut crab CPUE (number of coconut crabs per bait)

CPUE statistics by region and vegetation category derived from the November 2014 survey.

Region/Forest Category	Stations	Average CPUE	STDEV	SE
1 km coastal primary forest	1, 2, 8, 19, 22	1.64	0.51	0.23
1 km coastal secondary forest	3, 5, 6, 7, 9, 12, 14, 15, 17, 20, 30	1.46	0.40	0.12
1–2 km coastal primary forest	10, 11, 13, 23	0.41	0.10	0.05
1–2 km coastal secondary forest	4, 16, 18, 21	0.30	0.42	0.21
Interior primary forest	24, 25, 27	0.11	0.10	0.06
Interior secondary forest	26, 28, 29	0.06	0.04	0.02

STDEV = standard deviation; SE = standard error.

Aggregated (primary and secondary forest) CPUE statistics for the three regions (1 km coastal, 1–2 km coastal and interior) derived from November 2014 survey.

Region	Stations	Average CPUE	STDEV	SE
1 km coastal	1, 2, 3, 5, 6, 7, 8, 9, 12, 14, 15, 17, 19, 20, 22, 30	1.51	0.43	0.11
1–2 km coastal	4, 10, 11, 13, 16, 18, 21, 23	0.36	0.29	0.10
Interior	24, 25, 26, 27, 28, 29	0.08	0.08	0.03

CPUE estimates derived from previous studies in Niue.

Unpublished data (1997)*	CPUE
Coastal primary forest	2.23
Inland primary forest	0.55
Light and scattered secondary forest	0.50

* Data provided by Niue Department of Environment. This survey was conducted within the Huvalu Forest Conservation Area.

Schiller (1992)	CPUE
Coastal forest	0.378
Primary forest (coastal)	0.070
Light and scattered forest (coastal)	0.063
Primary forest (> 2 km inland from coastline)	0.014
Light scattered forest (>2 km inland from coastline)	0.000

Appendix 3.

Summary information on coconut crabs studies from various countries

Island	Island type	Max. size TL (mm)		Average size (TL mm)		Sex ratio	Mean CPUE	Exploitation status/history	Source	Survey method
		Females	Males	Females	Males	F : M				
Niue	Up-raised	35	53	27.0	32.5	0.9 : 1	*App. 2*	Heavy	Schiller (1992)	Baited trails
Niue	Up-raised	41	55	29.0	33.0	0.6 : 1	*App. 2*	Heavy	*Unpublished data (1997)*	Baited trails
Niue	Up-raised	39	55	27.0	33.0	0.4 : 1	*App. 2*	Heavy	Barnett et al. (2008)	Baited trails
Niue	Up-raised	43	61	26.0	31.0	0.6 : 1	*App. 2*	Heavy	*This study*	Baited trails
Guam	Up-raised	47	76			0.4 : 1	~	Heavy	Amesbury (1980)	No baits used
Saipan (CNMI)	Up-raised			27.3	29.6		0.24	Heavy	Kessler (2006)	Baited trails
Hog Harbour A (Vanuatu)	Up-raised			29.8	38.7		0.25	Heavy	Fletcher et al. (1991)	Baited trails
Kole coast, close (Vanuatu)	Up-raised			32.0	37.0		0.13	Heavy	Fletcher et al. (1991)	Baited trails
Bokissa Island (Vanuatu)	Atoll			28.9	32.0		0.30	Heavy	Fletcher et al. (1991)	Baited trails
Hog Harbour B (Vanuatu)	Up-raised			29.8	38.7		0.43	Moderate	Fletcher et al. (1991)	Baited trails
Hog harbour ocean (Vanuatu)	Up-raised			30.7	41.8		0.48	Moderate	Fletcher et al. (1991)	Baited trails
Hog Harbour point (Vanuatu)	Up-raised			30.2	43.3		0.50	Moderate	Fletcher et al. (1991)	Baited trails
Kole cliff (Vanuatu)	Up-raised			30.0	35.6		0.40	Moderate	Fletcher et al. (1991)	Baited trails
Nukunonu (Tokelau)	Atoll	65	71	34.5	39.0	0.6 : 1	~	Moderate	Pasilio et al. (2013)	Transects
Kole coast (Vanuatu)	Up-raised			39.0	42.0		1.00	Light	Fletcher et al. (1991)	Baited trails
Maeva cliff (Vanuatu)	Up-raised			37.3	45.2		0.40	Light	Fletcher et al. (1991)	Baited trails
Maeva coast (Vanuatu)	Up-raised			36.0	47.8		0.50	Light	Fletcher et al. (1991)	Baited trails
Tegua Island (Vanuatu)	Atoll			38.9	54.7		4.20	Light	Fletcher et al. (1991)	Baited trails
Hiu islands (Vanuatu)	Atoll			36.8	53.3		5.00	Unexploited	Fletcher et al. (1991)	Baited trails
Igurin (Enewetak, RMI)	Atoll	52	74	34.5	44.5	0.6 : 1	~	Unexploited	Helfman (1973)	No baits used
Taiaro (French Polynesia)	Atoll	60	67	40.2	46.7	1.4 : 1	~	Unexploited	Chauvet and Kadiri-Jan (1999)	Transects
Diego Garcia	Atoll			38.0	42.0	0.4 : 1	2.10	Unexploited	Vogt (2004)	Coconut baits
Minni Minni Conservation Area	Atoll			42.0	48.0		1.78	Unexploited	Vogt (2004)	Coconut baits

~ No CPUE information available.

Appendix 4.

Thoracic length frequencies of coconut crabs from studies in Niue and Tokelau

Size class (mm)		Niue (1990)[a]		Niue (1997)[b]		Niue (2008)[c]		Niue (2014)[d]		Tokelau (2012)[e]	
Range	Mid-point	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
6.0–7.9	7										
8.0–9.9	9										
10.0–11.9	11							1	1	1	2
12.0–13.9	13		1							1	1
14.0–15.9	15		1				1	3			1
16.0–17.9	17	3	1	1				1	4		
18.0–19.9	19						2	8	10	1	
20.0–21.9	21	3	2	5	3	3	2	13	17	4	4
22.0–23.9	23	11	19	5	6	3	4	19	19	2	2
24.0–25.9	25	33	12	8	5	4	6	22	28	5	4
26.0–27.9	27	23	20	7	6	3	5	39	31	2	3
28.0–29.9	29	20	23	12	7	4	6	20	21	2	2
30.0–31.9	31	19	16	11	10	6	7	18	24	16	21
32.0–33.9	33	8	16	8	12		3	8	15	3	5
34.0–35.9	35	3	11	3	12	2	7	6	24	10	10
36.0–37.9	37		10	1	6		1	1	7	4	3
38.0–39.9	39		8	4	13	1	5	1	11	4	3
40.0–41.9	41		5	1	1		3		16	9	11
42.0–43.9	43		4		7		1	1	8	4	3
44.0–45.9	45		2		3		2		7	5	9
46.0–47.9	47		4		1		0		7	1	3
48.0–49.9	49		4		3		1		3	3	3
50.0–51.9	51		1		1		5		4	2	8
52.0–53.9	53		1				2		1		3
54.0–55.9	55				2		1				3
56.0–57.9	57										
58.0–59.9	59								2		2
60.0–61.9	61								1	1	11
62.0–63.9	63										
64.0–65.9	65									1	
66.0–67.9	67										
68.0–69.9	69										
70.0–71.9	71										1
Sample size	**123**	**161**	**66**	**98**	**26**	**64**	**161**	**261**	**81**	**118**	

[a] Schiller (1992); [b] Huvalu conservation area coconut crab survey data, Niue Department of Environment ; [c] Barnett et al. (2008); [d] current study; [e] Pasilio et al. (2013).

Appendix 5.

Summary statistics of monitoring of exports of coconut crabs via x-ray inspection of passenger baggage/cargos and interviews with departing passengers at Hanan international airport

Sample date	Sampled by X-ray					Sampled by interviews				
	No. of passengers taking crabs*	Total no. of crabs	Average no. crabs per passenger*	Range #		No. of passengers taking crabs*	Total no. of crabs	Average no. crabs per passenger*	Range #	
				Min	Max				Min	Max
7-Mar-14	23	139	6	2	12	20	153	8	1	17
18-Apr-14	11	80	7	3	14	13	98	8	2	20
2-May-14	7	52	7	2	12	7	55	8	2	12
23-May-14	11	76	7	1	17	17	97	6	1	17
3-Jun-14	13	100	8	3	14	*No interviews*				
6-Jun-14	*Data not used in analysis*					13	131	10	2	28
4-Jul-14	15	104	7	2	17					
22-Jul-14	16	176	11	1	27	16	163	10	1	40
26-Aug-14	13	154	12	3	36	*No interviews*				
29-Aug-14	*Data not used in analysis*					*No interviews*				
19-Sep-14	13	107	8	1	20	17	165	10	2	40
14-Oct-14	27	280	10	2	20	*No interviews*				
11-Nov-14	4	35	9	2	25	*No interviews*				
15-Nov-14	8	62	8	1	18	*No interviews*				
29-Nov-14	*Data not used in analysis*					*No interviews*				
6-Dec-14	21	138	7	1	27	*No interviews*				
13-Dec-14	16	166	10	1	33	15	120	8	1	35
24-Jan-15	11	80	7	1	15	*No interviews*				

* This includes a single passenger or groups, for example families, where an individual was responsible for checking in baggage or responding to interviews. The data were collected in such a way that separating travelling individuals from families or groups was not possible.

the minimum and maximum number of crabs taken abroad for a passenger (individual or group).

Appendix 6.

A note on farming or culturing coconut crabs

Coconut crabs fall into the category of a protein food resource in short supply. It may, therefore, be subject to farming or culturing to supply highly sought-after animal protein or for rebuilding depleted stocks. The biology of coconut crabs dictates very slow growth, a pelagic larval phase, unpredictable recruitment and a very cryptic juvenile phase. These biological characteristics are major bottlenecks to farming or culturing coconut crabs as food for people or for restocking depleted wild populations. Unpredictable recruitment means that the supply of juveniles from natural recruits is unreliable. The juvenile cryptic phase means that if juveniles are around, they are obscure or hidden so considerable effort is required to locate them for further grow-out. For farming, the ideal approach is to culture crabs throughout their entire life cycle, rather than collecting wild juveniles and rearing these to a size suitable for consumption. The pelagic larval phase is not well studied, so considerable research and money are required to fully understand this phase and to close the life cycle for successful artificial breeding. Finally, the slow growth means it will take more than ten years for very small coconut crabs (<5 mm TL) to reach a size suitable for food. During the grow-out period, the cultured crabs will need to be fed, kept in an enclosure, and disease or predation will need effective control measures. There remains a considerable amount of research required to fulfill coconut crab farming knowledge.

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