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Stock Assessment of Coconut Crabs

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W.J. Fletcher and M. Amos

Background

Coconut crabs are a resource unique to the island communities of the tropical Indo-Pacific region. They are the largest land-dwelling crustaceans, having been found to attain weights in excess of 5 kg. The crabs can form an important cash crop, especially for communities in remote regions. They are in demand for restaurants because of their peculiar looks, habits and in some places, their presumed aphrodisiac properties (Brown and Fielder 1991). They have, therefore, often been the target for intensive harvesting which, exacerbated by their ease of capture and basic biology, has resulted in the numbers of crabs in many regions having declined quickly. In some areas and countries the crabs are virtually extinct (e.g. Amesbury 1980). For the continued survival of the crabs, particularly as a commercially viable commodity, adequate management must be implemented in any area where the crabs are being harvested.

To manage any stock rationally it is essential to have information on their basic biology and some assessment of the number of crabs remaining in the area. The biology of coconut crabs has been extensively studied during the past 10 years, much of their life history being determined through the ACIAR study in the Vanuatu region (see Brown and Fielder 1991; Fletcher 1993, for reviews). Furthermore, this project developed methods of stock assessment (Fletcher 1988a and 1988b; Fletcher et al. 1991b; Fletcher 1992) which utilised the results of field sampling plus experimental additions and removals. From these, a relatively simple system was developed to convert the catch rate of an area into an estimate of the number of crabs remaining (Fletcher et al. 1990b). Using this system, estimates of the number remaining in the heavily fished regions of Vanuatu have been calculated (Fletcher 1988b), from which a series of management

regulations was formulated that included a minimum legal size, closed seasons and catch quotas for various areas (Brown et al. 1991). These methods have also been employed for assessments of coconut crabs in the Niue region (Schiller 1988) and are still being used to monitor the impact of management on the number of crabs in Vanuatu (Fletcher 1992).

This manual has been written to assist circulation of the methods developed in northern Vanuatu for use in other countries where coconut crabs are found. The methods are not complicated, nor do they involve large amounts of time or equipment. Most of the analyses are very simple. This manual includes a summary of the biology of the coconut crab, particularly areas that potentially affect the reliability of this stock assessment method; for more complete reviews of the crab's biology, the cited references should be consulted. There is a complete description of the field methods used to sample the crabs,

especially items not covered in previous publications. Finally, the manual includes discussion of the assumptions and rationale for the procedures used to convert between catch rates and the estimate of crab numbers in an area, including where subsequent data have indicated problems and biases in some of the analyses. Hopefully, this should allow local research staff to replicate the sampling strategies with relative ease and not fall into the same traps as encountered in the original studies, or at least to understand their limitations. Further work in this field may help increase understanding of the species and possibly tighten the estimates used in the calculations.

Coconut Crab

Biology and Behaviour

The coconut crab, *Birgus latro* L., belongs to the Phylum Crustacea, Class Anomura, Family Coenobitidae which includes most of the land-based hermit crabs. *Birgus* is unique in that it dispenses with the habit of protecting its abdomen with a gastropod shell at a very small size (< 10 mm). The crabs are most commonly found on island habitats, and on big islands, only in the coastal regions up to 4 km from the ocean. The areas

inhabited are mainly dense forest regions, the crabs typically requiring additional protection, e.g. cracks, crevices, caves and hollow tree stumps, in which to hide. Crabs found further inland are associated more closely with defined shelter areas that are generally uplifted coral limestone reefs, common throughout most islands in Vanuatu. Importantly, they are not usually found in areas cleared for agricultural purposes or where livestock is kept.



Unlike other hermit crabs, coconut crabs are generally solitary individuals. At low densities, the crabs are found out only at night, but at high densities are found out also during the day, and more so during the wet season (Fletcher 1988b; Reese 1987). This additional daytime foraging is probably a response to reduce the number of encounters between coconut crabs, which Helfman (1977a) showed could lead to damage and even death of individuals. The frequency of foraging

Large and small coconut crabs.

appears to vary among areas and this may also be a response to local environmental conditions and crab abundance. Thus, Helfman (1973) concluded that on an islet in Palau where crab numbers were high, foraging occurred every night during the wet season, whereas Reese (1987) concluded that this was reduced to every fourth night during the dry season. Fletcher et al. (1990a), by contrast, found that in an area where the density of the crabs was relatively low, the frequency of foraging was only 5–10% of the population per evening. The crabs are capable of homing to specific locations often in excess of 100 m apart (Fletcher et al. 1990a). But most importantly for stock assessment purposes, on larger islands the crabs moved out of sampling areas within a week to a few months, precluding the use of mark-recapture experiments on all but the smallest islands (Fletcher et al. 1990a).

The crabs are omnivorous scavengers, eating the fruits of many trees, rotting leaves and

animals that they can find or capture including, on occasion, other coconut crabs (Gibson-Hill 1947). Their survival is not dependent upon a supply of coconuts, although if present these are certainly eaten, especially by larger individuals (Reese 1987; Fletcher 1993). They are, however, dependent upon access to sea water which they drink on occasion, presumably to maintain their osmotic balance (Gross 1955).

The growth rate of the crabs is slow. They moult in underground burrows with the frequency of moulting dependent upon their size. Small crabs of less than 20 mm thoracic length (TL) (Fig. 1) probably moult 2–3 times per year. Those greater than 25 mm TL (approximately the size at sexual maturity) moult only once per year, generally in the dry season, and very large crabs may not moult every year. The increase in size following each

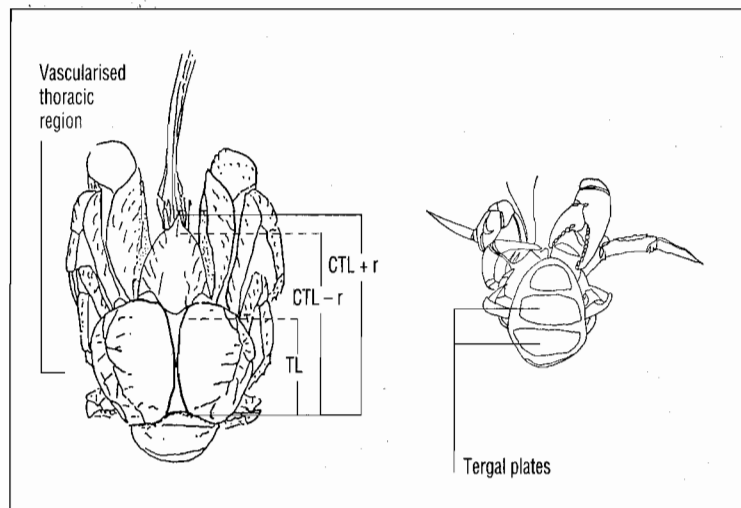


Figure 1. Dorsal view of a coconut crab showing the standard measurements taken. TL refers to thoracic length, CTL refers to the cephalothoracic length, including (+r) or excluding (-r) the rostrum. d is the distance (mm) between the first and second tergal plates used in the calculation of the abdominal expansion index.

moult is also not large, especially in bigger crabs (being less than 3%), probably a result of the limitations of moulting in a terrestrial environment (Fletcher et al. 1990c, 1991a). Consequently, it takes male crabs over 10 years to exceed the legal size in Vanuatu (9 cm cephalothoracic length, CTL-r) (Fig. 1) at a size of approximately 0.7 kg, and the crabs probably take in excess of 40 years to attain maximal size (> 4 kg). Females grow at even slower rates than males after sexual maturity and are rarely seen larger than 11 cm CTL even in unexploited populations (Helfman 1973; Fletcher et al. 1991b).

Coconut crabs are sexually mature at approximately five years of age, at a size of 22-25 mm TL (Fletcher 1988b; Schiller et al. 1991). Females may be easily distinguished from males by the presence on the ventral surface of the abdomen of three feathery pleopods used to support the egg-masses.

A moulting crab.

Copulation takes place on land with the female in a hard-shelled condition (not with a soft carapace just after moulting, as occurs in some crustaceans) (Helfman 1977b) with the spawning season occurring over the summer period (Schiller et al. 1991). Eggs are extruded 2-3 weeks after copulation and are initially bright orange, but during the gestation period of 25-45 days (Schiller et al. 1991) the embryo's eyespots develop and

the eggs darken. At the time of spawning, the eggs have become a dark brown or purple colour. The females release the eggs into the ocean just after dark and generally when a high tide at dusk coincides with a dark phase of the moon (Schiller et al. 1991). The eggs hatch on contact with the water and develop through four zoal larval stages, which takes a total of 2-3 weeks (Fig. 2).



The larvae remain in the upper layers of the water column by a combination of phototactic and geotactic responses until the final larval stage metamorphoses into an amphibious glaucothoe stage that is benthic in nature. Upon finding and entering a suitable gastropod shell, the glaucothoe emerges from the water and inhabits the upper intertidal areas, particularly areas where there is abundant coral rubble

that is shaded. This stage is particularly hard to find, being small and generally hidden under surface layers of rubble. It is also difficult to distinguish from other coenobitid glaucothoe but differ (among other criteria) in that they have a prominent rostrum which is lacking in the glaucothoe of other coenobitids (Reese and Kinsie 1968; Schiller, pers. comm.).

The glaucothoe metamorphoses into a juvenile coconut crab at a size of approximately 5 mm CTL. At this stage some reports indicate the crab is still using a shell (Reese and Kinsie 1968; Reese 1987), but Schiller (pers. comm.) has seen them at this size with no shell. This is also a very difficult stage to find. Enclosure studies (Held 1963; Fletcher 1988b) have shown that these stages are buried most of the time and only forage infrequently and for short periods.

Given the difficulties in finding juvenile crabs, estimates of recruitment are virtually non-existent. The only available data come from the examination of the numbers of the smallest size classes (20–30 mm TL) vulnerable to usual collection methods (Fletcher et al. 1991b). These indicate that recruitment varies between areas and may not be consistent among years, but it is an area of research that is far from conclusive.

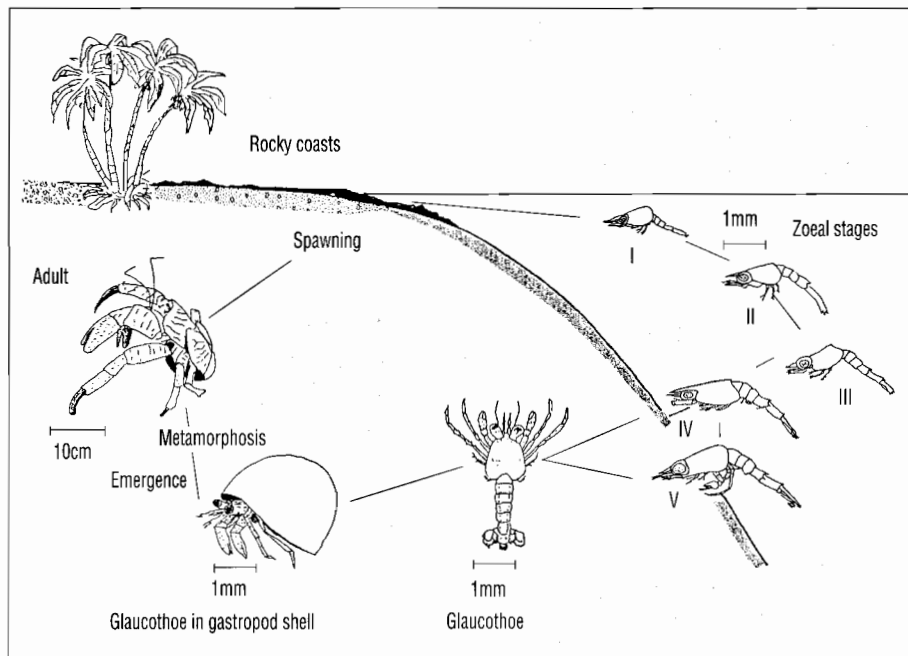


Figure 2. Summary of the life-history stages of the coconut crab.

Field Sampling

The basic method used in all our studies to sample the crabs utilised the same techniques as those of local crab collectors throughout Vanuatu. This was the 'baited trail' method, which involves cutting a trail through the jungle during the daytime (the first time in an area), or following an established trail, along which a number of coconut baits are placed. The trail is revisited after dark and the crabs that have been attracted to the baits or are merely found on the trail are captured, measured and recorded. The following sections detail the precise methods that should be used to both plan and execute a successful sampling program for coconut crabs.

Where to do the transects

The transects in Vanuatu were made using a combination of regions already being baited by local hunters and areas through which new trails were cut. Most sampling was restricted to areas where the vegetation, geology and proximity to the ocean were

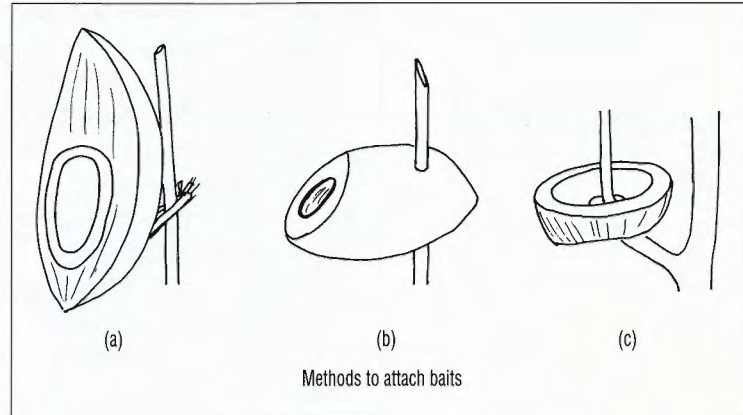
consistent with a high likelihood of crabs being found (see notes on habitat). If in doubt, ask the local people where they hunt or would hunt. It is important to be able to distinguish areas of different habitat so that their area and catch rates can be determined for later calculations. It should be noted also that cutting new trails in areas where the forest is not a mature canopy can take many hours and hard work. These trails varied in length from 100 m to about 500 m, depending upon local conditions. In general, the steeper the area, the shorter the trail.

Where and how to put out baits

In these studies, only unhusked coconuts were used as baits. The method of splitting and attachment of the baits varied among locations, particularly where crab densities differed. In areas of medium to low crab density, the unhusked coconuts were split into three pieces, strands were pulled off the back of the husk of each bait and used



to tie the bait to vines, nearby trees or, if necessary, to stakes driven into the soil (Fig. 3a). In areas of high density, only a small piece was sliced off the top of the coconut (leaving most of the nut intact), which was then skewered onto stakes (Fig. 3b). This latter style of baiting prevents the large crabs removing the small opened baits before the trail is revisited. In each case, the baits must be very secure, as coconut crabs are very strong and can break small attachments quickly. There are other methods of putting out baits demonstrated but not used here, for example, husking the nuts, chopping them in half and



creating a small hole in the top of each half (making them a doughnut shape). Each ring is then dropped on to a stake (Fig. 3c). These take a long time to prepare but have the advantage of being light and compact to carry. This could be relevant if no coconuts are available in an area to be sampled, some distance away from vehicle access.

Initially in these studies both 'random' and 'targeted' baits were used. Targeted baits are defined as those put within 3 m of a ledge, crevice or some other structure likely to house a coconut crab, whereas random baits are put anywhere along the

Figure 3. Diagram of the three main methods of attaching coconut baits.

trail. To test the relative effectiveness of these two methods, at three different sites a number of coconuts were placed out at random intervals and their rate of capture compared with baits placed in targeted areas (Table 1). Abundance was rated in terms of catch per unit effort (CPUE), determined by the number of crabs caught/the number of baits set (see later for details). In a paired analysis, the number caught at the targeted baits was always significantly greater than at random baits, and in many cases none of the random baits attracted a single

crab. It was therefore decided that because only limited numbers of coconuts could be carried, and the catch rate in many areas was already low, to maximise the number of crabs caught in every visit, only targeted baits were used.

Table 1. Number of crabs caught at randomly placed baits compared with baits placed near areas where coconut crabs were considered likely to be hiding.

	Random	Crevice
Mean CPUE	0.069	0.229
s.d.	0.02	0.092

Paired t-test
 $F = 6.5$ $n = 15$; $P < 0.05$

When placing the coconuts along the trail, it is essential to make a rough sketch or 'mud map' indicating the location of each bait (Fig. 4). It is easy at night to miss baits, particularly if there are no crabs on them. Similarly it is easy to get lost walking through the bush, losing the trail, and maps make this less likely. What is more important, if a crab has taken a bait it is vital that it be recorded. Without a map it is difficult to remember

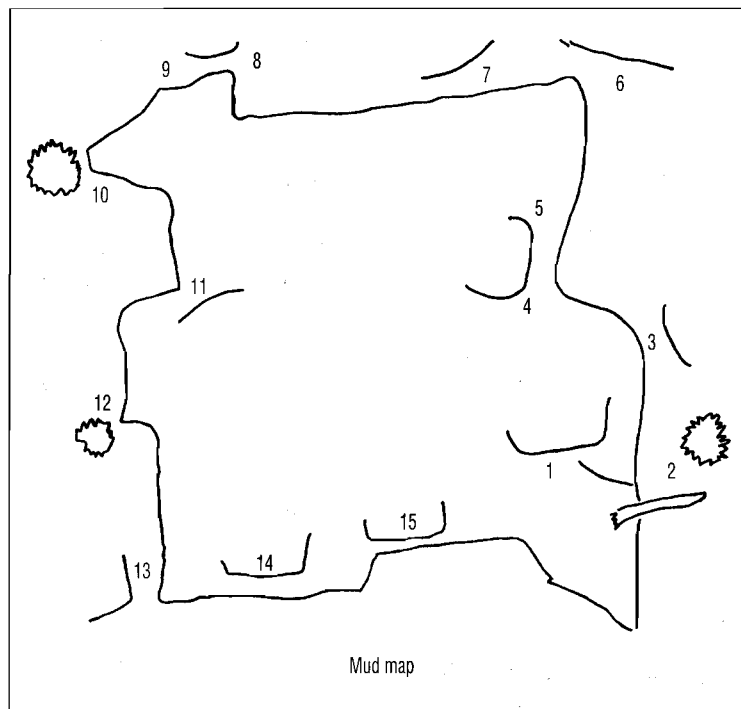
where every bait was put and many can be missed, particularly the first time an area is baited.

The baits should not be attached too close to a crevice (i.e. < 30 cm), as the crabs will be too hard to capture. They will be able to retreat quickly into the hole and there will not be enough room to grab them easily.

Similarly, the baits should not be too far from a hole (> 3 m) because this reduces the likelihood of the crab emerging.

In general, about 50–70 baits were put out on any one sampling trip in areas of low to

Figure 4. An example of a 'mud map'. All baits put out during the day are revisited and it can be determined when a bait has been removed.



medium abundance. These were usually divided into 3–4 transects each of 15–20 baits. In areas of high abundance only 20–30 baits were put out, as it is difficult to cope with more than 100 crabs in one trip.

Timing of visits

A number of different temporal scales are involved in influencing the timing and frequency of sampling.

Time of year

As stated in the summary of the crab's biology, most crabs vulnerable to being caught by the bait method bury once a year during the dry season to moult. In addition, the foraging frequency is likely to be lower in the dry season, even for crabs not moulting. The combination of these two behavioural characteristics results in catch rates having a seasonal cycle, with a peak in the wet season

and a minimum in the winter dry season (Fig. 5). Thus for proper stock assessment studies, sampling should be restricted to the summer wet season when the catch rate should be at a maximum.

Effect of local conditions

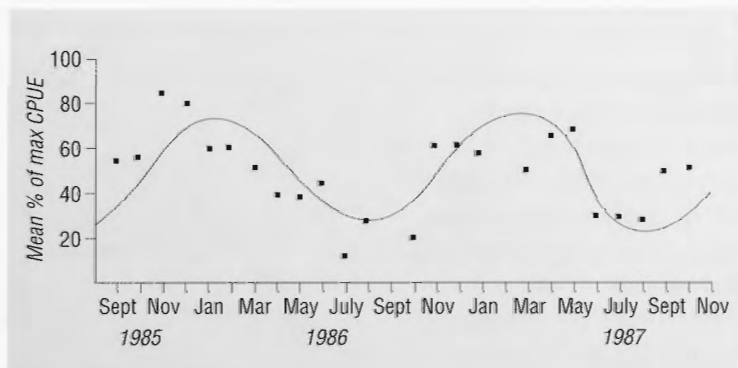
Even when the annual variation in catch rates has been taken into account, local weather conditions are still likely to influence the catch rate on any one night. If the area is unseasonably dry, this may artificially depress the catch rates obtained. Similarly, if it rains for the first time in weeks just before the baits are revisited then this may artificially raise the catch

rates. Finally, too much rain during the walk can result in virtually no crabs emerging that evening. If it is suspected that conditions are abnormal and the catch rate has been affected, the transect should be repeated on another night.

Influence of the moon

When the moon is up, light levels in bush at night are naturally higher. There are many collectors who insist that this reduces their catch rates. Our data showed no such tendency but, to be on the safe side, sampling is best done in the two weeks after the full moon has started to wane and moonrise occurs at least two hours after sunset.

Figure 5. Seasonal cycle in the CPUE of all Santo sites, expressed as a percentage of the maximum value recorded at any site.



Time for putting out baits

Baits should be put out at least three hours before sunset to minimise the possibility of disturbing crabs that may have started to emerge. If cutting a new trail, start about midday. The exceptions to this are areas where crabs are in such large numbers that they forage during the day, when baits are put out too long before sunset they may be consumed prior to being revisited, despite being only partially opened.

Timing of walks to revisit the baits

As the studies began, originally three visits were made, at two-hourly intervals, along each of the baited trails, the first visit being within 15 minutes of full darkness. It was found that more than 80% of the crabs caught on any one night were obtained on the first walk of the evening (Fig. 6), the second yielded only about 10%, and the third less than 5%. In fact, often no crabs were caught

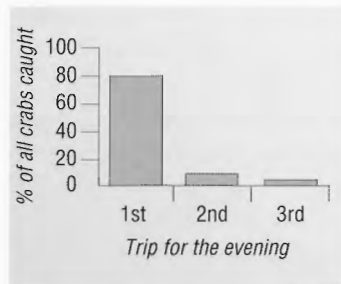


Figure 6. Percentage of all crabs caught in an evening on the first, second and third trips done along the transects. Each of these visits was at least two hours after the previous visit.

on the later visits. Because of the poor returns on these additional visits they were discontinued as being a waste of time. All catch-rate data here come from a single walk around the trails.

The difference in the rate of capture between visits could have been due to (a) most of the crabs that would come out that evening being captured on the first walk, (b) crabs which may have come out after the first visit being disturbed by the first visit, or (c) that at a later time, the crabs are simply less active. An indirect method of testing these three

possibilities utilises the fact that a number of transects is done in any evening and the second and third have to be done after the first, in some cases up to two hours later. Examination of these data found no significant differences in the numbers of crabs caught during transects begun at different times, but those for second transects were slightly greater than the other two, albeit not significant (Table 2).

Table 2. Difference in the catch rate of crabs at baits on the first, second and third transects during the same night.

Transect	1st	2nd	3rd
CPUE	0.1523	0.1540	0.144

A more direct method of testing the effect of starting-time on the number of crabs caught was merely to start the first transect later. In these samples there was a slight tendency for reduced captures of crabs compared to those transects begun immediately after dark, but again it was not significant (Fig. 7). More importantly, there was no difference in the size of crabs

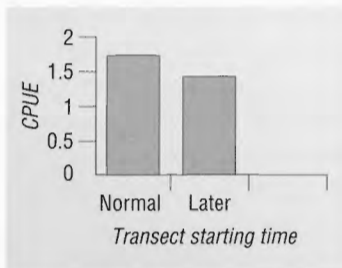


Figure 7. Average CPUE values for transects which were started at progressively later times.

caught or any variation in their sex ratio (Table 3).

It is interesting to note that collectors in the Torres Islands now insist that the best time to catch crabs is later in the evening, beginning transects at about 2300. If true, it represents a change in the effective effort of the hunters who, previously, when crab numbers were very high, went just after dark or else the baits would have been removed.

Table 3. The catch rate and mean size of male and female crabs captured on the first visit along a transect which were begun at different times after dark.

	CPUE	Male TL (mm)	Female TL (mm)
Just after dark	0.177	41	26
> 2 hours after dark	0.144	39	31

Thus to ensure that the catch rate is consistent with previous methods, it was vital that the transects be made not long after dark and not altered because of changing crab abundance, otherwise the results could be confounded.

To summarise, the optimal strategy for sampling the crabs is to walk once around the bait trail, with the first transect beginning just after last light.

Basic equipment required

1 A bush knife (copra knife, machete) for chopping the baits and also the trails. Each person should have a knife during the setting out phase. Generally only two or three people were involved in sampling.

- 2 Each person requires a torch, preferably a head lamp torch which leaves both hands free to capture the crabs, clamber over rocks and trees, and make measuring and recording easier.
- 3 A set of callipers is the easiest device to measure the crabs, but a ruler will do if callipers are not available.
- 4 If required, a spring balance to weigh the crabs. There are a number on the market that weigh crabs in the range up to 5 kg, but they are expensive and two or three are needed adequately to cover the range (0–500 g; 0–2 kg; 0–5 kg), depending on the size of crabs in the sampling area. Do not let the crab grab the end of the balance while weighing. Crabs often grab the main body of the balance and, with their strength, crush it and ruin the balance. Attach at least 30 cm of rope or vine to the end of the balance, and let the crab grab that.

- 5 Some type of recording board is needed. Plastic or waterproof paper guards against spoilage of the data on normal paper if it rains. Even if there is no rain, the humidity and even the excess perspiration of the recorder can ruin a normal page—it is hot sweaty work!

What to record on the transects

At the beginning of each transect record the time the baits were put out and the time started back along the trail after dark, whether the area is wet or dry, how strong the wind is, whether the moon is up and at what stage of its cycle it is. At the end of the transect record the time the transect was finished, and any relevant notes about conditions or what has been seen.

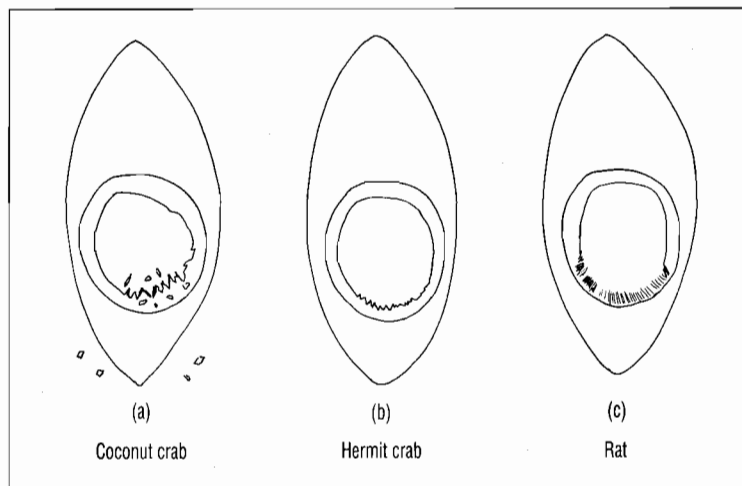
At each bait location write down what was found. Were there any coconut crabs? If so, how many? Our studies counted even those seen but not caught. If more than one crab, we made notes on

which crab(s) was actually on the bait, and which around the bait. If there were none in the area surrounding the bait we looked at the coconut flesh to see if there was evidence of a coconut crab having already fed and left the area before our reaching the bait. We also recorded the number of other coenobitids on or near the bait, or whether it appeared that rats had been eating it. Finally, we recorded whether a bait was no longer present. These missing baits were assumed to have been taken by coconut crabs and the remains

of the bait were often found at the back of a nearby crevice. Between baits we also recorded any coconut crabs that were seen or captured.

It took us about one year of sampling to understand the distinguishing features of the different feeding marks made by these three groups. Coconut crabs generally make large incisions in the flesh of the coconut and leave chunks lying around on the ground (Fig. 8a).

Figure 8. Diagram of the three possible feeding marks seen on coconut baits: (a) coconut crab, (b) other hermit crabs, and (c) rats.



Other coenobitids take out smaller bites and generally do not leave large chunks on the ground. It is relatively easy to distinguish feeding by rats because they make very neat gnawing marks on the coconut flesh, which looks as if it has been filed (Fig. 8c).

What to measure on each captured coconut crab

Length and size

During the main coconut crab study we measured a large number of variables on each captured crab. These basic measurements included the cephalothoracic length (CTL), both plus and minus the rostrum, the thoracic length (TL), the length of the large (left) chelae (see Fig. 1) and the weight of the crab. Subsequent analyses showed that all these variables were well correlated so in all later studies only the thoracic length (TL) has been measured. This greatly speeds up the sampling process because it is difficult to measure the CTL and chelae due

to the crab's strength and dislike of being captured. The TL can be measured with one hand pushing the crab down on the ground using the walking legs to cover the claws. Other methods require picking up the crab in an awkward position that often requires one person to hold the crab while another measures it. This takes much longer to accomplish.

There is one potential problem measuring the TL of coconut crabs using callipers. The anterior

(head) end of the thorax is located in the centre of a dip and if the rounded ends of the callipers are merely lodged in this area it tends to underscore the length of the crab by a few mm (Fig. 9b). To measure the TL either use the callipers upside-down using the sharp points located on this side, or use the posterior end of the TL as the anchor and push the callipers open until they line up with the distinct line at the top of the thorax (Fig. 9a).

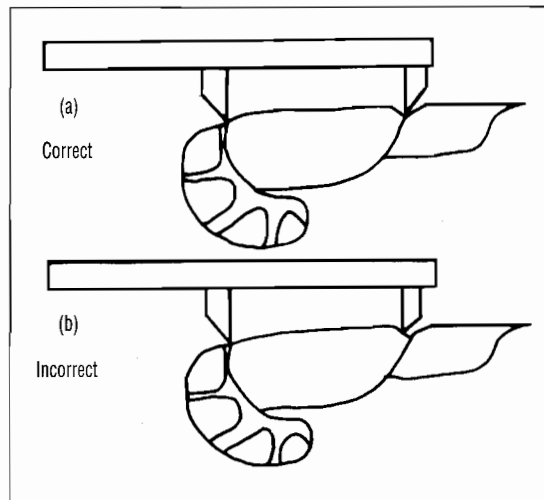


Figure 9.
(a) How to measure properly the thoracic length, and (b) the danger of under measuring.

Abdominal expansion

The level of expansion of the abdomen was also measured in our studies. This is the distance between either the second and third tergal plates or the first and second, whichever is the larger (Fig. 1). This measurement was taken because it has been observed in previous studies (Amesbury 1980; Fletcher et al. 1990c, 1991a) that the abdomen of the coconut crab swells considerably prior to moulting, while in contrast, all newly moulted individuals have no abdomen expansion and their tergal plates overlap. It was shown (Fletcher et al. 1991a) that the closeness to moulting can be predicted from the degree of expansion of the crab's abdomen. In females, however, a large abdomen (particularly if the ventral side appears red) can indicate the presence of eggs and that the female is ready for mating. In taking this measurement, be careful not to touch the abdomen or the crab will pull the abdomen in, reducing the measurement considerably. Similarly, if the crab is held down

on the ground too firmly while being captured or measured, this can also reduce the abdomen expansion measurement.

Shell (exoskeleton) index

An index of the newness of the exoskeleton ('shell') of each crab caught was also recorded. This was a subjective scale which rated individuals from 1 (moulted in the last week or two) to 4 (not moulted for about one year). The criteria used to evaluate these differences were the general

appearance of the shell, colour, softness, scratches, etc. The best indicators were the condition of the walking legs, particularly the dactyls (terminal segment). In newly moulted individuals the dactyls have numerous fine hairs and needle-sharp points (Fig. 10a). With time the dactyl tips become blunt and the hairs are progressively rubbed off (Fig. 10b). It is possible that the time taken to progress from 1 to 4 may vary among areas, depending upon the terrain, but

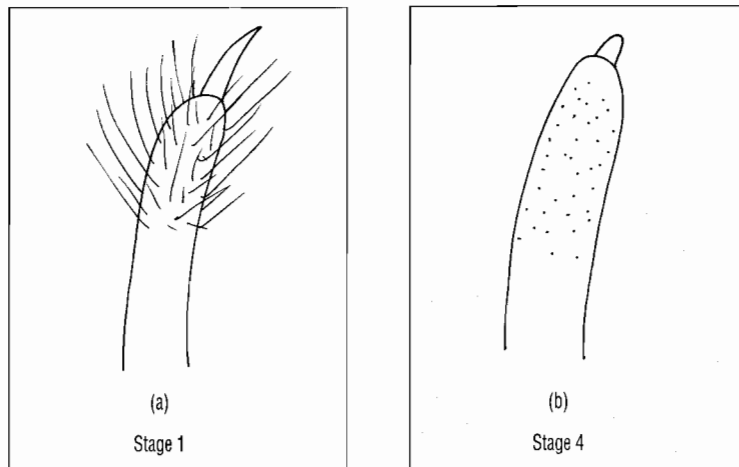


Figure 10. The range in stages of dactyls (walking legs) from (a) newly moulted (shell index stage 1) to (b) not having moulted in probably the past year (shell index stage 4).



A berried female with very mature eggs (stage 6) captured on its spawning walk.

A female crab with an attached spermatophore.



it was easy to distinguish newly moulted individuals from the other classes. Therefore the most reliable way of making between-site comparisons is to use the percentage of newly moulted individuals.

Female crabs were also examined for some indication of their spawning condition. Easy conditions to record were the presence of eggs or spermatophore masses. The various stages of the eggs were classified by Schiller and coworkers (1991) (see Table 4).

Small female crabs (< 30 mm TL) were also checked to see if they were sexually mature. This is determined by the presence or absence of hairs on the pleopods, absence indicating the crab is not mature. Schiller (pers. comm.) suggests that examining the hairs on the pleopod can also indicate if the females have spawned recently. This condition is usually noted by a small abdomen and damp hairs on the pleopods that are somewhat dark in colour.

Marking the crabs

In some cases it may be of use to mark crabs individually, particularly if an area is going to be surveyed more than once. Two types of marks are possible, short-term (only of use between moults) and long-term, those still present after moulting.

Short-term (until moulting occurs). Methods reported include painting the crabs with paint of different colours (Helfman 1973), scratching a number into the thorax (Fletcher et al. 1990), and writing numbers on them with a

Table 4. Classification of the different egg stages of gravid females (modified from Schiller et al. 1991).

Egg stage	Description
1	Freshly extruded round eggs, completely filled with yellow/orange yolk. The egg mass is bright orange in colour, granular in appearance and firm to touch (less than one week following extrusion).
2	Early stage differentiation; eggs ellipsoid and eyespots developed. Eggs now deep orange in colour and egg mass still resilient (1–2 weeks old).
3	Eyespots well developed and black in colour, well-formed embryo with limbs and half yolk gone. The eggs are dark orange to grey/brown, egg mass less resilient to touch (2–3 weeks).
4	Eyespots prominent, embryo fully formed with little yolk remaining. The egg mass is now light brown/grey in colour, if pressed causes deformities (2.5–4 weeks).
5	Near maturity; embryo fully formed. Egg sponge dark grey, easily deformed but comes back to shape (3–5 weeks, but transition to next stage may be rapid).
6	Mature egg sponge dark grey/brown, outer egg membranes have broken down and it is moist or 'slushy' in appearance. Readily deformed with no return to original shape. Exposure to fresh or salt water rapidly results in hatching (eclosion) (3–6 weeks).
7	Post-spawning females have a 'white mass' on their abdomens which is the remains of the evacuated eggs, which remain for a day or two.



Heat brand.

waterproof felt pen after lightly rubbing the area with sandpaper (Schiller et al. 1991). The latter is apparently the fastest method and lasts for a number of months.

Long-term (visible after at least one moult). We have used both freeze and heat brands to mark the crabs such that the marks would be evident after moulting (see Fletcher et al. 1989 for full details). Heat branding had the longer-term effect, and there is now some evidence of these brands surviving on large crabs for six years. Freeze branding appeared to disturb the crab the least, but was only visible for one moult.

Post-Sampling Analysis

Catch per unit effort (CPUE)

This relative estimate of crab abundance is the basis for the remainder of this manual. It is a fairly simple equation:

$$\text{CPUE} = \frac{\text{number of crabs caught}}{\text{number of baits set}}$$

In our assessments the number of crabs caught included crabs seen but not caught, and those for which the bait had been removed but the crab not seen. Interpretation of these indices as measures of population density is based on a number of large assumptions.

First, it is assumed that the crab's behaviour is similar in different areas, both in foraging frequency and the range over which it is attracted to a bait. Similar CPUEs should, therefore, indicate similar local densities of crabs. Second, the CPUE should be linearly related to local density, so that as the density of crabs increases, there should be a similar

percentage increase in the CPUE. Third, the size of the crabs attracted to the baits should be representative of crabs in the area.

All these assumptions are, under certain circumstances, violated, and a full discussion follows later in the text.

Activity levels

An alternative method of assessing the potential yield of the crabs at a site was the measurement of the level of 'crab activity' on a transect. This was defined as the percentage of coconut baits that had been eaten by coconut crabs at some stage during the evening, before the visit. This differs from the CPUE index in that it also includes situations where crabs had eaten at the bait but left before the bait was revisited.

This index was used only in a supplementary way to CPUE because it has the disadvantage of ignoring crabs not found at

baits, it does not include situations where more than one crab is at a bait, and has a maximum score of 100%. It is a more appropriate index to use when comparing different sampling nights at the same site, than comparing between sites.

Mean sizes and size frequency

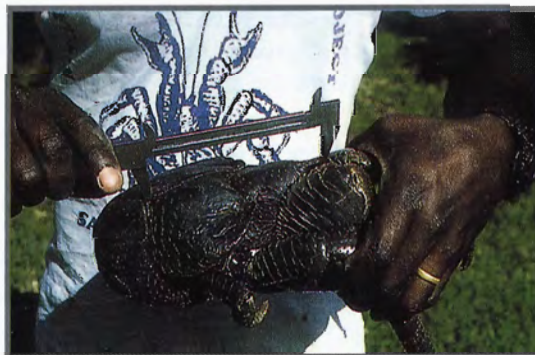
The mean sizes of both male and female (if present) crabs at each site were calculated for our studies. There is a definite trend for areas that have not been hunted extensively to have not only higher abundances but also larger mean sizes. The calculation of the mean size is, therefore, a good backup to the CPUE in assessing the status of any stock, but a more reliable analysis is obtained by examining size frequency distributions. This is particularly the case when examining yearly variations at the one site, but entails that at least 100 crabs per site be caught. In many survey situations, this is not practical, and sites that are

closest together need to be pooled, as were all the Santo sites in our Vanuatu studies (Fletcher et al. 1991b).

Abdomen expansion

To generate a mean abdomen expansion for individuals caught at a site it is first necessary to convert the raw measurement into an index. This is necessary because a large abdomen on a small crab (e.g. TL = 25 mm) will be only 3–4 mm, whereas this measurement is still fairly small on a crab with a TL of 60 mm. To allow for this size differential the abdomen expansion index (ABI) was defined as:

$$\text{ABI} = \text{abdomen expansion} / \text{TL}$$



Reporting

It is strongly suggested that a brief report be written after each sampling trip, in which the details of activity at each bait, measurements of the crabs caught and any environmental or other useful information be recorded as soon as possible while it is still fresh. The various indices should be calculated (CPUE, activity, mean sizes, mean abdomen expansion, mean shell condition), which makes it much easier to assess whether the value for any site is realistic and whether it should be repeated or ignored.

Stock Assessment

Mark-recapture

When our studies in Vanuatu were beginning, our original intention was to determine the stock size of crabs in any area utilising mark-recapture or Petersen methods. There are numerous books on this method, all of which rely on the basic formula:

$$\text{Total number} = (\text{individuals caught/markred caught}) \times \text{all marked}$$

On the large islands, despite many sampling trips and marking of up to 200 crabs, there were very few recaptures. We determined, using radio tracking (Fletcher et al. 1990a) that this was due to emigration of crabs from the area. Even if the assumptions of the Petersen method were met, this method relies on a large effort being put into each area, at least 3-4 nights at each location, and more, if the number of crabs caught per

evening is not large. Even so, the percentage of marked individuals to unmarked individuals will remain very low, which greatly increases the potential error associated with any population estimate. For example, if 100 crabs are marked and there are only four recaptured, if just one marked crab had been caught or missed, the calculated number of crabs would alter by 20-30%.

On one small island (0.1 km²) off South Santo, Venua Island (reported as Bier Island in other publications), good population estimates were obtained because the entire island was sampled and the number of marked crabs was greater than 30% of the total number on the island. Likewise, in the only other reported estimates of coconut crab numbers, Helfman (1973) was also able to calculate the numbers on two small islets in Palau.

Use of catchability coefficient to estimate numbers

In most cases, the direct estimation of the standing stock of a population is impossible, or at least impractical. Similarly, having only relative measures of abundance in the form of CPUE values may not be appropriate without a long time-series to equate to measures of actual population size. In situations where total population censuses are impossible, the relationship between relative abundance (as estimated by CPUE) and absolute stock size can be estimated if the catchability coefficient, q , is known. The catchability coefficient for coconut crabs was calculated using a series of depletion and addition experiments where the abundance of a geographically restricted population changed over a short period of time (Fletcher et al. 1990b).

The resident population of crabs on Venua Island was sampled three times between September and December 1986. Over the

next three months, 160 marked crabs were added to the island. The total number of crabs on the island, estimated using the Petersen method, began with initial estimates of 150 and increased to 360 after all the crabs were added (Fig. 11). There was good agreement between the actual (160) and estimated (210) increase in crab numbers. The mean CPUE during this time increased from 0.14 to 0.3, suggesting an approximate doubling in numbers that was consistent with the actual increase. Thus, in this range of

abundances, it appeared that CPUE was directly related to the number of crabs present.

From these data we calculated the catchability coefficient (q):

$$\text{Number of crabs present} = \text{CPUE} \times \text{area (km}^2\text{)} \times q$$

$$360 = 0.3 \times 0.1 \times q$$

$$\therefore q = 12\,000$$

Thus if an area had coconut crabs with a CPUE of 1.0, and it covered 1.0 km², the coefficient would predict that there should be 12 000 crabs present.

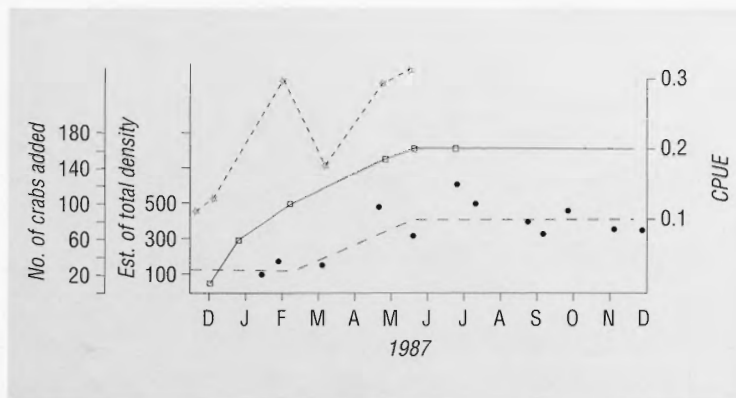
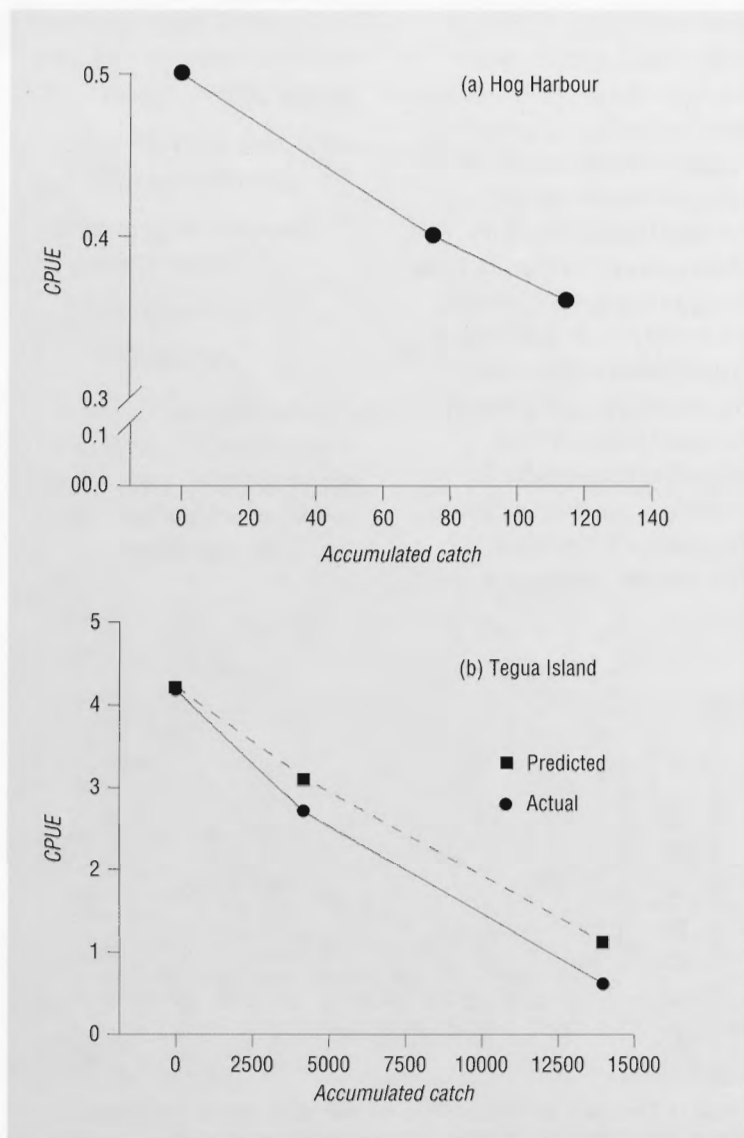


Figure 11. Changes in the CPUE and Petersen estimate of absolute abundance at Venua Island following the addition of a known number of crabs.



This coefficient also gave reasonable predictions of the drop in CPUE expected from another Santo site when a known number of crabs was removed (Fig. 12a). In this case the calculated difference was 117 and the actual decline was 110.

However, the relationship between CPUE and density is not linear over the entire range of densities. At the Torres Islands where initial CPUE values were very high, the drop observed in CPUE was consistently greater than the predicted decline (Fig. 12b). This indicates that the number of crabs may be over-estimated at higher CPUE values, suggesting a 'hypo-depletion' type of model for the relationship between CPUE and stock abundance. This pattern is not surprising, given the increase in crab activity, and therefore catchability, at higher crab densities.

Figure 12. (a). Changes in the CPUE of crabs at Hog Harbour following the removal of a known number of crabs; and (b) changes in the CPUE (actual and predicted) of crabs at Tegua Island following the harvesting of an estimated number of crabs.

Thus the general curve for CPUE against abundance is shown in Fig. 13, and relates to the changes in crab foraging behaviour with density. At high abundances (CPUE > 4) crabs can be found walking about during the daytime in large numbers and at night, and more than 20 crabs per hour can be captured without baits. At slightly lower abundances (CPUE = 3) crabs can still be found during the day, but only when conditions are good, i.e. during the wet season. At night crabs can still be found without baits. At

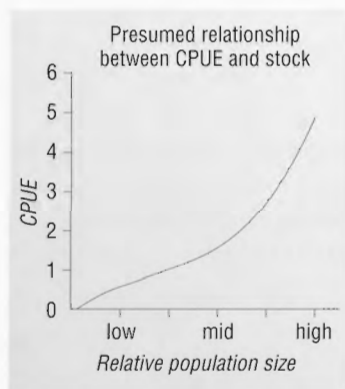


Figure 13. The estimated relationship between the abundance of crabs in an area and the resultant CPUE.

CPUE values of 2, crabs are found rarely during the daytime but a few may be captured at night without baits. At CPUE values of 1 or less, crabs are almost never found during the day, and rarely found at night without baits.

After catch rates have been determined, to calculate actual crab numbers for the region it is essential to estimate the area to

which the catch rates apply. This is best done from maps using the contour lines and preferably a planimeter or digitising board to delimit and measure areas considered to be the entire region for which the measured catch rates are representative. An example for some areas in Vanuatu is shown in Table 5.

Table 5. Example of a stock assessment table for the Torres Island region in 1991, utilising the relationship between the CPUE of an area and density developed for coconut crabs in Fletcher et al. (1990b).

Location	Area (km ²)	CPUE		Number of Crabs	
		All	Legal size	All	Legal size
Hiu Island					
Flatstone	1.2	1.3	1.0	18720	14400
Picot Bay	4.0	0.45	0.35	21600	16800
Sth west	2.4	1.3	1.0	37440	28800
Sth east	2.0	1.3	1.0	31200	24000
Hill	3.2	0.45	0.33	17820	13440
Tegua Island					
West	1.8	1.8	1.7	38880	36720
Village	0.4	0.5	0.4	2400	1920
Sth	3.1	1.5	1.3	55800	37200
Nth	4.2	1.0	0.6	50400	30240
Total				274260	170040



This calculation of area is possibly the least rigorous component of the whole endeavour because it assumes a uniformity across the entire region. It could be argued that it may have been more sensible to calculate the q value using randomly placed baits such that there would then be less bias in calculating areas, given the

difference in the density of coconut crab hiding-places among different regions. This may have been realistic in areas where crab numbers are high (i.e. $CPUE > 2$) but in most regions crab numbers are low ($CPUE < 1$). In these latter areas catch rates are very low and if random baits are used this greatly drops the

numbers of crabs caught. This can lead to problems in the variation of abundance estimates (a large difference in total abundance will be generated from the catching or not catching of one or two crabs).

To circumvent the problem of hiding-place density, if an area has very few hiding-places for crabs (if on average there is an average of more than 50 m between possible bait placement sites), the area used in the equation could be modified rather than trying to use a modified q value for random baits. If, however, randomly placed baits have been used, then the appropriate value for q would be between 1.5 and 2.0 times larger (see our data on the catch rates of random baits) making this q , approximately 20 000.

Application of Methods

Data generated by these field sampling techniques have already been used for the management of coconut crab resources in Vanuatu (Fletcher 1988b, 1992; Fletcher et al. 1991b) and Niue (Schiller 1988). For Vanuatu this sampling indicated how quickly the number of crabs in an area can be reduced following intense harvesting (Fig. 12). It also allowed the estimation of the numbers of crabs remaining in the main catching areas (Table 5) from which yearly catch quotas were calculated (Table 6).

The longer-term sampling of sites, which now extends in some areas over eight years (1985–93), is providing greater insights into the

population dynamics of the species. It is now possible to see that the initial drastic declines in some regions have slowed (Fig. 14a) which may necessitate some recalculation of the catchability function and possibly other parameters. Moreover, in some areas where there have been restrictions on the catching of crabs for large periods of the year, improvements in the catch rates have been monitored (Fig. 14b). In contrast, data from other areas where there has been some perturbation to the region (clearing, introduction of domestic animals) show further large declines in catch rates (Fig. 14c). Field sampling of the

Table 6. Catch quotas and management regime for Santo and the Torres Island region of Vanuatu.

All	Minimum size 9 cm cephalothoracic length (CL) No taking of berried females
Santo	Closed season November–March Annual quota for region, 2000 crabs
Torres	Closed season September–November Annual quota of 5000 crabs

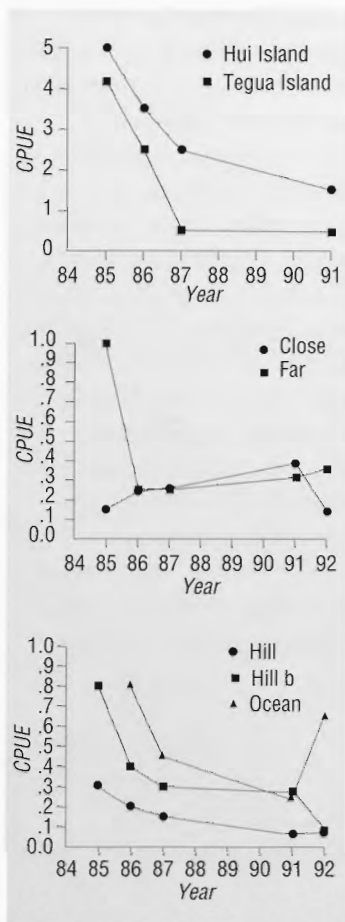


Figure 14. (a) CPUE for the Torres region 1985-1992; (b) CPUE for Kole (Santo) 1986-1993; and (c) CPUE for Hog Harbour 1985-1993.

crabs is, therefore, an ideal method for the assessment of the effects of any management regime that may be introduced to conserve local stocks. Thus this sampling is necessary before decisions can be made on management measures, and it is essential afterwards to keep track of their suitability.

Determining a 'safe' level of harvesting

The rule of thumb we have used in attempting to set realistic, long-term quotas for the crabs in Vanuatu has been to assume that harvesting should not exceed the level of natural mortality (M). This is about 5% per year of the standing stock. Thus for every 100 crabs above legal size, only 5 should be taken per year. For the Torres Islands, the

current quota is well within this boundary, being about 3% of the total standing stock. For the island of Santo, however, the 2000 crabs is probably greater than 5%, but a quota any smaller than this would probably produce widespread cheating. It does, nonetheless, represent a substantial drop in the number of crabs compared to years when there were no restrictions on the number that could be collected (e.g. more than 8000 in 1986, Fletcher 1988b).

On a local scale, in assessing whether an area should be temporarily closed to hunting, assuming this is practical, a CPUE less than 0.1 indicates that it would be wise to suspend collection of all crabs. This may mean that entire islands need to be 'rested'. This value is an absolute minimum; it is better, if possible, to keep the CPUE values above 0.15.

Methods of management

The management of coconut crab resources is not easy. Usually, by definition, the places where the crabs are caught are remote, which makes the enforcement of any regulation difficult. Nonetheless, the following are the main methods which have been either tried or suggested for use.

Minimum size limits

The most common form of management throughout the crabs' range has been the imposition of a minimum size. In Vanuatu this was 9 cm CTL-r (approximately 43 mm TL); in Guam and FSM, the size limit was 3" (76 mm) across the carapace (36 mm TL). These restrictions at least protect many females which reach sexual maturity at about 25 mm TL and rarely reach sizes larger than 45 mm TL (Fletcher 1988). The imposition of a size limit is essential for any reasonable management and has the advantage that it is also

the easiest to police. The precise size limit may vary between locations depending upon the local growth rate, but should not be much smaller than for Vanuatu, if for no other reason than marketing. This size represents a crab of only 0.6 kg, barely enough for a single serve at a restaurant.

Berried female crab ban

A ban on the catching of berried crabs is also in place in Vanuatu and in other countries. Again this is a very useful and easily understood method of management. It could be extended to a total ban on the collection of female crabs, which are easily identified and it could be enforced with relative ease.

Closed seasons

These can be put in place merely to restrict the period in which crabs can be caught to exclude the spawning season, to reduce the number of mating or

spawning crabs that are caught or interfered with. Closed seasons can also be used to restrict the total number of crabs collected. It is easier to monitor whether any crabs are being collected than to count the exact number of crabs caught. So this can be seen as an effort-limiting (input) method of management. It can be implemented as a total ban for the entire country for a set period, logistically the simplest method. Alternatively, closed seasons can alter among different locations to ensure a continuous supply of crabs. This method is particularly useful in countries with a number of separate isolated areas where crabs are caught and it is possible to monitor their origin.

Quotas

In countries such as Vanuatu, where the crabs are collected in a number of isolated locations and then flown to the markets, actual catch quotas are possible, the number of crabs caught in any one region being determined easily from air-freight manifests at each airport. When the quota for an area has been reached, the airline company is informed that it may no longer receive crabs for freight. In countries fully connected by road transport this would be a difficult option to police.

Sanctuaries

Sanctuary areas, where no collecting is allowed at any time, are a management option used or at least suggested in a number of countries. It is an attractive idea, but can suffer from a lack of adequate surveillance in the remote areas where the sanctuaries are, of necessity, located. In the one 'sanctuary' we have been associated with, in

Santo Vanuatu, considerable poaching occurred. Even if poaching is not a problem, depending upon local oceanographic conditions, the bank of larvae these crabs release may not reach all or any other regions. Furthermore, there is some evidence that when the density of crabs is very low, recruitment of juvenile coconut crabs may be adversely affected by competition with other coenobitids. This does not, however, mean that sanctuaries are a bad idea, merely that they should not be the only form of management.

Correct management methods will vary among countries depending upon geography, level of urbanisation, level of transport and especially the number of crabs remaining. The important thing to remember is that a good management plan is one for which impact can be monitored, which can be policed adequately, and is agreed to by the collectors. If either of the last two conditions are not met, then any such plan will fail.

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