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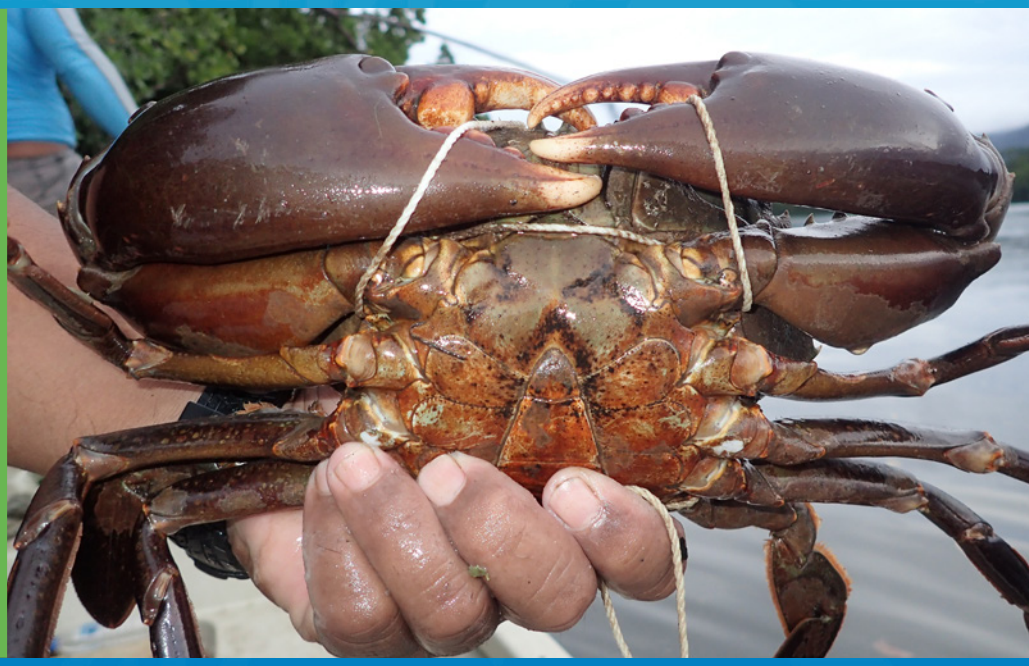

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Content

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Summary

- Mangrove crab populations around Pohnpei are currently in a sustainable state but are displaying characteristics associated with heavy fishing pressure. Our assessment showed that the average carapace width (CW) of all trapped crabs was 14 cm, which is 2 cm smaller than the average size reported in 1978 when the last detailed study was done.
- The minimum reproductive size for female mangrove crabs in the region was found to be 12–13 cm CW; therefore, female mangrove crabs are still able to contribute spawn to the population before capture.
- The average size of trapped male mangrove crabs, which was 14 cm CW, is significantly smaller than expected and two to three centimetres smaller than the average size reported in 1978. Healthy populations of mangrove crabs should display large size differences between the sexes with males being larger than females.
- There was no evidence that the mangrove crab fishery has room for expansion given that the current levels of exploitation are clearly having a long-term negative effect on mangrove crab stocks.
- Trapping revealed strong spatial differences in the sex ratios, size structure and abundance of mangrove crab populations around the island. Bigger crabs were found in rivers and creeks that are surrounded by more mangrove forest and further away from residential areas.
- Market forces appear to be working in encouraging only large specimens for sale in the local markets, where surveys of crabs that were for sale revealed median male and female carapace widths of 15–16 cm. This size range has remained unchanged for females but decreased from a previous size range of 16–17 cm CW for males.
- Despite only large crabs being sold in the markets, the smaller average size of trapped crabs indicates that there is still significant fishing pressure on the mangrove crab population around Pohnpei. There are at least four areas of fishing pressure that we were unable to survey and which need to be quantified to better understand the main forces behind the reduction of size and abundance of mangrove crabs. These four areas are as follows:
    - Sale of mangrove crabs outside the market system.
    - Sale of mangrove crabs to international fishing vessels.
    - Export of mangrove crabs by passengers travelling by air.
    - Retention of mangrove crabs for personal consumption, not sale.
- There is no management framework to support the mangrove crab fishery and collect information that would enable the Ministry of Fisheries to make informed decisions on how best to regulate and control the harvesting of mangrove crabs in order to ensure sustainability.
- There is a lack of resources available to support active management of the mangrove crab fishery.

Management recommendations

This report focuses solely on investigating the wild mangrove crab populations around Pohnpei and any management recommendations therein are made to facilitate the ongoing health of the wild population. While the Federated States of Micronesia (FSM) has a national aquaculture management and development plan that includes investigating the feasibility of mangrove crab culture, this report makes no assessment on the viability of such an enterprise.

- A comprehensive management plan should be developed that will provide the appropriate guidelines and legislative backing to ensure mangrove crab populations can be sustainably harvested. Factors to be considered include the following:
    - Minimum CW size limits (14 cm).
    - Allowing only male crabs to be harvested.
    - Preservation of mangrove areas with extensive waterways.
    - Setting aside some areas as permanently closed to fishing to ensure there remains a baseline population of mangrove crabs for sustaining populations.
    - Permitting system to be upgraded to include information on length and number of crabs being exported by individuals.
    - A reduction in the number of mangrove crabs that can be exported by an individual.
    - Enhanced monitoring and surveillance of international fishing vessels to ensure compliance with regulations.
    - Permitting system for markets to be upgraded to include information on number of crabs being sold – not just total weight.
    - Centralisation and standardisation of the export permitting system.
- Appropriate resources should be allocated to those sectors tasked with regular monitoring of mangrove crab catches.
- A community awareness programme should be developed to outline the management programme and its role in ensuring healthy mangrove crab populations for all.

Introduction

The mud or mangrove crab, *Scylla serrata*, is a highly desirable crustacean species that is geographically widespread throughout the Indo-West Pacific region, where it lives in close association with mangrove systems (Fig. 1). Genetic analysis has demonstrated that there are at least three distinct stocks in the Indo-Pacific region that are aligned with clearly defined geographic regions; these are western Indian Ocean, eastern Australia (Pacific Ocean), and north-Western Australia (Fratini et al. 2010). The larvae of *S. serrata* can be at sea for up to 75 days, which gives them the ability to colonise habitats far and wide, resulting in genetically well-mixed populations.

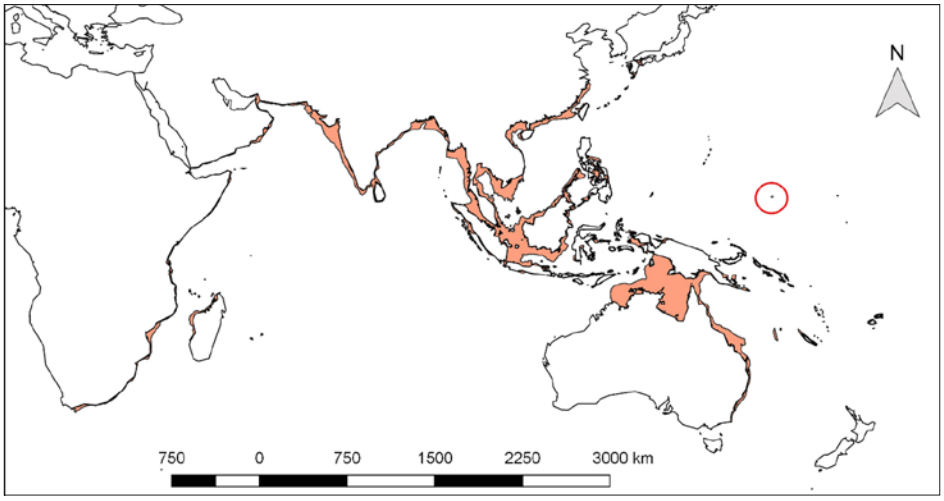

Figure 1. Global distribution of the mangrove crab *Scylla serrata*. Red circle indicates location of Pohnpei (source: FAO, GeoNetwork website http://www.fao.org/geonetwork/srv/en/main.home).

The life cycle of these crabs is complex, and involves an extended planktonic period for their larvae where they go through five development stages before settling into a habitat close to mangroves. Individuals then move incrementally further into the mangrove systems as they grow. Sexually mature females then undergo long distance migrations to off-shore waters to spawn and renew the cycle (Fig. 2). Crabs can reach maturity in as little as 12–18 months in tropical latitudes, but can take as long as 24 months to mature in more temperate locations. Sexual maturity for *S. serrata* also occurs when they are at different sizes throughout their geographic range. For example, male crabs in South Africa reach sexual maturity at 11–12 cm CW, compared with Pohnpei where they are a full centimetre larger at 12–13 cm CW (see table 2 in Alberts-Hubatsch et al. 2015). Mangrove crabs typically only live for a maximum of 3–4 years and constant recruitment is necessary to keep the population replenished and stable. Timing and extent of spawning and recruitment varies with latitude. In cooler climates, spawning is constrained to the summer months while spawning can occur year-round closer to the equator where temperatures are less variable.

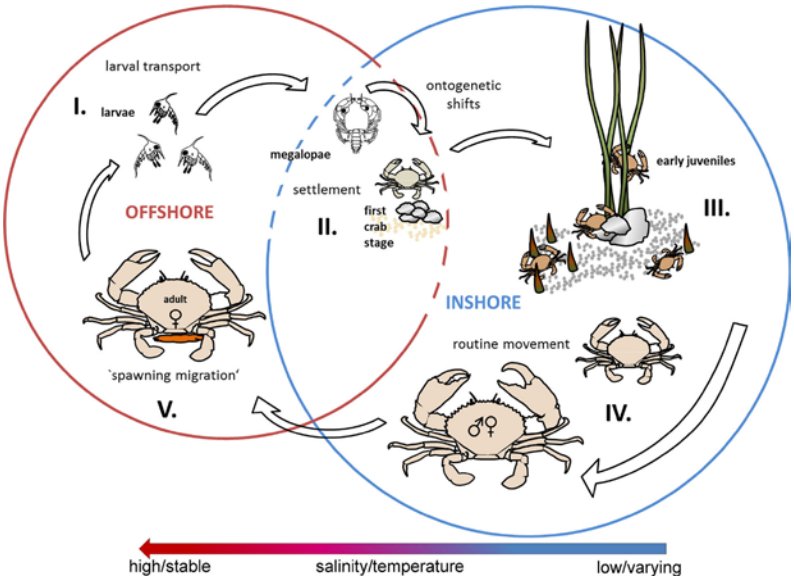

Figure 2. Illustration of the life cycle of the mangrove crab *Scylla serrata*. Salinity and temperature of the water are influential throughout the life cycle (source: Alberts-Hubatsch et al. 2015).

Mature crabs are found in all areas of the mangrove systems that they are closely associated with. Where significant mud banks exist, they dig holes with a depth of up to 2 m for sheltering in. They are also found within the root systems of mangrove trees, in hollows of more mature trees, and on the mud and seagrass flats that often exist adjacent to and within mangroves and estuary systems. While they are capable of making significant migrations, as evidenced by female spawning behaviour, tagging studies have shown that most crabs move less than a few kilometres from where they are initially captured (Hyland et al. 1984; Bonine et al. 2008).

Mangrove crabs are a well-known and highly desirable, premium seafood item. Their sweet, delicate flesh is highly sought after by consumers who will pay a high price for a meal of these crustaceans. Prices for wild caught, live mangrove crab can be as high as AUD 80/kg in Australia and Japan. China has by far the largest catches of wild mangrove crabs with a reported catch of 60,000–70,000 tonnes in 2015 (Wang 2015) while Indonesia has reported catches of 46,000 tonnes in 2018 with Singapore being the primary export destination (Aldon and Dagoon 1997; FAO global fishery & aquaculture production statistics[1]; Shelley 2008). Australia, by comparison, had a total commercial catch of approximately 1500 tonnes in 2018 (Grubert et al. 2018), while Thailand's catch was estimated at 412 tonnes in 2017. Most countries that have reported catches to FAO are showing a declining trend in annual harvests.

The increasing global demand for mangrove crabs is putting wild stocks under enormous pressure, which is driving calls for more investment in aquaculture of these species. However, despite progress in the culture of mangrove crabs within Japan, Vietnam and the Philippines, most culture facilities still rely heavily on wild-caught crablets and juveniles, with culture successes remaining low and inconsistent (Waiho et al. 2017). Considerable research is still needed before larval culture and rearing of mangrove crabs can become a viable alternative to harvesting of wild stocks.

While the largest populations of mangrove crabs are found in countries with the most extensive and mature mangrove systems – such as those that exist throughout SE Asia and Australia – there are nevertheless well established mangrove crab populations throughout many smaller countries that contain mature mangrove forests. Many of the Pacific Island countries and territories (PICTs) fit into this scenario. Within the Federated States of Micronesia (FSM), all four of the resident states of Yap, Chuuk, Pohnpei and Kosrae contain mature mangrove stands with resident populations of mangrove crabs. However, Pohnpei has significantly more mangrove area (~5500 ha) than all the other states combined (Yap: ~1100 ha; Chuuk: ~300 ha; Kosrae: ~1500 ha; Smith 1992).

Although the mangrove systems of small island states like FSM are not capable of producing enough crabs to be a major contributor to gross domestic product (GDP), this resource is nevertheless important as a high-value product within local markets. The animals can be kept alive out of water for up to a week if stored properly, which is an advantage in areas where post-harvest processing and transportation facilities may be less than adequate. Setting up a crabbing operation requires minimal capital investment and as the product is highly regarded in the tourist and restaurant trade, it commands a high price, which provides ready cash for artisanal fishers and their families. Mangrove crabs from Pohnpei are considered particularly tasty in the greater region and hence are highly sought after.

Previous research into mangrove crab populations within FSM has focused on Kosrae and, to a lesser degree, Pohnpei. The reports and papers on this previous work provide substantial insights into the mangrove crab populations of FSM and served as a baseline for the 2018 assessment of Pohnpei's mangrove crab populations, which is reported here. Mangrove crabs in Kosrae display biological and ecological characteristics similar to those reported elsewhere such as male crabs being significantly larger than females, restricted movements of mature crabs, maximum size of around 20–24 cm CW and a maximum lifespan of 3–4 years (Bonine et al. 2008). Observed differences in the size structure of crab populations from different parts of Kosrae were correlated with variable harvest pressure, which reflected the distribution of the human population and location of emerging commercial harvest operations (Bonine et al. 2008; Ewel 2008).

Prior to this survey, Pohnpei's mangrove crab populations were last studied in 1977 and 1978, which is now over 40 years ago (Dickson 1977; Perrine 1978). These studies, nevertheless, identified similar biological and ecological parameters to the Kosrae studies that were undertaken 20 years later. They also highlighted strong spatial differences in the size structure of mangrove crab populations between locations where crabs were trapped. These differences correlated with the density of people living nearby and the spatial extent of the local mangrove forests, which is again a similar result to the Kosrae studies. It was concluded, however, that crab populations were not being over-exploited at that time and fishing restrictions were not necessary.

[1] http://www.fao.org/fishery/statistics/en

Forty years later, the human population of FSM has risen by approximately 70 per cent and the pressure on natural resources is high. When responding to increased concerns from constituents about an apparent long-term decline in the abundance and size of mangrove crabs, a national senator requested help from the Pacific Community (SPC) to undertake an assessment of the health of Pohnpei's mangrove crab stocks, and to provide advice on the most effective management strategies moving forward.

In order to obtain the information that is necessary for assessing the health of Pohnpei's mangrove crab stocks, the following objectives were undertaken:

- An extensive island-wide trapping programme within each of the four sectors around Pohnpei.
- Surveys of local fishers to understand catch-and-effort and spatial distribution of effort.
- Surveys of local fish markets to understand volume, size and price of mangrove crabs being sold and who the main customers are.
- Surveys of exports through the local airport to better understand the volume of mangrove crabs exported from Pohnpei.
- Review of current data collection, storage and reporting by national and federal government agencies.
- Review of current legislation around exploitation of mangrove crabs.

Methodology

The data needed for the assessment was allocated across five separate areas and encompassed fisheries-independent trapping surveys, market surveys, fisher creel surveys, and airport surveys (among others) (Fig. 3).

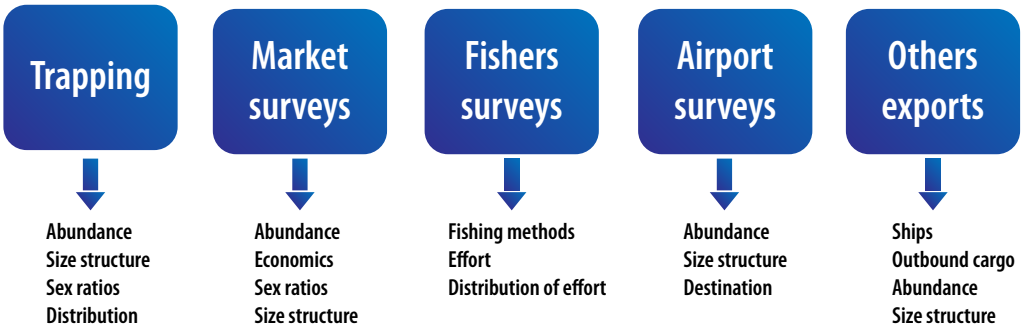

Figure 3. Infographic indicating the five areas where data collection was focussed and the range of outcomes that can be derived from each data collection module.

Trapping

Trapping locations were chosen to ensure coverage around the whole island and, where possible, to overlap with areas that were trapped by Perrine in 1978 (Fig. 4). Thirty traps were purchased from Australia with a design that has been proven to maximise catches of mangrove crabs (Houdini Crabflex traps from Crabmaster Systems, Caloundra, Queensland.) when compared with other styles of traps that are commonly used.

At each general location we set three groups of 10 traps (upstream, downstream and outside the river mouth). This amount of replication had to be reduced after the first week of trapping because of the loss of a number of traps. As a result, the subsequent three groups consisted of seven, seven and six traps set at least 50 m apart to avoid overlap in the catching zone of individual traps. Traps were baited with 500 g of skipjack tuna, which was replaced every 24 h, or less if the bait was taken within this period. Traps were fished for three days at each location.

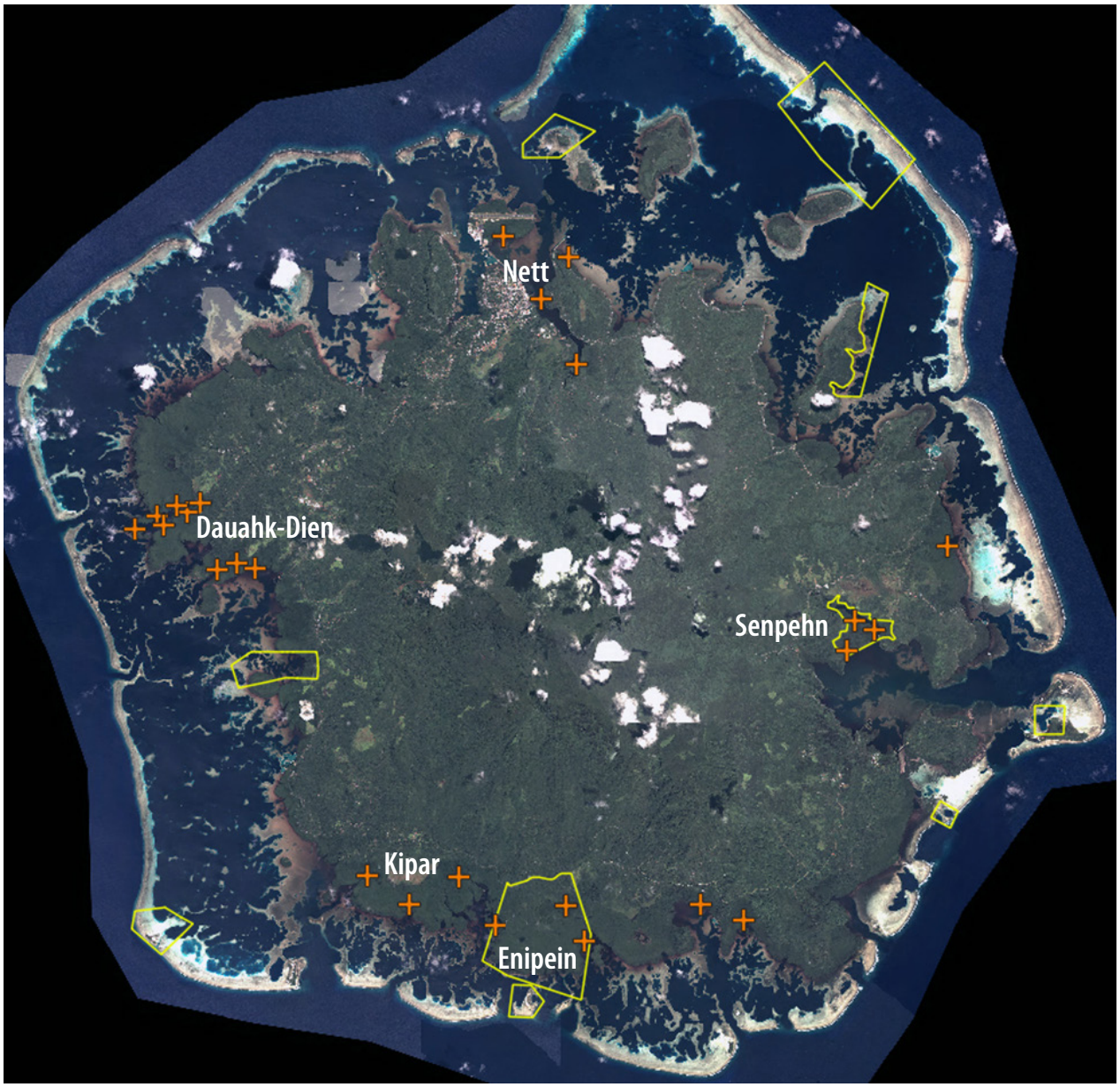

Figure 4. Map of Pohnpei Island indicating all locations[2] where trapping was undertaken (orange crosses). Yellow marked areas are mangrove protection areas.

[2] Location names used in this document are the most locally used ones, as recommended by Eugene Joseph, Conservation Society of Pohnpei. Different names or spellings are also commonly used, such as: Kolonia (Nett), Dawak-Dien (Dauahk-Dien), Laiap (Kipar), and Madolenimh (Senpehn).

Mark-recaptures

Individual traps were checked approximately every 10–14 h on a morning and evening schedule, although spring low tides sometimes made it difficult to stick to this schedule. All mangrove crabs caught in a trap were sexed and weighed, carapace width measured to the nearest millimetre, and then released after painting an identifying number on their shell using a correction fluid pen and attaching a coloured cable tie to the base of one of their swimming legs (Fig. 5). Crabs were marked to distinguish them from any new crabs that were caught in subsequent fishing periods. At each successive checking of a trap, any new crabs were marked while any previously marked crabs that were re-caught were noted on the data sheets that were used to record catches and then they were returned to the water. This mark-recapture trapping programme provides data from which estimates can be calculated of the total numbers of adult crabs that inhabit each mangrove system where trapping occurred.

The number of recaptures through time provides an index of relative abundance that can be used to infer how many crabs are actually available to be caught in each location where the trapping is happening. In a small population, it is more likely that marked individuals will be recaptured, whereas in a large population, this is less likely. As with all population estimates made from samples, there is always a certain amount of error associated with the estimate. This error is calculated as Standard Error (S.E.) and according to statistical rules around populations that follow a normal distribution, when multiplying the S.E. by 1.96 the result is 95% confidence intervals, which shows the range of population estimates within which the true mean of the population sits. This calculation is used to provide a minimum and maximum population size, which can be used for management purposes. The wider the difference between the high and low values, then the less accurate the population estimate is. While longer trapping programmes will provide more data and make the estimates more accurate, we only had a finite time to capture information around the whole island; therefore, we limited trapping to three days in each location so that more locations could be sampled.

For analysis of the mark-recapture data, we assumed that the crab population in each creek that we trapped them in was effectively closed, meaning that there was no nett increase or decrease of crabs into the creek during the period of trapping. We used two methods for estimating the abundance of crabs: the Schnabel estimator, and a group of log-linear models with slightly different assumptions about capture probabilities (see Ogle 2016: 176). The results of both methods were comparable; therefore, only the Schnabel model output is discussed here.

Model details are not included in this document but there is a dedicated website called FishR (http://derekogle.com/fishR/) where interested persons will find extensive information on the analysis of mark-recapture data. All analyses were done on the R software and graphics system (https://www.R-project.org) using the FSA package for fisheries stock assessment.

Figure 5. A captured crab has been marked with the number 11 using a correction fluid pen and the rear left swimming leg has a blue cable tie attached to aid with identification if recaptured.

Market surveys

Three individual markets were identified as the main buyers and sellers of mangrove crabs in Kolonia (Nett); these were H&D, Ellen's Market and Saimon's Market. Market stalls were visited at least once a day to check on the presence of crabs and, with the permission of the stall owner, all crabs that were for sale were weighed, measured and sexed (Fig. 6). The buying and selling process of crabs was not uniform and predictable, but on average, catches of crabs were sold to the market stalls by 8 am with sales proceeding any time after that.

Figure 6. Measuring of crabs at Saimon's Market.

Fisher surveys

Identifying individual fishers that could be interviewed was a time-consuming process, given the remoteness of many of the main fishing areas and the inability to contact individuals by phone. Finding interviewees required driving to individual villages and speaking to people about our request until we obtained a positive contact. We were eventually successful in interviewing 12 fishers over the course of one month (Fig. 7). Interviews were conducted using standard creel survey questions, which seek to understand the effort, cost and outcomes of targeting mangrove crabs.

Figure 7. Interviewing a crab fisher.

Airport surveys

Because mangrove crabs are so highly prized in the region, many travellers leave Pohnpei with crabs that they have bought from the local market. Regulations allow the export of 15 mangrove crabs per individual, per trip upon purchase of a permit; therefore, regular flights out of Pohnpei have the potential to contain significant numbers of mangrove crabs. After gaining permission from all the relevant departments, including the airlines, we were able to check coolboxes of travellers who were taking crabs out of Pohnpei in order to measure, weigh and sex all the crabs that we found.

Other

Anecdotal evidence from numerous sources identified another potentially significant source of mangrove crab sales and transactions – sale of mangrove crabs to individuals based on the longline and purse seine vessels that are moored in the harbour. Formal interviews were not possible with anyone directly involved with this process, so information was gathered from the observations of customers who were visiting the markets and general discussions were carried out with market stall personnel.

Results

Results of data analyses as described below were clear and highlight that Pohnpei's mangrove crab populations are biologically similar to other mangrove crab populations across FSM. Size and abundance patterns seen within Pohnpei followed a general trend of larger crabs in areas with less people and more crabs in areas with more favourable habitat.

Length–weight relationships

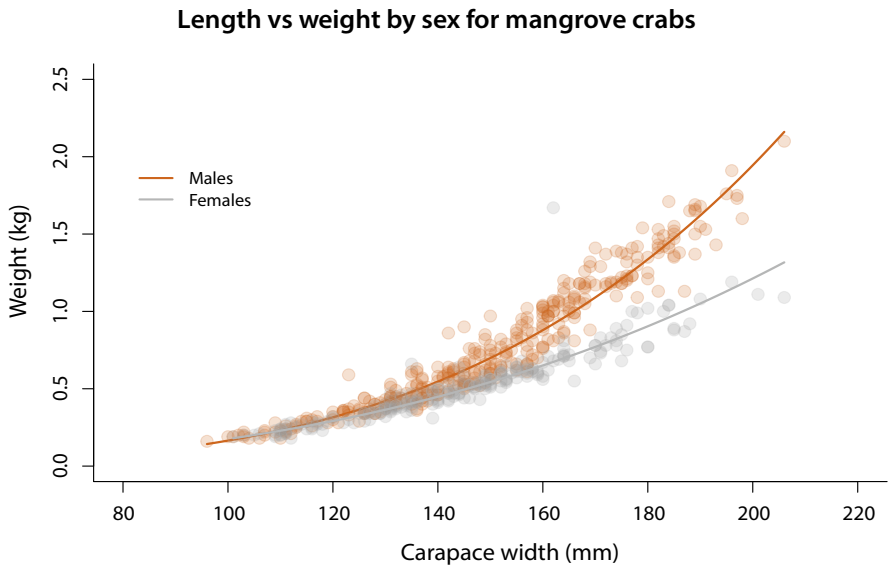

Figure 8. Length–weight relationship of male and female crabs in Pohnpei.

Length–weight relationships were derived separately for males and females with both relationships fitting a power curve of the form:

$$W = \alpha L \hat{} \beta$$

$$\alpha, \beta = \text{coefficients}, W = \text{weight (kg)}, L = \text{Carapace width (mm)}$$

Comparisons of the length–weight relationship between crabs measured around Pohnpei and crabs measured around Kosrae by Bonine et al. (2008) revealed no differences. Crabs of the same carapace width have a similar weight between the two locations. The Kosrae study found that a subset of their crabs was significantly heavier than the others and these were analysed separately. We did not find this in Pohnpei (Fig. 8).

Table 1. Comparison of length–weight calculations between Pohnpei and Kosrae.

	Pohnpei		Kosrae	
	α	*β*	*α*	*β*
Males	1.00E-08	3.56	1.00E-08	3.54
Females	5.00E-07	2.77	7.00E-07	2.69

	Males	Females	Males	Females
Length (mm)	Weight (kg)		Weight (kg)	
190	1.30	1.03	1.17	0.94
170	0.87	0.75	0.79	0.70
150	0.56	0.53	0.51	0.50
120	0.25	0.29	0.23	0.27

Trapping

We trapped a total of 338 crabs with a ratio of 148 female:190 male crabs. Mean carapace width was the same for males and females at 14 cm (Fig. 9), which is not usually the case with wild populations where the average size of males is significantly larger than females.

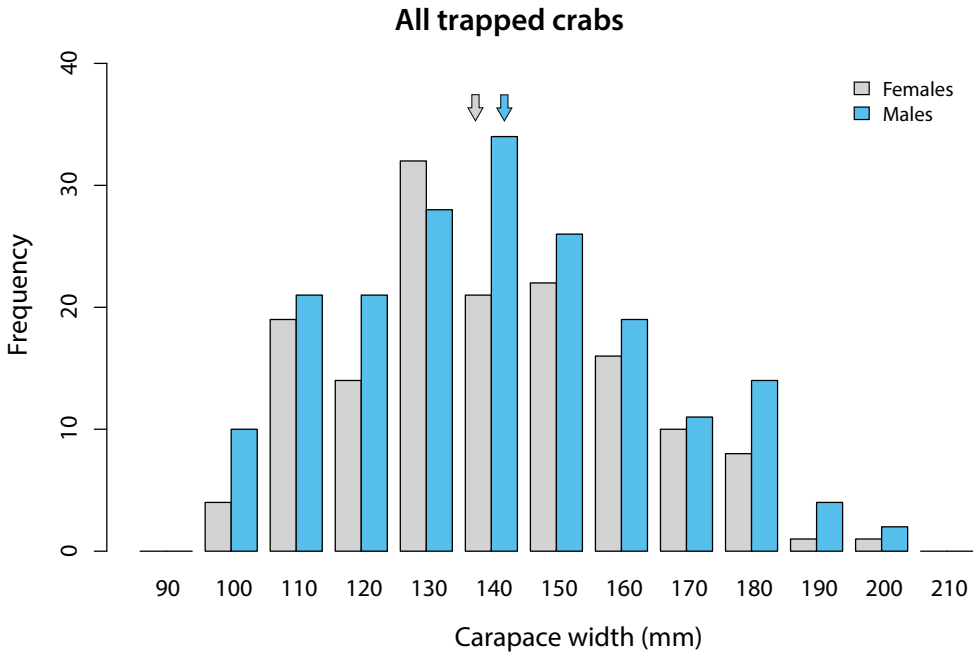

Figure 9. Size structure of mangrove crabs caught by trapping. Arrows indicate the bin size for the average male and female crab.

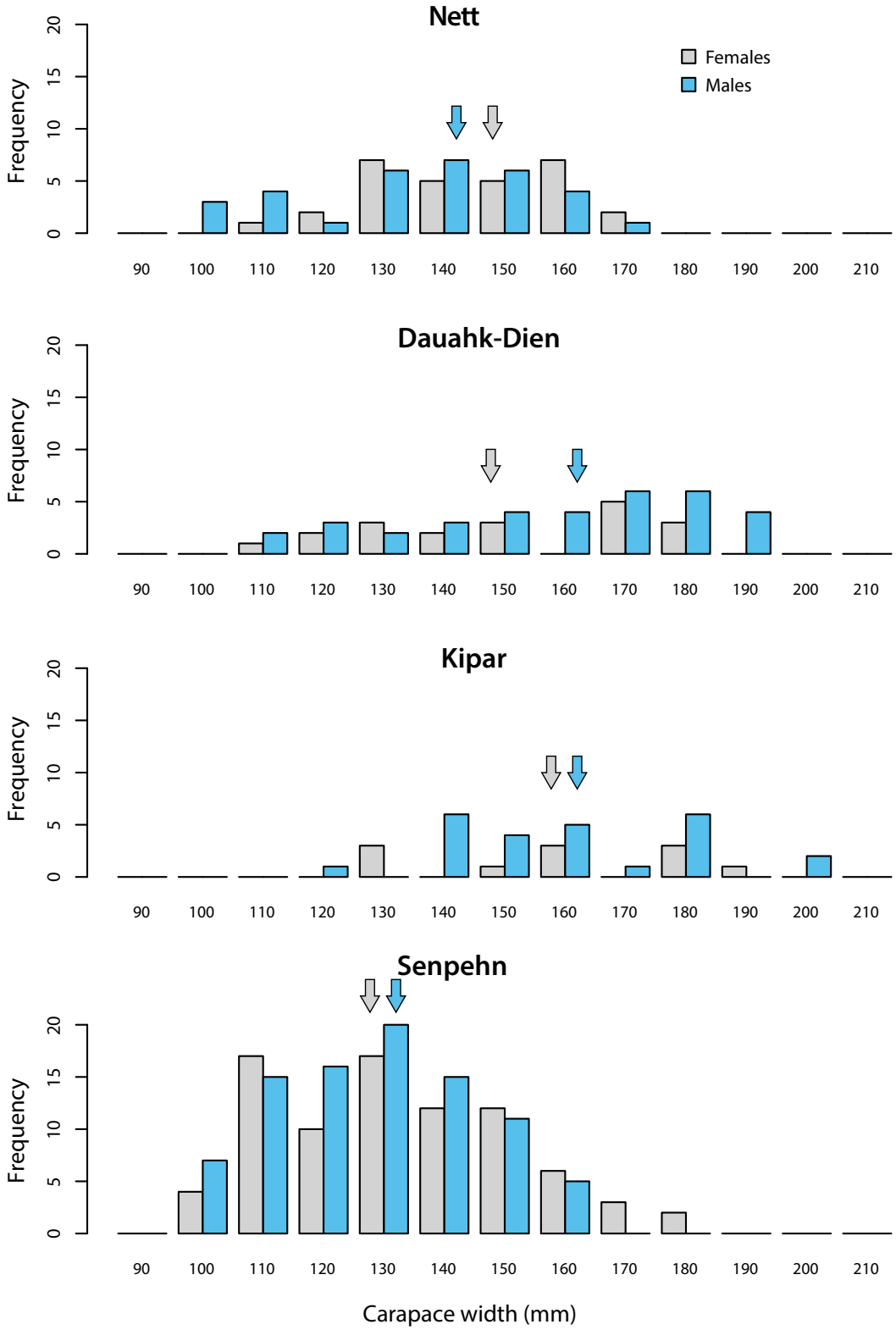

Figure 10. Size structure of trapped crabs from four locations around Pohnpei.
Arrows indicate the bin size of the average male and female crab.

When the trapping results were separated into the four separate locations (Fig. 10), there were clear differences in the size structure and abundance of the captured crabs. Kipar, in the south, had the largest mean sizes of male and female crabs, although the total number of crabs caught was only 16. Senpehn, in the east, had the smallest crabs, but the number of crabs caught was much higher than anywhere else we trapped with a total of 174 crabs. There was very little difference between the average size of female and male crabs, except around the Dauahk-Dien area. Again, this is not typical in unfished mangrove crab populations, where the male population should be larger on average than the female population.

Mark-recaptures

Results of the mark-recapture analysis revealed large differences between locations, which are a reflection of numerous factors including the amount of surrounding mangrove habitat, size of the creek system, linkages to the lagoon (migration of females for spawning and return of recruits) and the amount of fishing pressure (see Figs. 11 and 12 for mangrove distribution and population density respectively).

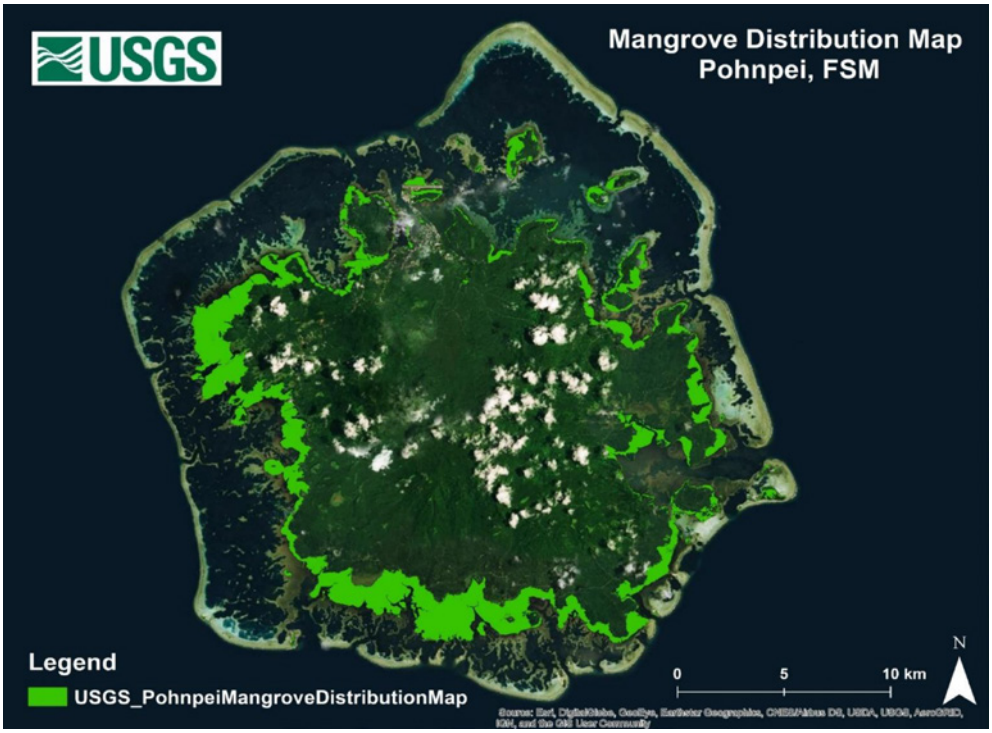

Figure 11. Map illustrating the extent of mangrove forests around Pohnpei (source: USGS Survey 2016).

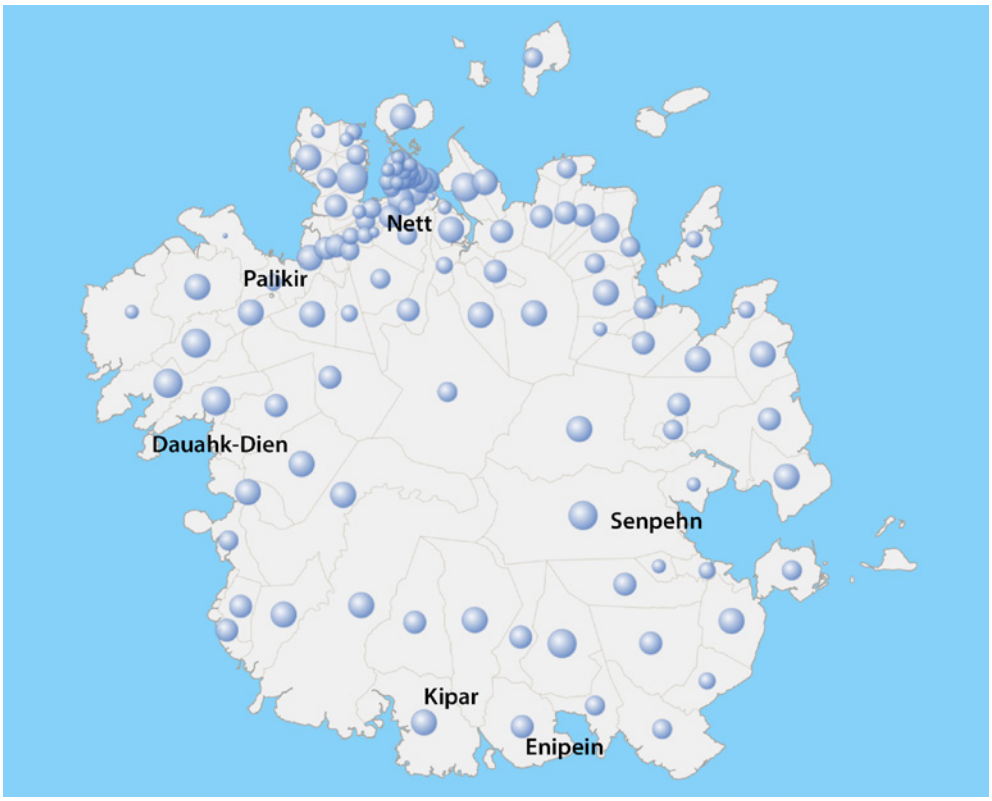

Figure 12. Map of Pohnpei Island indicating population distribution from 2010 census.

Table 2. Calculated abundance (N) with 95% confidence intervals (Lower – LCI and Upper – UCI) based on mark-recapture data from the four main trapping locations around Pohnpei. * The fifth general trapping location Enipein had very low numbers of crabs and was not amenable to mark-recapture analysis.

Location	N	LCI	UCI
Senpehn	295	224	396
Dien	43	25	82
Kipar	58	32	113
Nett	69	47	104

The Senpehn area had an overwhelmingly higher number of crabs than any of the other locations where we trapped, followed by Nett. The other areas where trapping was carried out had smaller populations of mangrove crabs but larger average size. It is also worth noting that Senpehn and Nett both have larger river systems than the other locations, which may have a large influence on the carrying capacity for mangrove crabs.

Market surveys

We measured a total of 307 crabs in the markets with an overwhelming majority of these being males (Fig. 13). Median carapace width was slightly larger for males (157 mm) over females (151 mm). Sizes in the markets were consistently larger than the average size of crabs caught through trapping, which suggests a consistent bias by fishers towards finding and selling only the biggest crabs.

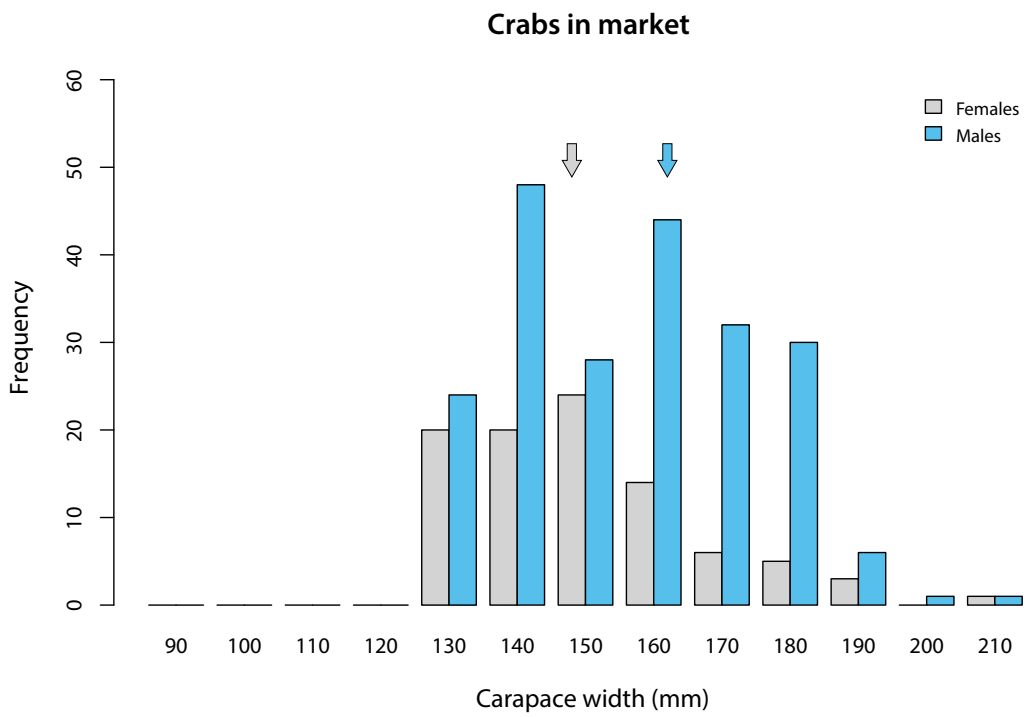

Figure 13. Size structure of mangrove crabs from the markets.

Fisher surveys

We conducted 12 interviews with mangrove crab fishers consisting of one woman and 11 men. Fishers were from all parts of the island with the majority coming from the south and west provinces where the most crab fishing occurs. A variety of fishing methods were utilised with trapping being the most common, followed by walking and snorkelling. The median carapace width was slightly larger for males (162 mm) over females (158 mm), but consistent with the market results, which indicates a targeting of large crabs (Fig. 14).

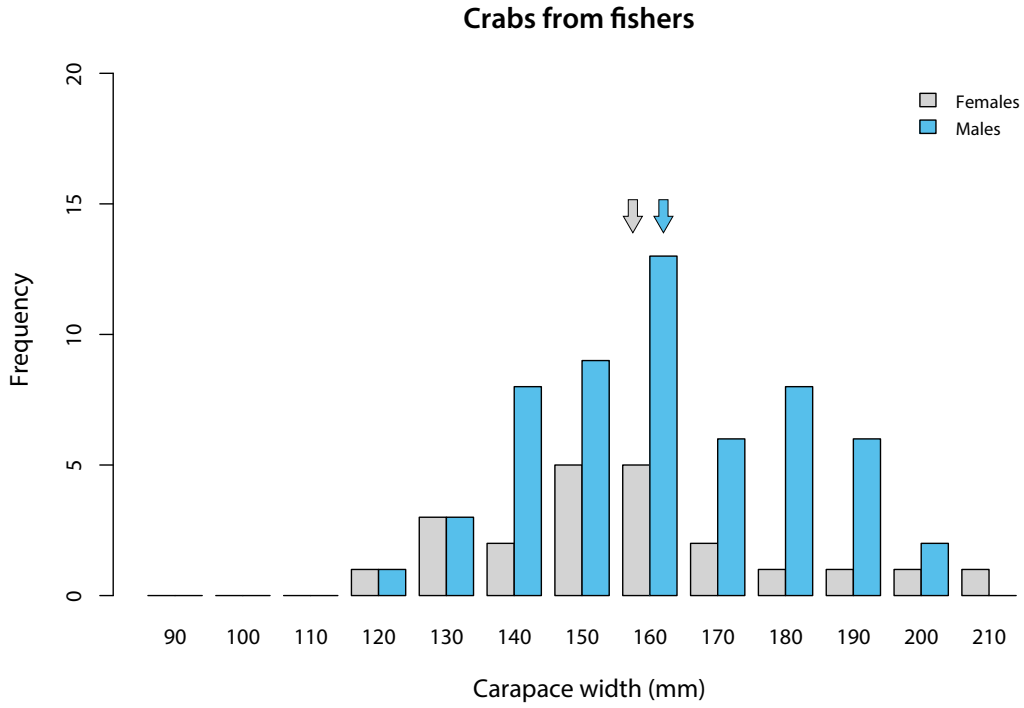

Figure 14. Size structure of mangrove crabs from fishers.

Airport surveys

A total of six flights were surveyed for the amount of mangrove crabs being exported. Four of the flights were east bound to Guam and had a total of 33 crabs. The other two flights were west bound to Honolulu, Hawai'i and had no crabs. It should be noted that an accident at nearby Chuuk, which involved an Air Niugini flight, had a significant impact on passenger numbers that were flying during the time that we were in Pohnpei. This area of the trade in mangrove crabs requires more oversight as it potentially represents a large biomass of crabs.

Other surveys

Anecdotal information suggested that there is a regular trade in mangrove crabs between fishers/markets and persons stationed on foreign fishing vessels. We were unable to conduct interviews in order to gain a more detailed understanding of this aspect of the fishery; however, informal discussions with fishers and market sellers, and personal observations at the markets indicated that entire market stocks of up to 80 crabs at one time are regularly purchased by foreigners from the foreign fishing vessels. The frequency of these purchases is dependent on the flow of crabs to the markets, but if catches are good then these purchases are often conducted multiple times a week.

Discussion

Our surveys indicated that the median size of mangrove crabs around Pohnpei is smaller than it was back in 1978 when the last surveys were done. The median size of all crabs trapped was around 14 cm CW for males and females, compared with a median CW closer to 16 cm back in 1978. This is not surprising given that the human population of FSM has increased by 70 per cent since 1978 and there are now more people fishing for mangrove crabs. There is no minimum size limit for the harvesting of mangrove crabs in Pohnpei and management regulations are limited to a prohibition on taking female crabs that are carrying eggs, and exporting crabs for commercial purposes. People are allowed to take 15 crabs out of the country for personal use on any given trip, upon purchase of a permit to do so. Unfortunately, the permit neither requires any information on how many crabs are being exported nor what sizes they are.

When trap catches were separated by location there were clear differences in numbers of crabs caught, as well as the median size of males and females. Those areas with the largest crabs have smaller populations of people living nearby and the largest areas of mangrove forests, which is a pattern consistent with previous work that has been done in the region (see Figs. 5 and 6). Male crabs were also larger than females in these locations. In contrast, those locations closest to population centres such as Kolonia (Nett) had much smaller crabs overall and the median size of male crabs was smaller than female crabs, which is not typical within an undisturbed population. These locations are clearly under greater fishing pressure, which is removing more of the males from the population than females.

Interestingly, the two locations with the most crabs were also the areas with the largest river/estuary systems. Thereby, despite very high fishing pressure in Nett, for example, there are still many crabs being caught there, although the smaller sizes, especially of males, is indicative of high fishing pressure. Larger systems will have a greater carrying capacity that allows more crabs to be present than in the smaller creeks.

Crabs in the markets were 1 cm higher in median size at 15–16 cm CW than the overall crab population as determined through trapping. The ratio of males to females was also more skewed towards males than in the general population. This indicates that fishing is preferentially targeting the larger crabs in the population, which are males. This makes sense economically because the largest crabs fetch the most money.

The median CW of crabs in the market in 1978 was 15–16 cm for females and 16–17 cm for males, with a 20:80 ratio of females to males. In 2018 we found median sizes were 15–16 cm for both sexes with a 30:70 ratio of females to males. This indicates a long-term reduction in the maximum size of male mangrove crabs over time, which is a primary indicator of a response to fishing pressure. The median CW of females in the markets appears to be more stable and similar to 1978. The median size of females in the population, which is around 14 cm, is above the estimated length at maturity, which indicates that there is still adequate recruitment happening within the crab populations of Pohnpei. However, there has clearly been a long-term decline in the size and abundance of mangrove crabs around Pohnpei with the changes most evident in the male population. This reality is also perceived by the people who fish for crabs, with the 12 fishers we interviewed overwhelmingly stating that they believed the number and size of crabs was declining.

Our surveys, both in-water and at the market, give us a good general understanding of the structure of the crab populations around Pohnpei, which are showing signs of overfishing. While the harvesting of too many crabs is the primary reason for the current situation, what is less clear is what the primary drivers of the overfishing are. A larger population will inevitably lead to more fishing, but there are also external drivers that can inflate the level of fishing above what a local economy would normally undertake. In this study the one area we have not been able to quantify is the trade in crabs between fishers and foreign fishing vessels. Current laws do not prohibit individuals from purchasing as many mangrove crabs as they like from the markets; however, they are not allowed to take more than 15 crabs per individual out of the country and only if they have a permit. The anecdotal evidence that we were able to gather indicated that far more crabs than could reasonably be eaten at any given time are being bought by foreign fishers. While this trade from the markets to the boats is legal unless they are being exported, there is also anecdotal evidence that fishers are dealing directly with the boats. This trade pathway does not have any of the checks that can exist through a more formal market system and can easily encourage increased fishing intensity and a subsequent keeping of smaller crabs. Any attempts at instigating effective management plans will not be effective unless this area of trade in crabs is well understood.

While the continued presence of only large crabs in the markets is a positive sign that market forces are having a positive effect, it is nevertheless the case that the mean sizes are shrinking, which means that crabs are being harvested quicker than they can grow to maximum size. There is a clear need for a management framework to be implemented to ensure the sustainability of this favoured resource. The issues encapsulated within this fishery are typical across the Pacific Island countries and territories and lessons learned elsewhere will help inform the management protocols that need to be put in place. The important first step of recognising that there is a problem has already been undertaken. The equally important second step of collecting data to inform decision-making has also been done. There are, therefore, no impediments to introducing effective management plans; the challenge is to implement them as effectively as possible.

Capacity building

This programme of work was led by two SPC scientists from the Division of Fisheries, Aquaculture, and Marine Ecosystems (FAME) (Dr Andrew Halford and Ms Pauline Bosserelle) along with four staff members from Pohnpei's Office of Fisheries and Aquaculture (Dwight Damian, Johnathon Dewey, Itaia Fred and Ryan Ladore) and two staff members from Kosrae's Island Resource Management Authority (Sam Isaac and Anderson Tilfas). The six FSM fisheries officers were involved in all aspects of the programme, starting with putting the traps together and building the bait cages, and then being the main participants in fishing for the crabs, marking and measuring, and the recording of information. An extensive briefing was given at the start of the programme and again at the end, where some preliminary results were included. All officers were also involved in conducting land-based surveys of markets and fishers. There remains a need for scientific technical help and support in order to ensure that any future trapping programmes are well designed, and subsequent analysis and reporting is appropriate. However, the fisheries officers are now well-trained and capable of conducting a field sampling programme for mangrove crabs.

The traps used for catching crabs were left with the Office of Fisheries and Aquaculture (OFA) with an understanding that this equipment would be used to conduct similar surveys in other FSM states upon request.

Future calls for assistance from FSM states on their mangrove crab fisheries should involve using the fisheries staff from this programme to conduct training for other FSM fisheries officers with some technical support from FAME's Coastal Fisheries Programme Science team.

The COVID-19 pandemic has cancelled travel between countries for an indeterminate period, so face-to-face learning, which is a core part of SPC's technical assistance, is on hold. However, this situation is providing opportunities for SPC to develop online learning systems for country members to undertake continued skills training while the travel ban remains in place. Training module content will be guided by feedback on requirements from member states.

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Appendix 1: General survey methodology for assessing mangrove crab stocks

There is a hierarchy of approaches that can be used to survey mangrove crabs, and which approaches are used is usually a function of available resources and capacity. This appendix very briefly describes a methodology and approach that will enable sufficient data on the status of mangrove crab populations to be obtained, and will enable management plans to be implemented. Good quality data underpins all good management policy for sustainable fishing practices and, thereby, the focus is on ensuring the quality of the data collection process.

Habitat mapping

It is impractical to obtain the abundance of crabs by trapping all potential areas of a habitat. A more manageable approach is to find out which habitats crabs are usually found in and undertake trapping in a subset of locations. Then the total area of a crab habitat can be estimated from satellite photos and combined with the trapping information in order to estimate the total abundance.

The simplest model for estimating total abundance is as follows:

abundance = area of critical habitat x density of animals per unit of habitat

The accuracy of this abundance estimate will depend on 1) how representative the trapping programme is, and 2) how accurate the assessment of the available habitat is. More trapping will provide more data, which will make calculations more accurate.

The most efficient way to ensure that all areas of a representative habitat are sampled effectively is to break the total area of interest into blocks and make sure to conduct some sampling within each block. For example, we broke Pohnpei into four blocks for this survey and made sure to conduct trapping within each of these blocks to ensure our data was representative of the whole island.

Mangrove cover is an important component of understanding the distribution and abundance of mangrove crabs; however, knowing the area of creeks and rivers adjacent to mangroves is more important for determining total mangrove crab abundance.

Total abundance calculations are most useful when total catch data is also available. This allows the proportion of the crab population that is being caught to be estimated, which is a powerful index of fishing pressure for informing management. Total abundance within a specific area will also provide an indicator of the density of crabs within that area. This calculation can be used to understand the different carrying capacities of particular rivers and creeks, and when used in conjunction with the size data, can indicate the level of fishing pressure in a particular area.

Trapping

The use of well-designed traps is recommended as they will be better at catching crabs and, therefore, will provide more accurate data on abundance. Regardless of what type of trap is used, the same trap type must be used for all trapping work. Mixing different trap designs will result in different catching rates, which will make any abundance calculations inaccurate.

There is no standard number of traps that should be used to collect abundance data so we can offer some general guidelines only. As is the case for all data collection programmes, the more data that can be collected the better the calculations that stem from this data will be. Creek and river systems in FSM are not extremely long and wide, so we recommend 10 traps be used for trapping each kilometre of river or creek. These traps should be located 50 m apart and set close to the mangroves. This means that if a river or creek is 2 km long, then there should be two sets of 10 traps used – one set within each kilometre section. As the traps will be approximately 50 m apart, this will mean approximately 500 m will be surveyed within each kilometre. Where the river is wide (> 100 m) the traps will be on one side only but when the creek is narrow the traps can be on alternating sides.

Once the total area of interest has been divided into blocks, then a selection of rivers or creeks that are typical of an area or block should be chosen for trapping. The number of rivers to survey in each block is dependent on how many rivers or creeks exist, but at least three out of 10 rivers or creeks in a block should be a minimum.

Trapping should occur for at least three 24 h cycles per location. The bait should be changed every 24 h to keep it fresh. Traps should be checked every 12 h if possible, but every 24 h is still appropriate. All crabs caught should be measured and weighed and marked before being returned to the water. On each successive return trip, all new crabs should be measured again and returned to the water and any crabs that have previously been caught and marked should be noted on the datasheet and also returned to the water.

The same type and volume of bait should be used for all traps for the duration of the trapping programme. Changing the type of bait could change the effectiveness of the traps and hence the data will not be comparable.

Market surveys

Apart from the trapping programmes, market surveys are the other major component to any assessment of mangrove crab stocks. The markets are usually where the bulk of crab product is being sold, therefore this information needs to be gathered to provide estimates of numbers of crabs being sold and the sizes and sex of the crabs.

Data from the markets can be obtained in two ways. Fisheries officers can visit the markets regularly and measure the crabs that are for sale in the market. Another effective way is to introduce self-reporting by vendors. Any transaction should have information on the number of crabs and the total weight of product sold. This information can be linked with size measurements and sex ratios in order to gain a good understanding of the mangrove crabs that are being sold through markets.

Indices

There are a number of key results that any survey of mangrove crab stocks should try to obtain.

Fisheries-independent counts

This means data collected through independent trapping. This data gives a more realistic assessment of the population structure. All crabs should be sexed, weighed and measured for carapace width.

Size structure

All crabs that are counted – whether through trapping or at the markets – should be measured for CW (and weighed). This enables the size structure of a population to be plotted. Data from trapping should be evaluated independently from market data for size structure.

Sex ratios

This information is one of the core parts of data along with CW and weight that should be obtained from every crab that is counted. The sex of the crab is easily noted from the shape of its abdomen flap. Sex ratios can be very powerful indicators of the health of a population and can also indicate if overfishing is occurring.

Size at maturity

Understanding the size that crabs are when they are reproductive (~13 cm CW in Kosrae studies) is crucial for knowing the appropriate minimum size that crabs can be in order to be able to catch them. There must be enough reproductive stock in the system to keep it viable and this is a key way to trace this. There has been substantial work done in Kosrae on mangrove crab life-histories and results from this work would be appropriate for other member states of FSM.

Spatial patterns

This component is important because crab populations will differ according to a number of factors such as the size of river or creek system, type and number of mangroves, how much freshwater runoff enters the system and the size of the local human population. This means that trapping in only a few locations will not give a proper assessment of crab populations everywhere. Blocks that are divided up across the entire area of a crab habitat should be sampled.

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