A baseline study of Fiji's small-scale lobster fishery using value chain analysis and size at maturity thresholds

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ABSTRACT

Lobsters are an important catch component in Fiji's small-scale fisheries (SSF), but data are scarce. Seafood value chain analysis can provide insights on different actors involved in the fishery, thereby addressing human-wildlife interactions that may not otherwise be revealed. Data-poor SSF can further benefit from species-specific length-based spawning potential ratios and size at maturity thresholds deriving from relatively easily collectable data. In this study, 73 actors in the value chain of Fiji's lobster fishery were interviewed and 1636 individual lobsters across five species were measured. Lobsters are part of a multispecies fishery, mainly speared in reefs within traditional fishing grounds. The value chain is characterized by strong links among the key actors, but non-standardized units and non-uniform prices hamper the assessment of the actual income, profits and proportional values received. The length-based spawning potential ratio indicate that *Panulirus penicillatus* is around levels expected for a well-managed fishery, while *Panulirus versicolor* is vulnerable to being caught as juveniles, whereas estimates indicate a very high fishing mortality for *Parribacus caledonicus*. Thus, a focus on size-limitations and mitigation measures that allow *P. versicolor* and *P. caledonicus* to recover, is paramount, while SSF co-operatives based on community ownership can collaborate to generate economies of scale to increase the stability of the value chain. This study characterizes Fiji's small-scale lobster fishery, thereby providing a first mapping of the value chain, and allowing insights into the fishery's sustainability.

1. Introduction

Fisheries management relies on biological data to inform stock assessments and needs to consider the socio-economic context within which management decisions are affected [1–3]. Still, a large proportion of global fish catches comes from unassessed fisheries, particularly from unassessed small-scale fisheries (SSF) [4]. Although SSF provide food security, employment, and exports, in addition to their recreational and social attributes [5,6], limited available data led to a marginalization of SSF [7,8]. Moreover, the absence of official statistics and national accounts hamper management and monitoring in many productive yet depleted coastal ecosystems, where SSF are predominant [9,10]. More recently however, SSF and their role in supporting human development are gaining increasing visibility for the Food and Agriculture Organization of the United Nations [11] and priority through the sustainable development goals (https://sustainabledevelopment.un.org/sdgs).

Unassessed SSF can benefit from a suite of reference points based on relatively easily collectable data. The length-based assessment of spawning potential ratio (*LBSPR*) is a relatively new technique developed specifically for this purpose requiring only size at maturity (L_m) estimates and catch size composition, two of the least expensive and simplest forms of fisheries data [12]. The *LBSPR* methodology is based

on the simplifying assumption that the assessed populations exist in a relatively stable, or 'equilibrium' state, so that size compositions are expected to change relatively slowly, over a species' lifespan. The methodology estimates the spawning potential ratio (*SPR*) of fished population, a metric developed to index the risk of recruitment failure and similar to the Human Reproductive Index, which can support the development of simple policies to ensure fishery's sustainability [13, 14].

However, the increased commercialization of coastal fishery commodities also requires socio-economic micro level data of actors involved in the fishing and trading [15,16]. In recent years, there has been growing interest in the dynamics of agriculture and seafood value chains, in the context of national and international markets [17–21]. Value chain analyses (VCA) systematically describe the economic actors participating in the production, distribution, marketing, and sales of a particular product [22]. Therefore, VCA can provide a different perspective on SSF to traditional socio-economic or resource-based assessments, which tend to focus on individual economic agents, and information to support the development of sustainable fisheries management policies [16, 23–25].

In Fiji, SSF target a wide range of vertebrate and invertebrate species [26,27], thereby generating local food security [28,29] and income for up to 28,880 fishers, 842 traders and 2480 vendors [30]. Large marine crustaceans such as lobsters support a lucrative product on the domestic market, as well as being used for subsistence [31]. There are five species of lobsters in Fiji, four of which are spiny lobsters, including the golden rock lobster - *Panulirus penicillatus*, which is the most abundant [32]; the painted rock lobster - *Panulirus versicolor*, the ornate rock lobster - *Panulirus ornatus*; the slipper lobster - *Parribacus caledonicus*, and the whiskered lobster - *Panulirus longipes femoristriga* [31,33]. To date, there are no restrictions prescribed under the Fisheries Act and Regulations, although the harvesting of lobsters is discussed under the Cabinet Guidelines approved in 1984 [34]. These Cabinet Guidelines state among other things that the participation in lobster fishing activities is restricted to Fiji nationals and in the first instance to uninhabited islands and reefs and only permitted with the written approval of resource custodians. Implementing management regimes, however, was not deemed necessary at that stage and the guidelines further declare that due to the resource's restriction to seaward reefs, which are often inaccessible due to weather conditions, lunar phases and tidal cycles, some measure of protection is confered [35]. Fiji's Endangered and Protected Species Act 2002 lists *P. ornatus* and *P. versicolor*, nominally placing restrictions on their export and import [36], an uncommon occurrence for Pacific Island countries [37]. In effect, lobster fishing in Fiji currently is largely unregulated. This, together with economic incentives can result in resource over-use and dependence on maintaining yields. Given the often-multispecies nature of SSF, commodity based VCA are crucial as fishing efforts could be reduced if incomes were improved [38–40]. While baseline data on the distribution of benefits from trade in Fiji's sea cucumber, grouper, freshwater mussel, and mud crab fisheries have been assessed [41–44], comparable information on lobsters and estimates of biological parameters are lacking.

Here, we examined the prices across the various factions of lobster value chains stemming from SSF in Fiji, using in-depths interviews. Further we estimate L_m of lobsters and with those calculations use *LBSPR* and catch size composition data to estimate the *SPR* of Fijian stocks. Finally, we use those data to approximate legal minimum size limits (*LML*) which could sustain stocks and optimize yields. With this initial study aimed to provide baseline information on Fiji's small-scale lobster fishery and was therefore designed to 1) characterize the fishery, 2) present a mapping of the value chain and 3) support conclusions on the fishery's sustainability for different lobster species.

2. Materials and methods

2.1. Fishery's characteristics and VCA: Interviews

A value chain analysis can either follow a narrow or a broad approach. The former includes the range of activities performed within a firm to produce a certain output. The latter starts from the production system of the raw materials and moves along the linkages with other actors and enterprises engaged in trading, processing, assembling, and transporting [28,45]. In this study, a broad approach was applied. Prior to the interviews, consultation of various parties likely being involved in Fiji's lobster fishery was performed. From these efforts, potential interview participants, including traders and restaurant and resort operators, were identified. Hence, we used a non-probability purposive sampling technique [46]. Due to the COVID-19 pandemic, potential participants were initially contacted via phone to confirm whether they were still active in the lobster fishery.

To characterize Fiji's lobster fishery and to assess the VCA, semi-structured, in-person interviews were then conducted with fishers, traders, and restaurant and resort operators using a pre-categorized questionnaire. Interviews were performed between January 2020 and March 2022. Questionnaires (see Supplementary Information S1 for the lists of questions) were adapted from previous VCA studies on Fiji's mud crab fishery by the Wildlife Conservation Society [42]. The questionnaire covered topics related to the lobster fishery, such as catch sites, fishing frequency, or gear specification, but also on commercial activities. Interviews were performed opportunistically [47] and the number of respondents at one site was determined by availability of interview partners [48]. All interviews were conducted by two of the authors (MT, KM) and colleagues (see Acknowledgment). Potential participants were asked to volunteer for interviews and were not given any incentives to partake. The purpose of the survey was explained in English and Fijian, and individual interviews were held in places convenient for respondents [49]. Participants were further informed that the survey can take up to 30–60 min and assured that all information will be kept confidential and only data aggregates will be revealed for the purpose of the study. All responses were noted as they were encountered, and no leading questions and no *a priori* coding dictionary were used.

2.2. Fishery's characteristics and VCA: Study area

The study area is comprised of Suva in the Central Division, Sigatoka, Nadi, and Lautoka in the Western Division, as well as Savusavu and Labasa in the Northern Division (Fig. 1). The interviews with fishers and traders were performed at fisheries wharfs and municipal markets, while the consultation of restaurant and resort operators was conducted in touristic and economic centres such as Nadi, Lautoka, Suva and Sigatoka. Noteworthy, the Lautoka fisheries wharf in the Western Division differs from the other markets as it also serves as a landing site for fishers from the Yasawa Islands. Unlike the other sites, the Lautoka fisheries wharf is operated by the Ministry of Fisheries and not by the municipal council. Moreover, this wharf opens daily, twice from Tuesday to Saturday and once on Sunday and Monday. Due to these unique arrangements, the Lautoka fisheries wharf serves as an epicentre for seafood related businesses in the Western Division.

2.3. Fishery's characteristics and VCA: Data handling

Interview data were recorded in SurveyMonkey which is an online survey tool that facilitates developing, collecting, and analyzing survey data [50–52]. Stored data were exported to Microsoft Excel for the calculation of frequency distributions.

2.4. Size at maturity: species identification and measurements

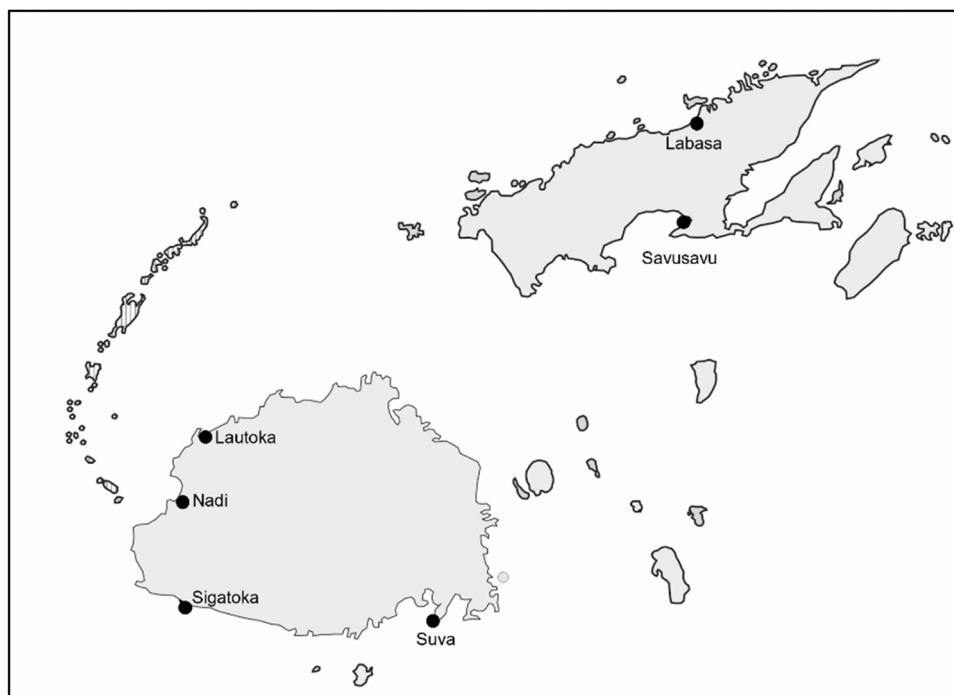Sampling occurred at the fish markets in Lautoka, Suva, Labasa, and

Fig. 1. Selected sampling sites across Fiji's main islands Viti Levu and Vanua Levu.

Savusavu (Fig. 1), and was performed between September 2020 and March 2022. The five species of lobsters present in Fiji are distinguishable, based on shape, coloration, and color patterns. Also, lobster show sexual dimorphism, which following George (2005) allows for visual identification of its sex and stage of maturity [53]. Their sex and stage of maturity were recorded as either immature (1), which represented lobsters that could not be identified as either male or female. Male lobsters were recorded as either immature (2) or adult (3). Female lobsters were either recorded as immature (4) or depending on the number of visible sexual maturity indicators such as soft window (5), tar spot (6) and berried (7) as mature (Fig. 2, Table 1).

2.5. Size at maturity and SPR

The *SPR* is defined as the proportion of unfished reproductive potential remaining in a fished population [54]. In unfished populations,

Fig. 2. Pictures of mature female and male specimen across the five species of lobster present in Fiji's water, with visible sexual maturity indicators as detailed out in Table 1, from the top left to the right, and bottom left to the right. Note, *P. caledonicus* is only represented with a female specimen (top left).

Table 1

Number of sexual maturity indicators for female and male specimens across the five species, and as visible in Fig. 2. Numbers refer to pictures in Fig. 2 starting from the top left to the top right, continued with bottom left to the right.

No	Species	Sexual Maturity	Maturity Level
1	*P. caledonicus*	Mature female	5, 6, 7
2	*P. longipes femoristriga*	Mature female	5
3	*P. longipes femoristriga*	Mature female	5, 6
4	*P. longipes femoristriga*	Mature female	5, 6,7
5	*P. longipes femoristriga*	Mature male	3
6	*P. ornatus*	Mature female	5,6
7	*P. ornatus*	Mature male	3
8	*P. penicillatus*	Mature female	5,6,7
9	*P. penicillatus*	Mature male	3
10	*P. versicolor*	Mature female	5,6,7
11	*P. versicolor*	Mature male	3

fish, on average, live natural life spans and fulfil natural levels of reproductive output, or *SPR* 100%. Fishing diminishes average life spans, reducing the *SPR* of populations, to some ratio of unfished levels (*SPR* < 100%). The metric of *SPR* is internationally accepted as a gauge of fisheries sustainability; 20% *SPR* is regarded as the replacement level, and used as a Limit Reference Point, which stocks should be prevented falling below. While *SPR* = 30–40% is used as a target range likely to optimize long term yields, and *SPR* ~ 50% a level likely to optimise economic returns from a fishery [55]. The *LBSPR* algorithms uses the catch size composition to estimate *SPR* and relative fishing pressure (*F/M*, where *F* is 'fishing mortality', and *M* is 'natural mortality'). Essentially *LBSPR* compares the size of the fish (or in this case lobsters) in the catch with L_m. If fish are all caught before becoming adults their populations have little or no spawning potential (~ *SPR* 0%). On the other hand, with low fishing pressure, fish are likely to survive to grow to around their average maximum, or asymptotic, size (L_∞) and fulfil *SPR* ~ 100%. The algorithms needed to apply the LBSPR methodology were accessed at the freely available website: http://barefootecologist. com.au. As the determination of sexual maturity is more definitive in female lobsters than in male lobsters, only female lobsters were used for the LBSPR assessment.

Input data for the *LBSPR* methodology are:

1. Catch size composition data that are indicative of the size of the adult population. If the type of fishing being conducted fails to catch the largest size classes of a species, then the estimate of *SPR* produced for that species will be too small.
2. Estimates of L_m which is defined by L_{50} and L_{95}, the sizes at which 50% and 95%, respectively, of a population are observed to be mature.
3. The two life history ratios (*LHR*) that characterise differing taxa and which determine the relative shape of population size and age compositions [54]. The *LHR* are:

a. L_{50}/L_∞; and
b. *M/K* - the rate at which a cohort of fish dies off from natural causes (*M*), divided by the von Bertalanffy growth parameter (*K*), which is the instantaneous annual rate of grows to L_∞.

The first two of these data inputs need to be estimated locally for each lobster species as they vary from place to place. The two *LHR*, together define the shape of adult size compositions, relative to L_m [14] are similar across species complexes and ranges, and across genera and entire taxonomic families [55,56]. In theory they would be best estimated generically by species from high quality age and growth studies, if sufficient high-quality studies exist, in practice the best estimates are generally derived through synthesis of the literature for entire families due to the larger number of studies. We found 31 internationally refereed journal articles (see list of references in Supplementary Information S2) on the growth and size of maturity of lobsters of the family

Palinuridae from which we derived, eight estimates for $L_{50}/L_\infty = 0.636$, and 21 estimates for $M/k = 1.151$ (Table 2). We did not find sufficient studies of *P. caledonicus* to derive any *LHR* estimates. In this context we will assume the same *LHR* for all four species assessed.

3. Results

3.1. Characteristics of interview participants

In total, 73 participants were interviewed, composing of 35 fishers, 16 traders, and 22 restaurant and resort operators (Table 3). Interviewed fishers were all indigenous male Fijians and between the ages of 24 and 60 years with a mean length of operational experience of 15 years. Overall, 29 interviewed fishermen were involved in lobster harvesting since the beginning of their fishing activities. Interviewed traders composed of nine male and seven female participants. The age of interviewed traders ranged from 25 to 60 years, with a mean operational experience of seven years. These traders supplied four restaurants within hotels or resorts and 18 independent restaurants, of which eight served Asian cuisine, nine high-end international cuisine and one bistro-style restaurant.

3.2. Characteristics of the lobster fishery

Lobsters were captured in a multispecies fishery, together with fin-fishes, rays, and invertebrates, such as octopus. Twenty-nine interviewed fishermen speared their lobsters; four fishers used a range of techniques, spearguns, hand-nets and hand collection, while one used a gillnet. One fisherman left this question unanswered. Except for three fishers who reportedly captured lobsters alone, harvesting was carried out in co-operative units, comprised of family and or community members, accompanied either by a boatman and captain, or captain only. When asked about the fishing sites, 31 respondents referred to their *iqoliqoli* (traditional fishing ground), including reefs, while four interviewees left this question unanswered. Most of the interviewed fishers spent five to six hours per fishing trip (Fig. 3 A) and reached their fishing areas within one to two hours of travel time (Fig. 3B). Almost half of the respondents' fished five to six days per week and year-round, subject to weather conditions (Fig. 3C). At the Lautoka fish wharf, lobsters appeared to be sold predominantly in the morning compared to the afternoon (M. T. pers. obs.).

3.3. Value chain

3.3.1. Fishers: sales

At the markets and/or roadside, fishers sold lobsters either in kilograms, individually or in heaps (Table 4). Number of lobsters per heap ranged from two to five lobsters and heaps could include different species, particularly when small individuals were sold. The asking price for individual lobster was solely determined by the respective fisher. Of the interviewed fishers, 16 were always able to sell all captured lobsters, five interviewees were sometimes able to sell all lobsters, three very often sold all their catch, another three respondents did not often sell all their lobsters, and the remaining eight fishermen chose not to answer this question. Unsold lobsters were subsequently either offered at a reduced priced or used for subsistence by the fishermen and their families. Fishers stated that consumer's demand for lobsters was relatively stable

Table 2

Estimates based on a meta-analysis of 31 internationally refereed journal articles on the growth and size at maturity of lobsters of the Palinuridae family.

	L_{50}/L_∞	M/K
Average	0.636	1.151
SD	0.096	0.427
N	8	21

Table 3

List of key actors interviewed in the Central, Western and Northern Division.

Key actors	# Interviews Central Division	# Interviews Western Division	# Interviews Northern Division
Fishermen	6	14	15
Traders	4	2	10
Restaurant operators	6	16	0

throughout the year.

Of the fishermen interviewed, 10 sold lobsters to traders. According to fishers, traders paid USD 5–9 / kg of lobsters, compared to prices being USD 18–23 / kg prior to the COVID-19 pandemic. In the Western Division, traders travelled to fishermen or to pre-arranged meeting spots. In the Central Division, traders met fishers at various landing sites. Saturday is the main market day for fish sale in Fiji's capital Suva, where all the key players in the value chain are present. In the Northern Division, traders bought directly from fishers at the Labasa and Savusavu fish markets. At the Labasa market fishers also sold directly to consumers. In contrast, in Savusavu only traders were present. Three fishers from the Western Division who sold to restaurants and hotels, stated that large *P. ornatus* and *P. versicolor* were preferred due to their higher meat weight. The prices fishers received were negotiated but predominantly determined by the restaurant operator and mainly depended on the species and weight (Table 5).

3.3.2. Fishers: operational costs and weekly turnovers

Seventeen fishers provided breakdowns of cost items per fishing trip, such as USD 5–46 for fuel, USD 5–9 for boat hire, USD 5–9 for the captain, USD 2 for ice and USD 9 for transportation to and from home. Three respondents stated that total costs per person and fishing trip ranged between USD 28–37 and according to one fisher, total crew costs per trip amounted to USD 184–230. Six of the fishermen interviewed provided information on their weekly turnovers generated from the sale of lobsters, which ranged between USD 18–161. The respective response rate was low, partly because information on financial income was not readily shared and partly because the fishermen did not keep commodity-related accounts.

3.3.3. Traders: purchasing and sales

Traders stated to also trade in giant clams, mud and reef crabs, octopus, finfish, and shrimp. Fifteen of the 16 respondents purchased lobsters from local fishermen, and one bought from other traders. In general, no prior arrangements between sellers and buyers were made. Eleven traders bought dead, unfrozen and unchilled lobsters, three only bought live specimens, and two preferred dead frozen and chilled lobsters. Of the respondents, 14 traders sold to private consumers, while two retailed to restaurants. Price was primarily determined by size and weight, with quality and species being of lower priority (Table 6).

Table 4

Minimum and maximum prices reflective being received by fishermen when selling lobsters to consumers at the markets and roadside. Prices refer to different units, thereby incorporating kg, pieces, and heaps, at the time of data collection. All prices were converted from FJD into USD based on the average exchange rate in 2020 and rounded off to the closest dollar value.

Size	Price in USD / kg	Price in USD / piece	Price in USD / heap
Small-Medium	5–12	7–9	12–28
Medium-Large	9–14	7–14	32–37
Large	12	14–23	9–14
n/A	2–21		

Table 5

Prices for different species and sizes of lobsters being received by fishermen and as determined or negotiated between fishers and restaurant operators. All prices were converted from FJD into USD based on the average exchange rate in 2020 and rounded off to the closest dollar value.

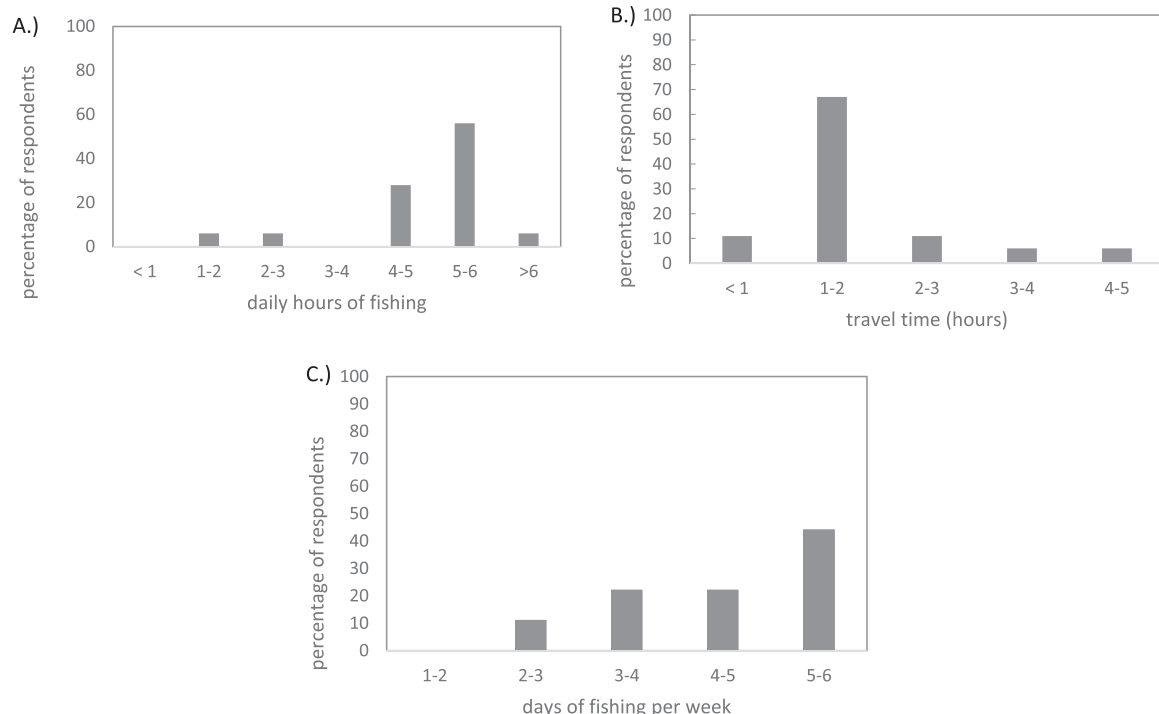| Species	Price in USD / kg Small	Price in USD / kg Medium	Price in USD / kg Large
P. ornatus	5	14	21
P. versicolor	5	14	21
P. penicillatus	5	16	16
P. caledonicus	n/A	n/A	5

Fig. 3. (A) Daily time spent for fishing/harvesting lobsters. (B) Travel time to the fishing area (C) Number of days of fishing per a week.

Nevertheless, 10 traders reported being dissatisfied with the quality of lobsters, and only six respondents expressed satisfaction with quality. According to the traders interviewed, demand for lobsters increased during the festive season.

3.3.4. Restaurants and resorts

The price restaurant and resort operators paid for lobsters ranged from USD 5 / kg for small lobsters to a maximum of USD 55 / kg for large specimens. Of the 22 interviewed restaurant and resort operators, 10 bought lobsters directly from fishers, seven operators bought exclusively from traders, while the remaining five bought from both (Fig. 4). Alive and dead (frozen or chilled) lobsters were bought, weight being the main selection criteria applied, then size and species. Restaurants increasingly opted for buying lobsters from fishers directly, while fishermen in turn appeared to approach restaurant operators. Menu prices ranged from USD 7 for lobster salad using 0.1 kg of meat to USD 92 for a grilled 1.5 kg lobster (Fig. 4). According to interviewed restaurant and resort operators, demand for lobsters increased during the festive season.

3.4. Size at maturity and SPR assessment

In total, 1636 lobsters were sampled; 661 *P. versicolor*, 433 *P. caledonicus*, 461 *P. penicillatus*, 51 *P. ornatus*, 20 *P. longipes femoristrigia* and 10 specimens remained unidentified (Table 7). There were in-sufficient samples of *P.longipes femoristrigia* for L_m to be estimated at this stage. The estimates of L_{50} ranged from 99 mm for *P. versicolor* and 98 mm for *P. ornatus* to 75 mm and 69 mm for *P. penicillatus* and *P. caledonicus*, respectively. As a rule-of-thumb for fisheries management a robust minimum size limit (*MSL*) that should conserve > 20% *SPR*, preventing both growth and recruitment overfishing, ensuring sustainable 'pretty good yields', is estimated by 1.2 x *L50* [12]. Applying that rule-of-thumb to these data the optimum *MSL* for each species has been estimated and tabulated in Table 7, alongside the *LHR* estimates derived through meta-analysis, and implicit L_∞, used as input assumptions for our *LBSPR* assessment.

The results of the *LBSPR* assessment are tabulated in Table 8 for the three species for which sufficiently large sample size (N > 100) was obtained. The three assessed species are estimated to have distinctly different levels of *SPR*, with *P. caledonicus* (*SPR* = 0.09) and *P. versicolor* (*SPR* = 0.18) both having low SPR, around levels that could potentially cause recruitment declines, and *P. penicillatus* (*SPR* = 0.49) apparently having optimally high *SPR*.

4. Discussion

4.1. Fishery's characteristics and key players

This study provides baseline information derived using a combination of methods for the previously unassessed small-scale Fijian lobster fishery. The apparently opportunistic fishery is dominated by indigenous Fijian male fishers a pattern of gender involvement that typifies Fijian SSF, with female fishers being primarily active in gleaning, and

Table 6

Tabulated wholesale and retail prices for five different species of lobsters as reported by interviewed traders. All prices were converted from FJD into USD based on the average exchange rate in 2020 and rounded off to the closest dollar value.

Species	Price in USD / kg Wholesale	Price in USD / kg Retail
P. ornatus	5–9	n/A
P. versicolor	5–14	10–28
P. longipes femoristriga	n/A	n/A
P. penicillatus	3–12	6–14
P. caledonicus	5–9	9
Any species	7	6–7

more littoral fisheries [5,42]. The operational costs incurred by fishermen are critical to understanding investments in the fishery, as well as redundancies or inefficiencies in the value chain. Fishers require sufficient income to cover both capital expenditure on fishing gear, and operational costs to facilitate continued harvesting and sale. The operational costs per fishing trip, combined with travel times and duration of fishing trips, at least partly, account for the multispecies and opportunistic nature of the fishery. The seafood VCA included fishers, traders, restaurant, and resort operators as key players. With many fishers, an unknown number of traders, and a diversity of consumers such as tourists, locals, and the fishermen themselves, we suggest a sand-clock pattern [57] for the lobster value chain in Fiji. At the beginning of the chain, we located the fishers, who mostly act in operative units and depend upon each other. According to interviewees, traders participate in multiple activities in the chain: purchasing product directly from fishers in various forms (alive, dead, frozen, unfrozen), as well as selling product to other traders, restaurants, and consumers. The VCA is characterized by strong links among the key actors. There is little if any value-adding in the VCA, with no processing by fishers, despite lobsters potentially have a longer sales window compared to finfish. Non-standardized units and non-uniform prices hampered our assessment of generated net income and the proportional value received, which in turn impeded the identification of opportunities on how the value chain can be improved. Nevertheless, moving away from spearing lobsters to catching and holding lobsters for live export market depicts an obvious value adding technique. Also, spearing lobster compromises quality, which is corroborated by respective statements of almost two-thirds of the interviewed traders. In general, seafood produce quality control is challenging for SSF in this region, which affects both, pricing, and export. Past attempts to export lobsters from Fiji were unsuccessful [36], however export volumes particularly to New Zealand and Hongkong increased since the re-opening of Fiji's boarders in December 2021 (Nanise Tuqiri Kuridrani pers. comm. - Principal Research Officer and Head of Fiji's Ministry's Research Division). Thus, the regulation of alternative harvest methods to ensure lobsters are landed alive, and training in post-harvest handling is warranted. In the present context, the domestic market was in focus and exporters were not included. It is therefore recommended, that future studies on Fiji's lobster value chain include exporters, which might reveal previously unrecognized value-adding options for the suppliers.

4.2. Marketing system

Overall, the marketing system varies according to site, which is comparable to other domestically traded commodities in Fiji [58]. Except for economic ruptures during the COVID-19 pandemic, demand appeared to be relatively stable, with increases being related to the festive season. These results are similar to Mangubhai, 2017, where key actors reported increased demand and prices for mud crabs around Chinese New Year and Christmas. Interviewed fishermen reported having started to approach restaurants directly more often, and in turn, were increasingly being contacted directly by restaurant operators, perhaps indicating changes to business links as a strategy to become less dependent on single traders.

4.3. Size at maturity and SPR

With the estimates of size at maturity, this study provides crucial baseline biological data for four of the five lobster species in Fiji. Results suggest that with $SPR = 0.49$ and relative fishing pressure $F/M = 0.83$ the stock status of *P. penicillatus* is around levels expected for a well-managed fishery, for both metrics. With a size of first capture ($SL_{50} = 74$ mm) similar too its size at maturity ($L_{50} = 75$ mm) juvenile *P. penicillatus* are apparently naturally protected from capture prior to maturing. In addition, the relative fishing pressure on *P. penicillatus* is apparently lower than for the other species, despite it being the main
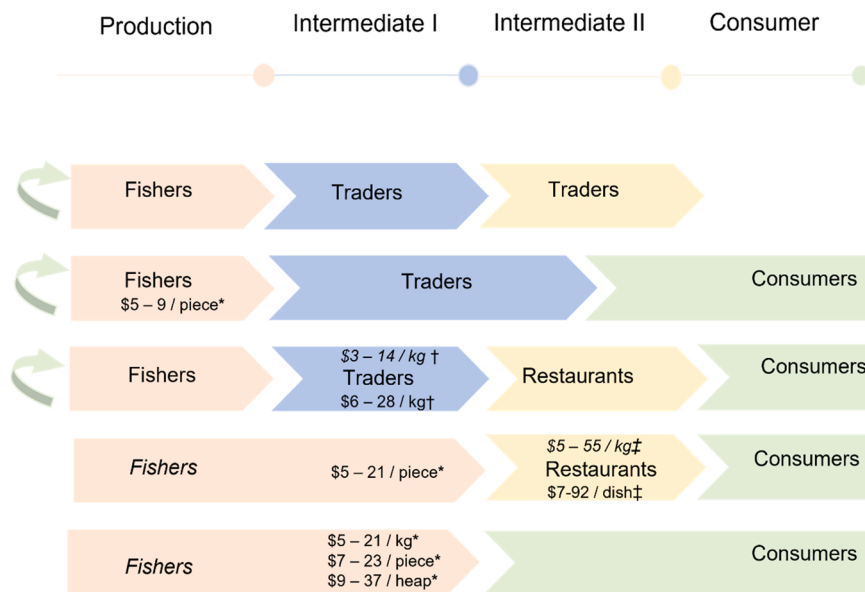
Fig. 4. Tracking the lobster production flow across the value chain in Fiji's domestic market. Price ranges marked with * represent minimum and maximum prices across all sizes of different units at which fishermen sold lobsters to consumers, traders, and restaurants. Price spans marked with † represent the price range of purchasing (*italics*) and retail prices as reported by traders. Prices marked with‡ refer to purchase prices (*italics*) of restaurant operators and to the price ranges for different dishes that include lobsters, as offered by restaurant operators. Green arrows refer to subsistence use of lobsters by fishermen. All prices were converted from FJD into USD based on the average exchange rate in 2020 and rounded off to the closest dollar value.

Table 7

Estimates of the size at which 50% (L_{50}) and 95% (L_{95}) in millimeters, of the female lobsters of four species in Fiji attain maturity, *n* - sample sizes, set size = 1.2 x L_{50} approximates the size for a minimum legal length preserving ~20% *SPR* and optimizing yields. Also shown are the input parameter estimates *M/K*, L_{50}/ L_{∞} and L_{∞} used for the *LBSPR* assessments.

Species	n	L_{50}	L_{95}	MSL	M/K	L_{50}/L_{∞}	L_{∞}
Panulirus versicolor	268	99	120	118	1.15	0.635	155
Parribacus caledonicus	146	69	85	83	1.15	0.635	109
Panulirus penicillatus	197	75	95	90	1.15	0.635	118
Panulirus ornatus	23	98	120	118	1.15	0.635	154

species caught. Interestingly the VCA revealed a preference for the larger *P. versicolor* and *P. ornatus*, suggesting they might be targeted more heavily by fishers, although our estimate of relative fishing pressure for *P. versicolor* is only somewhat higher (*F/M* = 1.2), than for *P. penicillatus*. Nevertheless, the results indicate that *P. versicolor* is vulnerable to being caught as juveniles, with the size of first capture (SL_{50} = 55 mm) being significantly smaller than their size of maturity (L_{50} = 99 mm), so that fishing pressure on this species is being applied over a greater part of its life cycle, resulting in much greater depletion of its reproductive potential (*SPR* = 0.18). One limitation of this study is that the small sample size of *P. ornatus* prevented us assessing its statement. Individual *P. ornatus* of any size were rarely encountered during the market surveys. One possible explanation could be that fishers sold them directly to hotels and restaurants, although we discount this possibility because our surveys gave no indication of this. Another possibility is that this species is naturally rare and has always been a valued but minor species, however, extrapolating from our results for the similarly prized large sized *P. versicolor* leads us to postulate

that its apparent rarity in current catches indicates that its stocks have already been heavily depleted. Additional sampling might in time accumulate a sufficient sample to enable *LBSPR* assessment and allow this idea to be tested quantitatively. In the meantime, interviewing older and retired fishers as to whether this species was previously more prevalent in catches might make it possible to qualitatively test this idea.

Puzzlingly, *P. caledonicus* which is first caught at sizes slightly greater (SL_{50} = 73 mm) than size of maturity (L_{50} = 69 mm) does not appear to be naturally protected in the same way as *P. penicillatus*. Our estimate of *F/M* ~ 11 for this species is unrealistically high, reflecting the asymptotic relationship between *F/M* and catch size composition at very high levels of relative fishing pressure, but is still robustly indicative of a very high fishing mortality (*F/M* > 3). Perhaps the Fijian populations *P. caledonicus* are small and geographically constrained by the area of soft sandy bottom, so that they can be heavily fished by divers. Alternatively, this result might be explained by larger adult *P. caledonicus* ranging out beyond the depths fished by divers, causing them to be under-represented in our samples, or that *LHR* for this taxon are significantly different to Panulirid *LHR* we assumed. If it were found that both *P. versicolor* and *P. ornatus* are overfished, the weight of evidence would seem to favor the former explanation and that this species is also being overfished.

4.4. Management

Unlike Fiji, several Pacific Island states have adopted management practices to combat overfishing of lobsters. These management practices employ restrictions and enforcements on the type of gear used, seasonal closures, no-take of soft-shelled lobsters and egg bearing lobsters as well as size limits [59]. As we identified indicators of overexploited fishery for *P. versicolor* and potentially *P. caledonicus*, implementation,

Table 8

Tabulated results of *LBSPR* assessment of female catch size composition data for three Fijian lobster species; of *SPR*, size at which 50% of lobster become vulnerable to capture (*SL50*), size at which 95% of lobster become vulnerable to capture (*SL95*) and relative fishing mortality (*F/M*) are shown with 95% confidence intervals.

Species	SPR	SPR − 95%	SPR + 95%	SL50	SL50 − 95%	SL50 + 95%	SL95	SL95 − 95%	SL95 + 95%	F/M	F/M − 95%	F/M + 95%
Panulirus versicolor	0.18	0.11	0.24	55	51	58	66	59	74	1.2	0.86	1.54
Parribacus caledonicus	0.09	0.01	0.17	73	66	80	88	79	97	11.04	2.08	20
Panulirus penicillatus	0.49	0.31	0.66	74	66	83	98	85	111	0.83	0.23	1.43

surveillance and enforcement of the legal-size limits suggested above is strongly encouraged. However, achieving a management-induced reduction in catch is reactive only and not trivial [60]. In Fiji, marine resources are traditionally controlled by local social units, such as clans and villages, a system commonly known as customary marine tenure [61]. Such communal rights-holding ought to develop the SSF value chain to economically benefit the fishers and communities [62,63]. With the strong relationships amongst the key actors in the value chain, SSF co-operatives based on community ownership can collaborate to generate economies of scale and work against price-control, but only if well managed, [64] for example by an active, organized and well-respected leadership. The identification of client requirements could enable the fishers and co-operatives to augment their marketing strategies. In this, information-sharing among key actors could facilitate both value-adding and marketing networks, eventually leading to a greater stability of the value chain. One example could be linking up lobsters with the tourism industry. Management is eventually about regulating the action of people [65] and acceptance and compliance with regulations strongly depends on the local communities. Hence, knowledge on measures needs to be transferred and communities ought to be consulted and involved in decision-making processes [66,67].

4.5. Limitations

The COVID-19 pandemic impacted the field work's continuity, yet simultaneously provided the opportunity to observe real-time response strategies to serious economic disruption [68,69]. The strategies employed by fishermen and traders along the value chain ensured consumers access to lobsters as new ventures offered home delivery for little to no extra costs. While these inventive measures led to continued income for fishermen and traders, they increased the number of participants in the value chain fueling the risk of overexploitation. It is worth adding, that while our study design allowed us to record response strategies related to the COVID-19 pandemic, the questionnaires clearly focused on general aspects of the value chain. Hence, we are confident that we captured a reliable picture of Fiji's lobster fishery.

5. Conclusions

This study mapped out the value chain of Fiji's small-scale lobster fishery and assessed biological characteristics of commercially fished lobsters. It highlighted the opportunistic nature of the multispecies fishery and underpinned how socio-economic factors can be analyzed to understand key actors involved. The research described here does not attempt to cover all aspects of Fiji's lobster fishery but rather focuses on providing a baseline of the fishery. The combined methodological approach can be further applied to other Pacific Island countries to understand involved actors and fishery commodities in a Pacific-wide context. Additional research is needed, especially in biological data of *P. ornatus* and *P. longipes femoristriga*. Despite the inherent complexity of fishing communities, exploring alternative pathways for fishers to reach economic independence, and strengthening of existing fisheries association through the provision of new scientific results, could help reduce market driven exploitation of a limited resource. In the present scenario and coupled with Fiji's commitment to develop policies for the protection of economically important fisheries commodities, a focus on species-specific mitigation measures that allow *P. versicolor* and *P. caledonicus* to recover is paramount. Finally, it is suggested that follow-up studies include questions related to exporters, account for species-specific differences regarding demand, price, and sales quantities, and identify a common denominator to reveal actual incomes, profits and proportional values received.

Ethical Statement

This research was approved by The University of the South Pacific

(USP), by the Provincial Offices, and by the Pacific-European Union Marine Partnership (PEUMP) programme Project Management. All interview procedures were approved under the "Human Ethics Committee" section of the USP Research Committee and performed in accordance with relevant guidelines and regulations. Also, in accordance with protocols of the USP, provincial offices were consulted, to explain the research, objectives, methodologies and expected outcomes prior to the data collection.

Author statement

M.T, C.M., and J.P. conceived the study. M.T. and K.M. did the field work. M.T., K.M. and K.G. analyzed the VCA data under the supervision of C.M. and J.P. analyzed the catch size composition data. K.G. and J.P. wrote the paper. All authors reviewed the manuscript.

Conflict of interest

The authors declare no conflicting interests.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105513.

References

[1] M.N. Maunder, K.R. Piner, Contemporary fisheries stock assessment: many issues still remain, Ices J. Mar. Sci. 72 (1) (2015) 7–18.
[2] E. McKinley, T. Acott, K.L. Yates, Marine social sciences: Looking towards a sustainable future, Environ. Sci. Policy 108 (2020) 85–92.
[3] S. Jentoft, The community: a missing link of fisheries management, Mar. Policy 24 (1) (2000) 53–59.
[4] C. Costello, et al., Status and Solutions for the World's Unassessed, *Fish.* Sci. 338 (6106) (2012) 517–520.
[5] L.C.L. Teh, et al., An overview of socio-economic and ecological perspectives of Fiji's inshore reef fisheries, Mar. Policy 33 (5) (2009) 807–817.
[6] S.L. Hendriks, Sustainable small-scale fisheries can help people and the planet, Nature 606 (7915) (2022) 650–652.
[7] C. Pita, S. Villasante, J.J. Pascual-Fernandez, Managing small-scale fisheries under data poor scenarios: lessons from around the world, Mar. Policy 101 (2019) 154–157.
[8] D. Zeller, et al., Synthesis of underreported small-scale fisheries catch in Pacific island waters, Coral Reefs 34 (1) (2015) 25–39.
[9] J.B.C. Jackson, et al., Historical overfishing and the recent collapse of coastal ecosystems, Science 293 (5530) (2001) 629–638.
[10] H.K. Lotze, et al., Depletion, degradation, and recovery potential of estuaries and coastal seas, Science 312 (5781) (2006) 1806–1809.
[11] Kurien, J., *Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication: summary*. 2015, International Collective in Support of Fishworkers.
[12] J. Prince, A. Hordyk, What to do when you have almost nothing: a simple quantitative prescription for managing extremely data-poor fisheries, Fish Fish. 20 (2) (2019) 224–238.
[13] A. Vahabnezhad, et al., Length based spawning potential ratio (LBSPR) of javelin grunter, Pomadasys kaakan (Cuvier, 1830) in the Persian Gulf and Oman Sea, Iran. J. Fish. Sci. 20 (6) (2021) 1560–1572.

[14] P.M. Mace, M.P. Sissenwine, How much spawning per recruit is enough? Can. Spec. Publ. Fish. Aquat. Sci. (1993) 101–118.

[15] E. Gudmundsson, F. Asche, M. Nielsen, Revenue Distribution through the Seafood Value Chain, Food and Agriculture Organization of the United Nations, Rome, 2006.

[16] R.A. Watson, et al., Global seafood trade flows and developing economies: insights from linking trade and production, Mar. Policy 82 (2017) 41–49.

[17] U. Johansen, et al., The Norwegian seafood industry - importance for the national economy, Mar. Policy 110 (2019).

[18] E. Coronado, et al., Who's who in the value chain for the Mexican octopus fishery: mapping the production chain, Mar. Policy 118 (2020).

[19] S.W. Purcell, et al., Distribution of economic returns in small-scale fisheries for international markets: a value-chain analysis, Mar. Policy 86 (2017) 9–16.

[20] B.G. Smith, Developing sustainable food supply chains, Philos. Trans. R. Soc. B: Biol. Sci. 363 (1492) (2008) 849–861.

[21] J.M. Bloemhof, M. Soysal, *Sustainable food supply chain design.* Sustainable Supply Chains, Springer, 2017, pp. 395–412.

[22] R. Kaplinsky, M. Morris, A handbook for value chain research Univ. Sussex, Inst. Dev. Stud. Brighton Vol. 113 2000.

[23] R.M. Rosales, et al., Value chain analysis and small-scale fisheries management, Mar. Policy 83 (2017) 11–21.

[24] B. Carbonetti, R. Pomeroy, D.L. Richards, Overcoming the lack of political will in small scale fisheries, Mar. Policy 44 (2014) 295–301.

[25] R.S. Pomeroy, Managing overcapacity in small-scale fisheries in Southeast Asia, Mar. Policy 36 (2) (2012) 520–527.

[26] N. Rawlinson, et al., A survey of the subsistence and artisanal fisheries in rural areas of Viti Levu, Fiji (1995).

[27] K.B.J. Glaus, et al., Fishing for profit or food? Socio-economic drivers and fishers' attitudes towards sharks in Fiji, Mar. Policy 100 (2019) 249–257.

[28] J.D. Bell, et al., Planning the use of fish for food security in the Pacific, Mar. Policy 33 (1) (2009) 64–76.

[29] K.E. Charlton, et al., Fish, food security and health in Pacific Island countries and territories: a systematic literature review, BMC Public Health 16 (1) (2016) 1–26.

[30] Starkhouse, B.A., *What's the catch: Uncovering the catch volume and value of Fiji's coral reef-based artisanal and subsistence fisheries.* 2009, University of British Columbia.

[31] Wright, A. and L. Hill, Nearshore marine resources of the South Pacific. Information for Fisheries Development and Management. International Centre for Ocean Development. 710pp. South Pacific Commission, 1993.

[32] Lewis, A., *Fishery resource profiles: information for development planning.* Fisheries Division, Ministry of Primary Industries, Suva, Fiji: 90p.(Partially updated in 1988), 1985.

[33] L. Holthuis, Marine lobsters of the world. An annotated and illustrated catalogue of species of interest to fisheries known to date No. 125FAO Fish. Synop. 13 1991 292.

[34] S. Lee et al. Fiji Fishery Resource Profiles Inf. Manag. 44 Most Important Species Groups 2021.

[35] Lagibalavu, M., S. Sharma, and K. Swamy, *Fiji Fisheries Resources Profiles.*

[36] J. Uluivuda, Endangered and Protected Species Act 2002 Enacted Parliam. Fiji Isl. 23 2002.

[37] R. Gillett, M.I. Tauati, Fisheries of the Pacific Islands: regional and national information FAO Fish. Aquac. Tech. Pap. 625 2018.p. I-400.

[38] Berkes, F., *Managing small-scale fisheries: alternative directions and methods.* 2001: IDRC.

[39] S. Salas, et al., Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean, Fish. Res. 87 (1) (2007) 5–16.

[40] S. Cunningham, Fishermen's incomes and fisheries management, Mar. Resour. Econ. 9 (3) (1994) 241–252.

[41] R. Ram, R.V. Chand, P.C. Southgate, An overview of sea cucumber fishery management in the Fiji Islands, J. Fish. Aquat. Sci. 11 (3) (2016) 191–205.

[42] S. Mangubhai, M. Fox, Y. N, and Value chain analysis of the wild caught mud crab fishery in Fiji Suva, Fiji: Wildl. Conserv. Soc. 2017.

[43] J. Lako, N. Kuridrani, M. Sobey, Freshwater mussel (Batissa violacea) fishery and its value in Fiji, J. Pac. Stud. 39 (1) (2019) 192–215.

[44] Y. Sadovy de Mitcheson, M.S. Witter, A N. Kuridrani, A. Batibasaga, S.R. Waqainabete, P Value Chain Analysis of the Fiji Grouper Fishery Rep. Sci. andConservation Fish. Aggreg. (SCRFA), U. S. 2018.

[45] T. Purcell, S. Gniel, R. van Gent, Making value chains work better for the poor: a toolbook for practitioners of value chain analysis Mak. Mark. Work Better Poor Proj. Lond.: UK Dep. Int. Dev. (DFID) Phnom Penh: Agric. Dev. Int. 2008.

[46] I. Etikan, S.A. Musa, R.S. Alkassim, Comparison of convenience sampling and purposive sampling, Am. J. Theor. Appl. Stat. 5 (1) (2016) 1–4.

[47] J.J. Honigmann, Sampling in Ethnographic Fieldwork in Field Research, Routledge, 2003, pp. 134–152.

[48] Boxill, I., C.M. Chambers, and E. Wint, *Introduction to social research: With applications to the Caribbean.* 1997: Canoe Press (IL).

[49] S. Piovano, et al., Evaluation of a bycatch reduction technology by fishermen: a case study from Sicily, Mar. Policy 36 (1) (2012) 272–277.

[50] C.R. Massat, C. McKay, H. Moses, Monkeying around: use of survey monkey as a tool for school social work, Sch. Soc. Work J. 33 (2) (2009).

[51] E. Waclawski, How i use it: survey monkey, Occup. Med. 62 (6) (2012), 477-477.

[52] E. Symonds, A practical application of SurveyMonkey as a remote usability-testing tool, Libr. Hi Tech (2011).

[53] R. George, Comparative morphology and evolution of the reproductive structures in spiny lobsters, Panulirus, N. Z. J. Mar. Freshw. Res. 39 (3) (2005) 493–501.

[54] A. Hordyk, et al., Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio, ICES J. Mar. Sci. 72 (1) (2015) 204–216.

[55] R.J. Beverton, S.J. Holt, On the Dynamics of Exploited Fish Populations, Vol. 11, Springer Science & Business Media, 2012.

[56] Prince, J.D., Wilcox, C., Hall, N., *Life History Ratios: invariant or dimensionless ratios adapted to stoichiometric niches?.* Submitted to Fish & Fisheries, In prep. 1(ICNAF Special Publication): p. 77–95.

[57] A. Wamukota, T.D. Brewer, B. Crona, Market integration and its relation to income distribution and inequality among fishers and traders: the case of two small-scale Kenyan reef fisheries, Mar. Policy 48 (2014) 93–101.

[58] C. Morris, a.B.S., *Supply chain and marketing of seagrapes, Caulerpa racemosa (Forsskåål) J. Agardh (Chlorophyta: Caulerpaceae) in Fiji.* SPC Women Fish. Inf. Bull. 2016 **27**.

[59] Prescott, J., *A handbook for lobster fishermen of the tropical Pacific Islands.* 1980: South Pacific Commission.

[60] S. Vieira, M. Tull, Restricting fishing: a socio-economic impact assessment of artisanal shark and ray fishing in Cilacap, Bull. Indones. Econ. Stud. 44 (2) (2008) 263–288.

[61] J. Cinner, Socioeconomic factors influencing customary marine tenure in the Indo-Pacific, Ecol. Soc. 10 (1) (2005).

[62] M. Botha, Reorganising the lobster fishery value chain, Mar. Policy 120 (2020), 104149.

[63] Ro.S. Africa, *Policy for the Small-Scale Fishing Sector in South Africa.*, Government Printer, Pretoria, 2012.

[64] O. Amarasinghe, M. Bavinck, Building resilience: fisheries cooperatives in southern Sri Lanka. Poverty Mosaics: Realities and Prospects in Small-scale Fisheries, Springer, 2011, pp. 383–406.

[65] R. Hilborn, Managing fisheries is managing people: what has been learned? Fish Fish. 8 (4) (2007) 285–296.

[66] A. Breckwoldt, H. Seidel, The need to know what to manage—community-based marine resource monitoring in Fiji, Curr. Opin. Environ. Sustain. 4 (3) (2012) 331–337.

[67] Veitayaki, J., et al., *Mainstreaming resource conservation: The Fiji Locally Managed Marine Area Network and its influence on national policy development.* 2004.

[68] N.J. Bennett, et al., The COVID-19 pandemic, small-scale fisheries and coastal fishing communities, Coast. Manag. 48 (4) (2020) 336–347.

[69] C.E. Ferguson, et al., Local practices and production confer resilience to rural Pacific food systems during the COVID-19 pandemic, Mar. Policy 137 (2022), 104954.