



# When ‘fishing down the food chain’ results in improved food security: Evidence from a small pelagic fishery in Solomon Islands



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## ABSTRACT

Solomon Islanders are highly dependent on their coastal resources for food and livelihoods. Parts of some islands are now quite densely populated and some groups are being forced to adapt to resource scarcities. One such adaptation is the relatively recent development of nocturnal fisheries for small coastal pelagic fish in Langalanga Lagoon, Malaita Province, in tandem with declining reef fish stocks. The technique involves using lights to attract fish to gill nets and strike-lines deployed from dugout canoes anchored in and around lagoon passages. In the first detailed study of a fishery based on this gear combination in the Pacific, we report a mean catch-per-unit-effort (CPUE) from over 190 light fishing trips of 3.41 kg/h/person. This figure is two to five times higher than CPUE's obtained for reef-associated fisheries in Solomon Islands, including sites with much lower population and market pressures. The main targets of the light fishery were clupeids, along with small carangids, small sphyraenids and small scombrids. Interviews with fishers revealed there were regular seasonal fluctuations in the abundance of the dominant species (*Amblygaster sirm*, the Spotted Sardinella) but no long-term (i.e. decadal) variation. Langalanga people now rely heavily on this high-yielding fishery for subsistence and cash, and some said they would need to relocate in search of alternate livelihoods if it did not exist. The high fecundity, rapid growth, early maturation and short life span of the key target species indicate that stocks are likely to be much more resilient than those of most reef-associated species. Many aspects of the behaviour and ecology of the key species remain poorly understood. However we argue that this study should encourage more scientists and fishery managers to think beyond reef-centric and larval connectivity-based models of tropical coastal fishery production and food security, and to pay much closer attention to biological oceanographic processes, including nutrient inputs, which fundamentally underpin the productivity of these increasingly important small pelagic fisheries.

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## 1. Introduction

Coral reef associated fin-fisheries appear to be declining in many parts of the world (Bellwood et al., 2004; Jackson et al., 2001; Sale et al., 2014), particularly where population and market pressures are high (Muallil et al., 2014a,b). In the Pacific region, where population pressure is generally comparatively low (Foale et al., 2011; Secretariat of the Pacific Community, 2014) it is nevertheless predicted to exceed the capacity of coral reefs to produce sufficient fish for subsistence needs in many countries by 2030, with shortages forecast to occur earliest in Papua New Guinea and Solomon Islands (Bell et al., 2009). Small-scale subsistence fishers who rely on these

resources face shortfalls and hardship if alternative sources of protein cannot be found. We investigate one such alternative here.

Much research to date has emphasized the centrality of coral reefs for tropical subsistence fish production and food security. However, Pacific small-scale, subsistence fisheries are diverse and are certainly not limited to reef-associated species (Dalzell, 1993c; Dalzell et al., 1996; Nordhoff, 1930). One area where non-reef species appear to be particularly important for subsistence is Langalanga Lagoon in the Solomon Islands (Fig. 1). This stretch of relatively shallow water runs for about 22 km along the heavily populated northwestern coast of Malaita Island. The population density of the Langalanga Lagoon coastal zone is now around 100 people/km<sup>2</sup>—more than five times the national average density of 17 people/km<sup>2</sup> for Solomon Islands and three times the average density of 33 for Malaita Province (Foale et al., 2011; Solomon Islands Government, 2008, 2009a,b). The average household size

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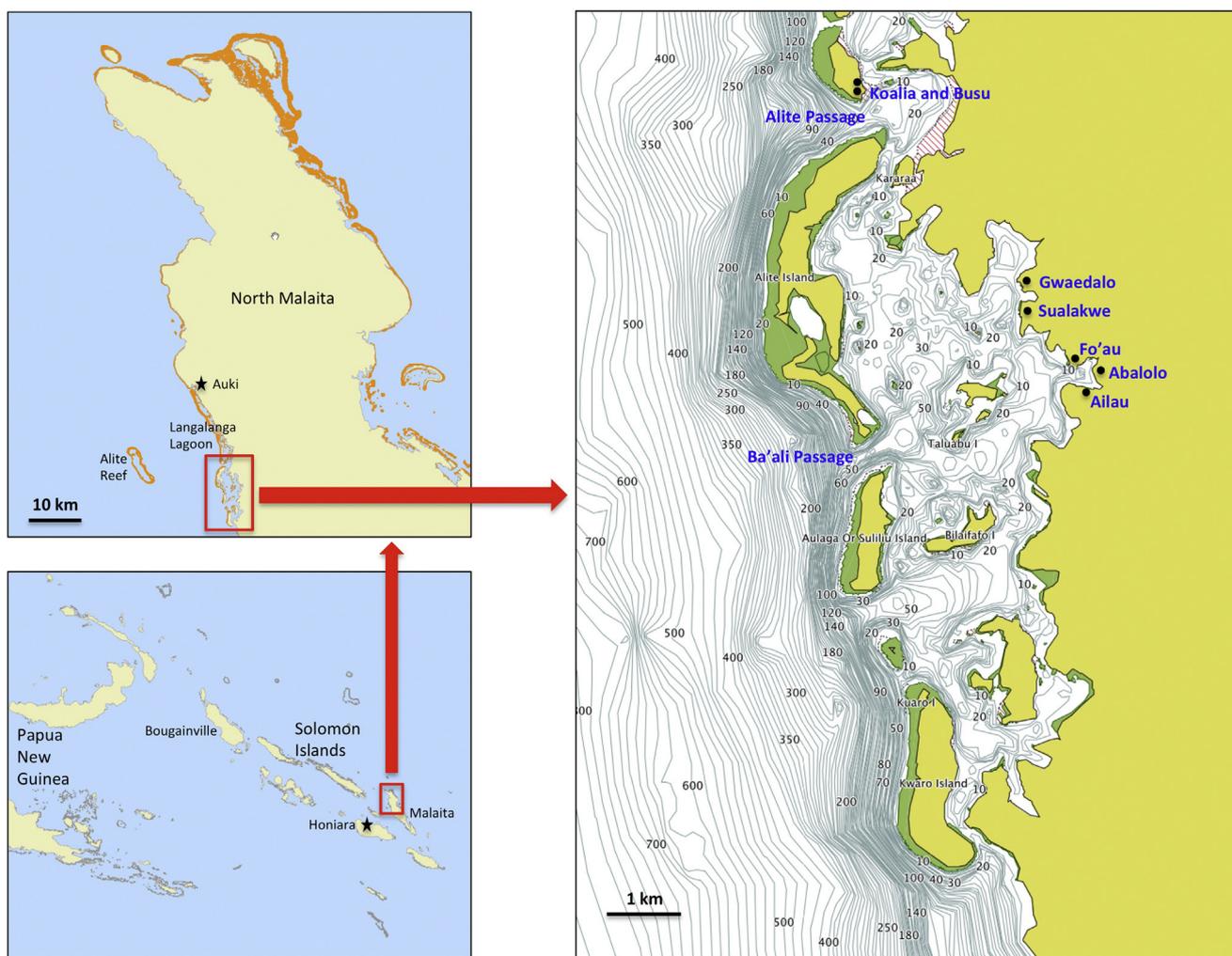


Fig. 1. Map of Solomon Islands, North Malaita and Southern Langalanga Lagoon, showing villages that participated in the study.

is 5.6. The busy provincial capital of Auki is located at the northern end of Langalanga Lagoon, roughly 18 km north of our study site, and represents a significant source of market pressure on local fisheries. Villages occupy most of the mainland coastline down the perimeter of the lagoon, as well as along some of the larger offshore islands. All of these communities are highly reliant on marine resources for both dietary protein and income, much of which is used to buy staple foods such as rice and flour. The Langalanga people, like the Lau people of northeastern Malaita, were prehistorically confined to small artificial islands constructed from coral stones on top of coral reefs and small coral islands (Ivens, 1930), and culturally identify as 'saltwater people' (wale asi). Their traditional economy was substantially based upon trading fish for starch grown by 'mainland' tribes (Akimichi, 1978; Goto, 1996a). Since the 1970s some groups have acquired small patches of coastal land and have relocated to coastal villages (Goto, 1996a). Available land for food gardens is nevertheless very limited and, apart from selling surplus fish catch at local markets, most people have only their labour with which to earn a meager income, mostly from the manufacture of traditional shell money (Cooper, 1971; Faradato, 2008; Goto, 1996a,c; Guo, 2006). Langalanga people, along with other Malaitans, have long been known for a willingness to migrate to other parts of the country in search of new economic opportunities. While the population growth rate of Malaita Province was 1.2% at the 2009 census, the population of Langalanga Ward shrank

at the rate of 0.9%, primarily due to emigration (Solomon Islands Government, 2009a).

Where population and market pressures are high, reef associated benthic fish stocks predictably decline and, where possible, people target fast-growing, schooling planktivorous species to maintain subsistence protein supply, in a process that Daniel Pauly and colleagues have termed 'fishing down the food web' (Pauly et al., 1998), commonly paraphrased to 'fishing down the food chain'. A relatively recent example of such a transition in Langalanga Lagoon involves 'light fishing': the use of kerosene pressure lamps (and some newer battery-powered lights) at night to attract small pelagic fish species which are caught using gill nets and 'strike-lines' (weighted drop-lines with multiple small un-baited hooks) deployed from dugout canoes, generally anchored in lagoon passages. Some of these fish are then used as bait to catch larger predatory species but most are consumed directly or sold locally. At the time of our study (April–June, 2013), light fishing was the dominant fishing method used by the majority of fishers in southern Langalanga Lagoon. The small pelagic fish species targeted by Langalanga light fishers are planktivorous, have schooling behaviours, fast growth, short life-spans and high abundances in near-shore habitats (Dalzell, 1993c) which make them a good source of food and potentially a more sustainable alternative to less productive and increasingly overexploited reef fish (Bell et al., 2009; Foale et al., 2013; Sadovy, 2005).



Fig. 2. Photograph of fish laid out on a grid of known size for analysis of size frequencies (Photo: Jessica Roeger).

We focus especially on catch and effort data in this study because we believe this is the most informative way to compare fishery productivity both among and within biomes and gears. Small pelagic fish inhabiting comparatively turbid lagoon waters are far more difficult to count by visual census than coral reef-associated fish, and while different gear (mainly hook and line, and spear) is used across most of Solomon Islands for reef fish, we argue that CPUE is nevertheless a highly informative means to compare productivity both within and between small pelagic and reef-associated fisheries. However, while there are many reports of subsistence and artisanal use of small pelagic fisheries throughout the Pacific (Dalzell, 1993a,c; Gillett, 2011; Gillett and Ianelli, 1993; Hair and Magea, 1995; Hooper, 1990; McNaughton, 1998), there are comparatively few systematic studies of catch and effort on these fisheries. Some catch and effort data for small pelagics in various Pacific locations are reviewed by Dalzell et al. (1996) but data are generally expressed as weight of catch per net or trap set and thus difficult to compare to data expressed in terms of catch weight per fisher-hour. CPUE data are also provided for *Selar crumenophthalmus* and *Decapterus macrosoma* in Hawaii (Weng and Sibert, 1997), where the economic context is dramatically different from low-income countries such as Solomon Islands. Some catch and effort data for artisanal flyingfish fishery introduction trials are reviewed by Gillett and Ianelli (1993) but these authors note that none of these trials resulted in the establishment of a fishery. This lack of systematic, comparable CPUE data on artisanal or subsistence small pelagic fisheries represents a significant knowledge gap due to the increasing importance of small pelagic fisheries for food security across the Pacific region, exemplified here in the case of Langalanga Lagoon. Characteristics of the Langalanga small pelagic fishery, including CPUE, and species and size class data, as well as local knowledge of fishers, are vital for a basic understanding of its productivity, sustainability and importance for food security.

In contrast to the Pacific, a large amount of research has been published on small-scale (as well as industrial) small pelagic fisheries in Southeast Asia, particularly the Philippines (Dalzell, 1993b; Dalzell et al., 1990; Dalzell and Ganaden, 1987; Dalzell and Pauly, 1990; Department of Agriculture–Bureau of Fisheries and Aquatic Resources, 2004; Ruddle, 2005; Ruddle and Ishige, 2005), where data have been collected since 1948. In the Philippines, fishing pressure is at least an order of magnitude higher than for most of the Western Pacific, and small pelagic stocks have in fact been overharvested since the 1970s (Dalzell et al., 1987). Dalzell et al. (1990) estimated in the 1980s that small pelagics accounted for

around 40% of all marine fisheries landings in the Philippines (about half of this being subsistence or artisanal) which represented “an inexpensive source of animal protein for the 70% of the Philippine population that comprise the lower income groups in the country. . .” (Dalzell et al., 1990).

A substantial body of research was conducted in the 1980s and early 1990s on industrial bait-fisheries (associated with the tuna pole and line fishery) in the Pacific (Blaber and Copland, 1990; Blaber et al., 1990a,b; Dalzell and Lewis, 1989; Dalzell, 1986; Milton et al., 1993; Rawlinson et al., 1992; Wright and Richards, 1985). Good CPUE data has also been published for reef-associated subsistence fisheries in some parts of Solomon Islands (Bayliss-Smith, 1990; Cohen and Alexander, 2013; Goto, 1996a) and for several other locations in the Pacific (Dalzell et al., 1996; Kuster et al., 2005; Wright and Richards, 1985).

Anthropologist Akira Goto conducted research in the early 1990s on subsistence and artisanal fishing as well as diet and aspects of the local economy in the same area where we undertook our case study (Goto, 1996a,c). This work included some detailed catch and effort data, but almost all of this was for fishing trips where line fishing, mainly for reef fish, was the method used (along with a small number of spearfishing trips). At that time few people owned nets and the use of the light fishing technique we describe here was not reported.

The current study addresses these knowledge gaps, and highlights the pressing need for a more systematic examination of small pelagic fisheries so that a more complete and accurate picture of the fishing practices in the Solomon Islands and other countries of the Western Pacific can be obtained. At the very least this should facilitate more reliable forecasts about food security for this region where people are so intimately connected with their coastal resources.

## 2. Materials and methods

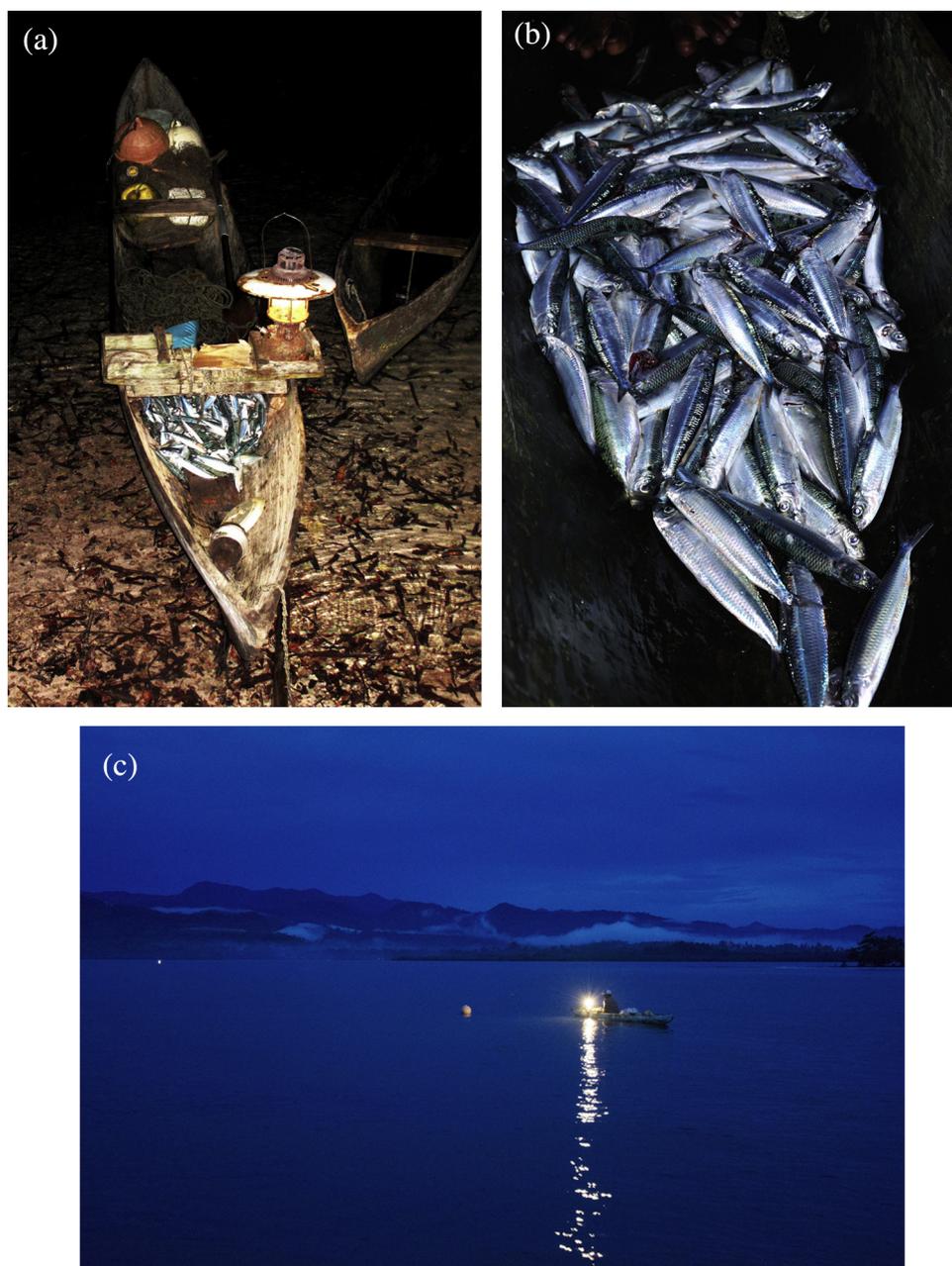
### 2.1. Research permits and ethics

Permission to conduct research was provided firstly by the community of Abalolo Village, Malaita, and then by the Minister for Education and Human Resource Development, Solomon Islands. Ethics clearance was provided by James Cook University, Australia under ethics approval number H4940. Interviewees gave their verbal consent to participate in the study and consent was noted on the interview transcript; if verbal consent was not given the interview did not proceed.

### 2.2. Study location

Between April and June 2013, data on fish landings and fisher effort were recorded in Langalanga Lagoon, Solomon Islands. Data were recorded from seven villages within the southern part of the lagoon: Busu, Koalia, Fo’au, Sualakwe, Gwaedalo, Abalolo and Ailau (Fig. 1). All villages were known to regularly employ light fishing techniques within two nearby outer lagoon passages, Ba’ali and Alite Passages.

Participant-observation data provided an overview of the ways in which catches were used for subsistence and for sale, and the overall economic importance of light fishing at the community scale. Abalolo was typical in most respects of the villages along the coast of Langalanga Lagoon. The community was made up of several extended families, with (on average) two men engaging in light fishing per extended family.



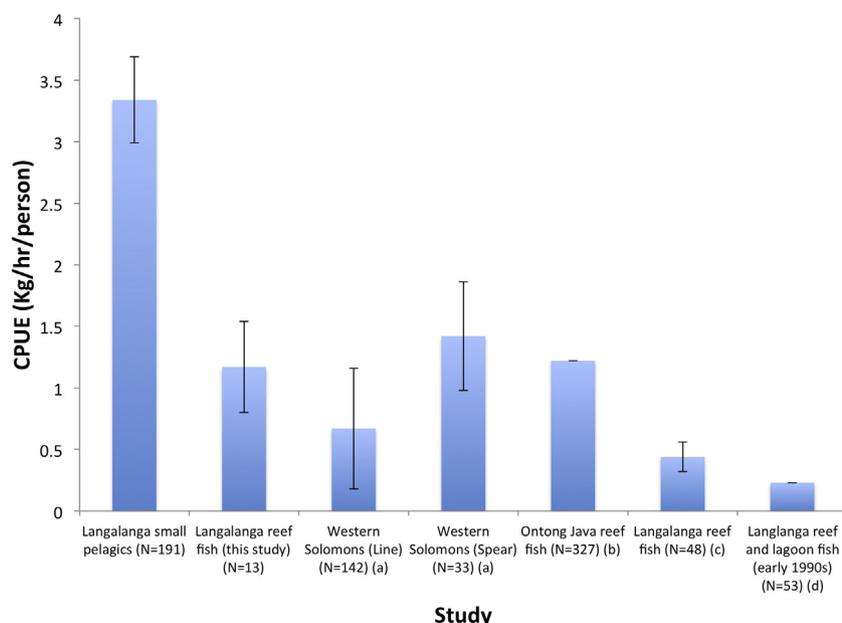
**Fig. 3.** (a) Photograph of dugout canoe with typical light fishing gear (Photo: Jessica Roeger); (b) close up of fresh *Amblygaster sirm* catch (Photo: Simon Foale); (c) a fisher anchored and with light on in Ba'ali Passage prior to deploying his net (Photo: Simon Foale).

### 2.3. Sampling methods

Prior to commencing the study, the methods, payment systems, and recruitment of research assistants were negotiated with the community. Research assistants were trained in CPUE measurement and data recording. Fishers were recruited to the study opportunistically, and generally by word of mouth (snowball sampling). We attempted to spread sampling effort so that most of the active fishers in each of the seven villages were contacted. CPUE data were generated over a period of 49 days in total (20th April–7th June, 2013), but we were not able to capture every fishing trip by all of the fishers contacted during that period. CPUE data included total weight of the landed catch, total time spent fishing, gear used, and species abundance for each individual fishing trip. Samples of fish were taken to record size frequencies. All trips were documented

upon the fisherman's return to shore. Catches were removed from the canoe and total weight of the catch was recorded using a spring balance. For species whose abundance was less than approximately 30 fish, the number of fish was counted and they were placed on a plastic sheet with a  $10 \times 10$  cm grid marked onto it (Fig. 2). A photo was then taken directly above the fish so that the total size of each fish could be determined using computer analysis. For species whose abundance was greater than approximately 30 fish, the total weight of that species was recorded and a random sample of 10 or more fish was placed on the plastic sheet for measurement.

The great majority of fishing trips deployed a light together with a nylon gill net (1" or 1.5" mesh), often also a strikeline (terminally-weighted line with multiple small hooks—naked or with simple lures) and sometimes a dropline (baited with small pelagic fish). A small minority of trips used other gears such as spearfishing. Light



**Fig. 4.** CPUE mean for all light fish catches in Southern Langalanga compared to CPUE means for other fisheries. Error bars are Standard Error (no standard error figures available for Bayliss-Smith (1990) Ontong Java data or for Goto (1996a) Langalanga data).

a) Cohen and Alexander (2013). Data is from reefs not subject to periodic closures.

b) Bayliss-Smith (1990). The data for this study was generated in the early 1970s. Because Ontong Java fishers worked in groups for most forms of fishing, the number of person-trips was actually 737.

c) Foale (unpublished data). This data is a combination of hook and line, spearing and gleaning, mostly from central and northern Langalanga Lagoon.

d) This figure is a weighted mean derived from Goto's Table 7.2 (1996a, p. 27).

fishing catches were dependent on the light attracting fish to the fisherman's dug-out canoe (Fig. 3a–c). The lights in all but two cases were pressure kerosene ('tilly') lights. Two fishers used LED electric lights powered by car batteries that were charged by solar panels.

Fishermen from the above-named villages predominantly fished in two passages, Alite and Ba'ali, as well as some fringing reefs and inner lagoon waters. Light fishing occurred only in Alite and Ba'ali Passages (Fig. 1). In addition to collecting landings data, from an independent canoe we also observed fishing methods, gear use, and fishing location (with GPS) of 20 fishing trips. The total time fishermen spent on the water from departure to arrival at the village was recorded, then catch-per-unit-effort was calculated as kilograms of fish per hour fishing, per person. Time spent paddling to and from passages or other fishing sites was typically a minor fraction of total time spent away so we did not attempt to separate this from time spent fishing. However paddling time for the fishers who used Ba'ali Passage was typically significantly greater than for those using Alite Passage.

#### 2.4. Statistical analysis

The size class composition of a large sample of fish ( $n = 1539$ ) caught using light fishing techniques was analysed using the program ImageJ. This program calculated the full length of fish from photographs taken of the fish against a known grid size (Fig. 2).

SPlus was used to complete a one-way ANOVA for comparing all fishing sites and for comparing fishing methods to see if there were significant differences among sites and gears. *T*-tests were used to test for significant differences between CPUE data from previous studies and this study. The data were transformed using  $[\log + 1]$  (as some values were '0') prior to running the ANOVAs and *t*-tests, to bring the data closer to normality after Shapiro Wilks analysis showed it was highly skewed to the right.

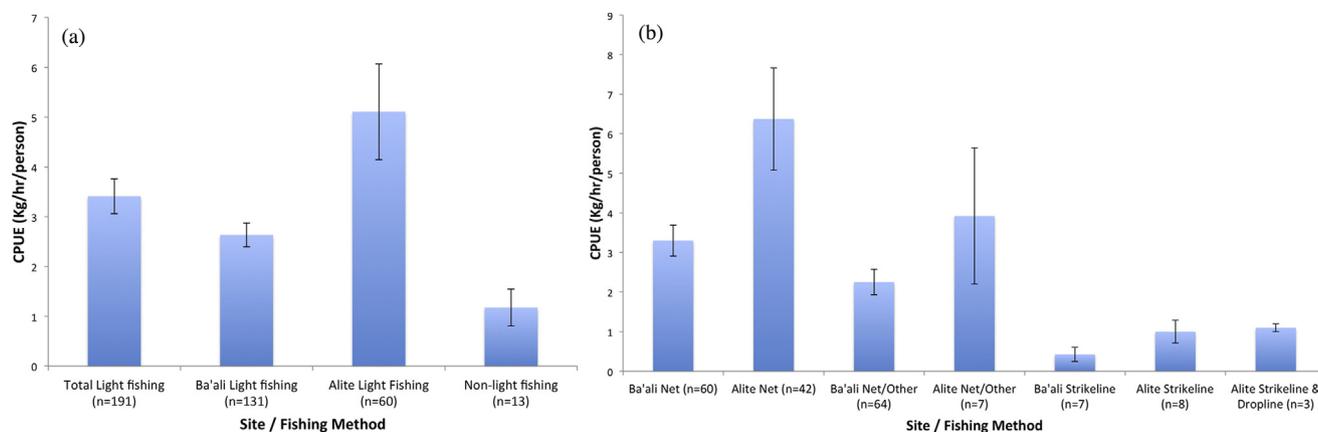
#### 2.5. Local knowledge, fishing practices and livelihoods

Semi-structured interviews were conducted with 13 key informants (fishers and elders) to record local knowledge about the fishery. Interviews were informal, conducted in Pijin, recorded on a voice recorder, and subsequently translated and transcribed into English. Experienced and knowledgeable fishers and elders were mostly identified by snowball sampling, and in some cases through chance meetings. The purpose of the interview was explained at the outset and in all cases those interviewed provided information willingly and freely.

Interview questions were designed to obtain information about the small pelagic fishery of Langalanga Lagoon. In discussing the fishery we used Langalanga language names for targeted fish (Goto, 1996a,c). To better understand what equipment fishers were using, how fishers perceived equipment to be affecting the fishery, and how fishers perceived the fishery to be changing over time, we asked fishers: (a) how long they had been using light fishing techniques; (b) whether, and how, light fishing techniques had changed or evolved in their experience; and (c) what other (if any) fishing methods they used, and (d) whether any traditional fishing practices or beliefs had been incorporated into light fishing methods.

Key informants were also asked about the diurnal, monthly and annual patterns of the behaviour and catchability of the important small pelagic species in the fishery. They were asked when they thought were the best times of the night, month, and year for light fishing, where the best places were, and what they thought the fish did in the off-season.

We gathered interview data on the different livelihood options available to Langalanga villagers to understand the relative importance of light fishing, and how income was mostly obtained when they were not fishing. We also used participant-observation to corroborate interview responses on how the portions of catches that were surplus to subsistence needs were distributed beyond households and villages.



**Fig. 5.** (a) CPUE means for light fishing in Ba'ali and Alite Passages, and for non-light fishing. (b) CPUE means for different light fishing gear types used at Ba'ali and Alite Passages.

We asked fishers and elders how the number of fishers using light fishing methods had changed over time, whether they had observed any long-term trends in the fishery, whether they thought their fishing was impacting the fishery, and whether they thought the fishery needed management.

### 3. Results

#### 3.1. Recent history

Most of our informants believed that reef fish have been declining in size and number for many years in Langalanga Lagoon. In addition to the high local human population density, the rapidly growing nearby urban centre of Auki (Fig. 1) puts additional market pressure on the marine resources of the lagoon, including fish. Many residents also blame a long history of regular use of dynamite fishing for declining fish populations in and around the lagoon. Collectively, our interviews with fishers describe the innovation and expansion of a specialized fishing technique – light fishing – by the people of the southern part of Langalanga Lagoon, in order to obtain a much higher yield per unit of labour than is possible for reef-associated fish species (Fig. 4). All light fishers reported that the CPUE of the small pelagic species had not decreased in their experience despite a steady increase in participation over the past three decades. Most of them also believed the fishery would remain productive for many years. This fishery is clearly a vital source of food and livelihoods for people of southern Langalanga Lagoon, and yet it is of comparatively recent origin.

Elders said that people began light fishing in the 1980's after large Japanese pole-and-line tuna fishing operations had used large submersible lamps to attract bait-fish and scoop nets to harvest them. The Japanese operations employed some Langalanga fishermen, who then began using their own kerosene “tilly” lamps attached to their canoes to attract fish. Initially these fishermen just used strikelines and attempted to catch species such as *Selar crumenophthalmus* (*Gorigori amadi* in the Langalalanga [LL] language), and *Sphyraena* sp. (LL: *Baraulo*). It was not until a few years later that nylon gillnets, purchased from Chinese trade stores, were used with lights to capture large numbers of *Amblygaster sirm* (LL: *Uala*) and the technique really gained popularity. The nets used for light fishing cost between SBD600 (US\$73.60) and SBD700 (US\$85.90). Today people still predominantly catch these and other small pelagic species and use a mix of nets and strikeline, and occasionally also use dropline fishing to target larger mackerels (*Scomberomorus* spp.) and snappers (Lutjanidae).

People of Langalanga have fished small pelagic fish traditionally with a variety of gears (Goto, 1996a,c) but this particular method

of light fishing has only been in operation for the last 30 years, and has changed the fishing dynamics of local communities. Fishers said that light fishing typically did not incorporate any traditional magical rites or incantations associated with many of their older fishing methods.

#### 3.2. Light fishing—descriptive statistics

Our data suggest that the majority of southern Langalanga people derive considerable economic benefit from small pelagic fish. We believe the CPUE data (see below) generated during 49 days of sampling, across seven villages, provide a representative snapshot of fishing activity in southern Langalanga Lagoon for the light fishing season. Of 204 trips for which CPUE data was obtained, only 13 trips, made by eight fishers (out of a total of 31 who generated CPUE data), involved the use of methods other than light fishing. Only one of these fishers was a woman, who used strikeline during the day. 102 light fishing trips involved the use of nets only; 71 involved nets plus another method (strikeline and/or dropline); 15 involved strikeline only, and three involved strikeline and dropline together.

All fishers using the light fishing technique were men ranging in age from 21 to 70 and there were approximately two light fishermen per extended family. Just four fishers (three from Abalolo and one from Busu) accounted for 105 out of 204 recorded trips (i.e. more than 20 trips each). Five fishers accounted for between six and ten recorded trips each and 18 fishers provided data from five or fewer trips each. Table 1 gives details of the villages from which we obtained catch and effort data, and the locations used by fishers from these villages. While we did not attempt to obtain catch and effort data from every fisher in these villages, and we were unable to capture data from every trip made by all the fishers from whom we obtained some data, we believe our sampling strategy gives a good representation of the relative frequency of use

**Table 1**  
Villages from which CPUE data was obtained in the study, and locations fished (see also Fig. 1).

Village	Number of fishers	Total trips	Sites fished
Abalolo	10	107	Ba'ali (104), other (3)
Ailau	2	7	Ba'ali (1), Alite (1), other (5)
Fo'au	3	7	Ba'ali (5), other (2)
Gwaedalo	2	5	Ba'ali (5)
Sualakwe	5	17	Ba'ali (16), other (1)
Busu/Koalia	9	61	Alite (59), other (2)
Total	31	204	Alite (60), Ba'ali (131), other (13)

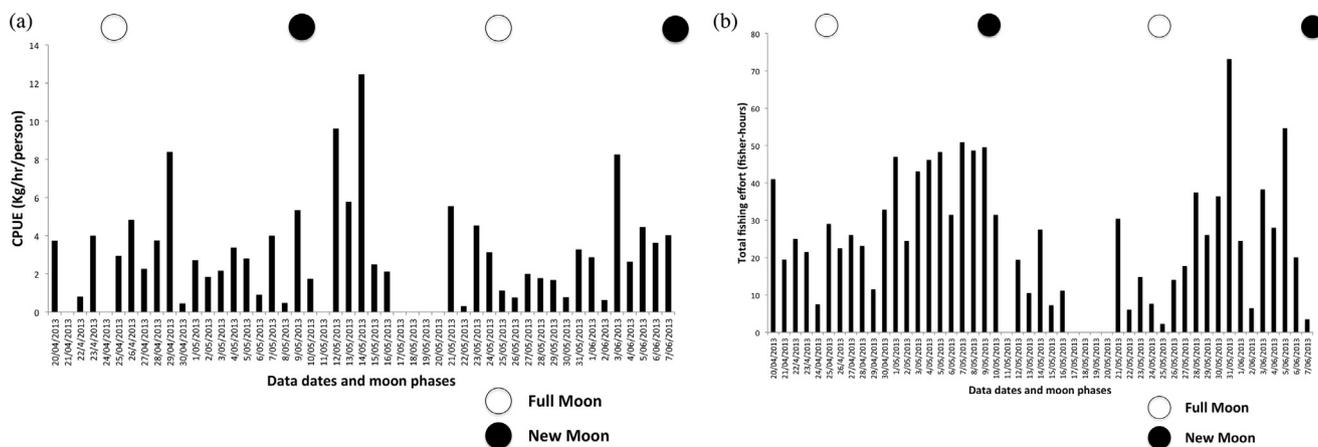


Fig. 6. (a) Nightly mean light fishing CPUE figures in relation to lunar phase. (b) Recorded total light fishing effort in relation to lunar phase.

of light fishing compared to other fishing methods by fishers in the southern half of Langalanga Lagoon, during the light fishing season. Ten out of 23 light fishers we interviewed claimed to go fishing frequently, or most nights. All trips recorded in this study involved one fisher per canoe. Mean catch weight for all light fishing trips was  $18 \pm 1.3$  kg and mean hours fished  $6.01 \pm 0.2$ . Mean catch weight for non-light fishing trips was  $4.1 \pm 1.2$  kg and mean hours fished  $4.2 \pm 0.8$ .

### 3.3. Catch-per-unit-effort

The overall mean CPUE obtained for all light fishing techniques in Langalanga Lagoon during the study period was  $3.41 \pm 0.35$  kg/h/person (Fig. 4). When this was separated into different sites and different gear types, a number of patterns can be seen (Fig. 5a,b). Firstly, Alite Passage had a significantly higher CPUE than Ba'ali Passage (Welch Modified Two-Sample  $t$ -Test,  $t(2) 87.67 = 2.15$ ,  $P = 0.03$ ; Fig. 5a). There were also significant differences between all gear types used (One-way ANOVA,  $F_{2,174} = 13.95$ ,  $P < 0.001$ ). The use of nets only returned a higher CPUE than use of both net and other methods (strikeline and/or dropline), or strikeline only or strikeline and dropline, which gave the lowest CPUE (Fig. 5b). The highest CPUE obtained was when just nets were used in Alite Passage ( $6.37 \pm 1.29$  kg/h/person) while the lowest was for strikeline use in Ba'ali Passage ( $0.43 \pm 0.18$  kg/h/person) (Fig. 5b). The range for individual CPUE's was from 0 to 47 kg/h/person with the largest catch at 80 kg. One fisherman who had switched from spearfishing to light fishing commented that he could fill up a canoe with *A. sirm* in the same time it took him to find and spear a single coral grouper.

### 3.4. Temporal and spatial variation

Most of our key informants believed that *A. sirm* stayed inside the lagoon during the day and moved into particular passages at night. While several had regularly observed schools inside the lagoon, none of them had observed this species in the open ocean beyond the passages. Some had also observed *A. sirm* schools near the mouths of rivers after rain. Some interview responses combined with our observations suggest that *A. sirm* is not commonly targeted in the northern half of Langalanga Lagoon, though several other small pelagic species are.

Almost all fishers reported that catch rates were better on darker nights, including nights when clouds obscured a full or close to full moon. We calculated mean daily CPUE figures for light fishing catches for each day between 20th April and 7th June, 2013 and present these, along with total fishing effort in fisher hours, in

relation to moon phases, in Fig. 6a and b respectively. It is possible to conjecture from this data that both mean CPUE and fishing effort increase leading up to each new moon, (i.e. as the moon wanes, and rises later each evening) but the pattern is not compelling.

Our sampling period did not extend across years or seasons, however all key informants agreed that there were strong seasonal cycles in the fishery. These fishers reported that *A. sirm*, the dominant species in the light fishery, was most abundant within the lagoon and its passages between the months of January–August, but decreased in abundance from September in most years and was generally not fished in November and December.

Most fishers thought that *A. sirm* moved somewhere else during the off-season. Some thought the fish were doing a full migration around the island of Malaita, some thought they moved to a harbour south of Langalanga Lagoon, and others thought some of the fish were staying in the lagoon but these were all too small to be caught in gill nets. All of the fishers believed this species was breeding somewhere else during the off-season. Several reported observing juveniles of the species in mangroves around the fringes of the lagoon.

Those who remembered the fishing from the beginning said they had noticed no changes in the numbers of small pelagic fish being caught per fisher by light fishing.

### 3.5. Size class descriptions

By far the most abundant size class caught with light fishing techniques was 16–20 cm. The total size range of fish caught using these techniques was 5–145 cm (Fig. 7).

### 3.6. Food and livelihood options

*A. sirm* was frequently caught in volumes greater than could be consumed by fishers and their extended families, so families often cooked the surplus catches in stone ovens (cooked fish could last up to five days before spoiling) and sold them at local markets as well as the large market in the regional centre, Auki. A parcel of ten to twelve cooked fish sold for between SBD8 and SBD10 (US\$1–US\$1.20) depending on where it was sold. The cost of kerosene burned by a pressure light in one night would be covered by the sale of two or three of these parcels. One fisher reported being able to make as much as SBD700 (US\$85) from a night's catch.

Interviews and participant-observation made clear the high level of reliance that the people of Langalanga have on light fishing. As the people of Langalanga have very limited land for growing food due to their historical conflicts with inland tribes, there are not many non-fishing options for livelihoods besides manufacture

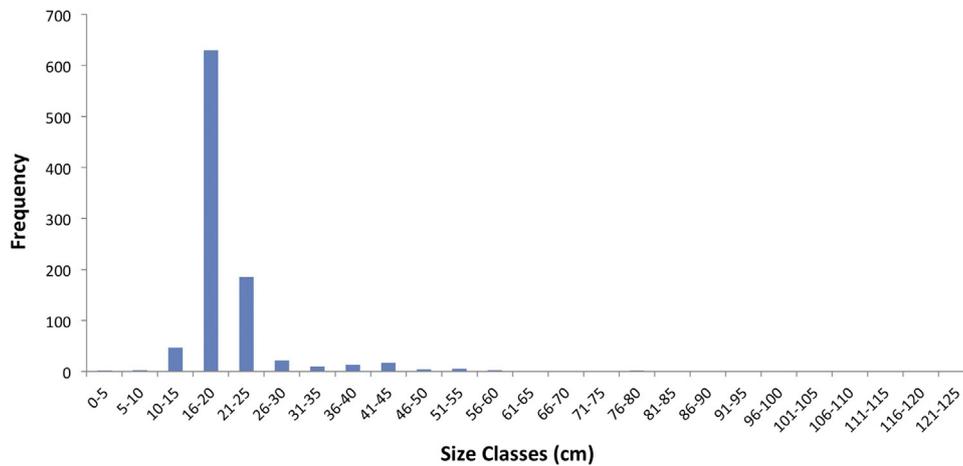


Fig. 7. Representative size frequencies of fish landed during the study.

of shell money (Faradatolo, 2008; Goto, 1996b; Guo, 2006), and employment in building, shipping, sawmilling, logging or tourism. The primary non-fishing livelihood reported by most of our key informants was shell money manufacture, and observation strongly corroborated this. As light fishing dominates subsistence and artisanal fishery production in southern Langalanga Lagoon for more than half the year, it is not only critical for food security but also a large component of the economy. Some fishermen confirmed that if they were unable to do light fishing they would have to leave their village and move to more urban areas to seek alternative livelihoods. A systematic quantitative survey of sales and gifts of small pelagic catches within and beyond the Abalolo community, while beyond the scope of the present study, could usefully build on the results we present here.

#### 4. Discussion

The most striking result of this study is the very high CPUE obtained for light fishing techniques from around Langalanga Lagoon (Fig. 4). This result is much higher than CPUE's for many subsistence fisheries (Dalzell et al., 1996; Kuster et al., 2005; Wright and Richards, 1985) and notably higher than reef-associated fisheries in parts of Solomon Islands where population pressure is much lower (Cohen and Alexander, 2013; Foale et al., 2011).

The comparatively low mean CPUE values for the two larger (and thus more reliable) samples of Langalanga reef fishing trips in Fig. 4(c and d) are corroborated by a variety of social data. These include the interviews conducted for this study, and unpublished interview and focus group data from other studies in Langalanga Lagoon, all of which unequivocally indicate significant perceived declines in reef fish abundance and size. Sales of reef fish at the large nearby regional market in Auki are also notably small and infrequent, particularly compared to sales of large and small pelagics, which dominate this market (Foale, personal observation). These various strands of evidence and the present high level of dependence on small pelagics in Langalanga Lagoon strongly invoke the notion of 'fishing down the food chain' (Pauly et al., 1998).

The higher light fishing catch rates in Alite Passage compared with Ba'ali Passage (Fig. 5a,b) are most likely due to the reduced travel time between the village and fishing ground for the people living in Koalia and Busu villages (adjacent to Alite Passage). Fishermen living on the mainland must paddle their canoes approximately 30 min each way to Ba'ali Passage, whereas Alite Passage is only a 10 min paddle for most fishermen who use it. Being closer to the fishing grounds gave those people more flexibility to make the most of the productive fishing periods. Those who lived close

to their fishing ground had a short distance to travel with canoes full of fish and were more likely to return home when catch rates were slow. Fishermen who had made the effort to paddle all the way from the mainland to the outer passages may think it more worthwhile to continue fishing, despite comparatively lower catch rates.

Interviews with fishers also indicate that CPUE of the small pelagic fishery has not declined noticeably in their experience, but if it were eventually to be fished down as well there would be few further available options for the people of Langalanga. In the Philippines, where the average human population density is roughly an order of magnitude higher than in Solomon Islands, small pelagic stocks have been extensively relied upon for over half a century, but were already overharvested in the 1970s (Dalzell, 1988; Dalzell and Ganaden, 1987). Continued increases in fishing effort on small pelagics in Langalanga Lagoon must inevitably also result in stock depletion at some point in the future, and a precautionary approach seems sensible in the meantime.

Most of the species in the catches of the light fishery (*A. sirm*, *Selar crumenophthalmus*, *Sphyrna* spp., *Rastralliger kanagurta* and *Exocoetus* spp.,) have received limited scientific attention, particularly in the Pacific. These species typically have fast growth rates, short lifespans (1–3 years in tropical waters), and early maturation (Dalzell, 1993c). They can have multiple spawning periods throughout the year and some are thought to be highly migratory although the exact factors affecting these events are unknown (Dalzell, 1993c; Galindo-Cortes et al., 2010). They also support relatively high exploitation levels due to their resilient life history characteristics (Dalzell, 1993c; Dalzell and Ganaden, 1987; Dalzell and Lewis, 1989).

Since most species of small pelagic fish are plankton feeders (Dalzell 1993a), one of the most important factors influencing their growth and abundance is the availability of nutrients, which dictate phytoplankton production (Brodie et al., 2007; Conti and Scardi, 2010; Oczkowski et al., 2009). At this stage, it is unclear which nutrient supplies are directly affecting small pelagic fish production in Langalanga Lagoon. There are river systems draining into the lagoon that could be providing terrestrial nutrients (the most likely source), and upwelling nutrients could also possibly be entering the lagoon from the open ocean. Studies by Messie and Radenac (2006) mapped surface chlorophyll of the western Pacific, which show large seasonal (southeasterly trade season) upwellings along the southern coasts of the larger islands in the Solomon Islands. Regardless of the source, there appears to be a sufficient supply of nutrients to support vast numbers of small pelagic fish and their predators in and around southern Langalanga Lagoon.

Populations of these species do, however, fluctuate dramatically in abundance, most noticeably on a seasonal cycle. Factors that could be associated with observed fluctuations include the life history of the dominant species (*A. sirm*), nutrient inputs, movements (seasonal, lunar and diurnal) of the fish, and fishing effort (Galindo-Cortes et al., 2010). Weng and Sibert (1997) found that rainfall correlates strongly with production of *S. crumenophthalmus* in Hawaii, with the implication that the primary nutrient input driving production of this near-shore small pelagic fishery is terrestrial. Significant inter-annual variation in rainfall around Langalanga Lagoon could mean that while there was high production in the system at the time of the study, this could change in the event of a significant drought. However our interview data indicated that production has been strong every year that our informants could remember.

Langalanga people are used to surviving without small pelagic fish on a short-term scale (i.e. weeks to months), however several fishermen said that if the fishery was to disappear they would have to leave their village to find work elsewhere. Short-term lulls in small pelagic fish abundance seem to be accommodated by targeting other coastal fisheries and increasing time allocation to more labour-intensive livelihoods such as shell money manufacture. But reef-associated fin-fisheries are comparatively unproductive (Birkeland, 1997) and it is easy to see how a failure of the small pelagic fishery could impact on the local economy.

## 5. Future studies

It would be useful to understand the primary factors underpinning the strong seasonality of the fishery. Ongoing study of inter-annual patterns may help to disentangle the roles of fishing pressure, rainfall variation (particularly in relation to El Niño cycles) and any other factors affecting productivity. While CPUE has been researched for other fishing practices in Langalanga (Goto, 1996a,c) and other parts of the Solomon Islands, more concurrent data on both light fisheries and other fisheries would provide a more detailed picture of their relative importance and how that importance changes throughout the year. Catch and effort data on large pelagic stocks, targeted as free schools, or associated with both offshore and inshore FADs, will be increasingly important for a comprehensive understanding of food security and livelihoods at this site and across the region (Albert et al., 2014; Bell et al., 2015). Further research is also needed on the networks (some of which are elaborate) through which small and large pelagic catches are distributed, as gifts and sales, to gain a better understanding of their livelihood and food security impacts.

Size-frequency data generated with alternative gear such as fine mesh lift nets would eliminate the effect of gear selectivity on size composition and would give a complete profile of the fish assemblage around the light fishery and determine what species are being influenced by these techniques. A longitudinal series of stock assessments (of reef-associated and small pelagic stocks) may also provide an indication of the speed with which 'fishing down the food chain' is occurring.

Continued explorations of subsistence and artisanal small pelagic fisheries in countries like Solomon Islands, with comparatively low but rapidly growing populations (Solomon Islands population growth rate is 2.3%), will help to describe correlations among trends of human population increase, deteriorating reef condition and long term changes in CPUE, so that an understanding of how humans are influencing their environment is gained. The fact that the Langalanga people have, over the past three or so decades, been prompted by declining CPUE of reef-associated demersal fisheries to switch to a more capital-intensive, but also much higher yielding fishery is not anticipated by the dominant

paradigm of food security declining in tandem with inexorably declining coastal fisheries. This should prompt us to think beyond reef-centric and connectivity-based models of fishery production and pay closer attention to the role of nutrient inputs in fishery productivity and food security.

## 6. Conclusions

The high mean CPUE (3.41 +/- 0.35 kg/h/person) for nocturnally fished small pelagics contrasts strikingly with the much lower mean CPUE figures for reef-associated fisheries in Langalanga and elsewhere in Solomon Islands. The switch to targeting small pelagics represents an intensification of fishing effort (investing in new gear, kerosene for the lights, and fishing at night) that is rewarded with a dramatically higher and apparently more sustainable yield. Langalanga fishers consistently assert that the small pelagic fishery shows no signs of decline to date, and that their economic dependence on it is now so high that any decline would have significant economic and social impacts. The fishery is strongly seasonal which means that fishers fall back on lower-yielding reef-associated fisheries and other livelihoods in the comparatively short off-season (September–December).

The nature and origins of nutrient inputs driving the productivity of the planktonic food for the dominant species (*A. sirm*) warrant further research. As population pressure on comparatively unproductive reef fisheries increases in Melanesia, both small and large pelagic fisheries are likely to assume greater importance for food security. Greater research effort into the role of nutrients in coastal fishery production, along with the delivery mechanisms (runoff and upwellings) would facilitate more accurate predictions of food security scenarios over the long term. Improved knowledge of the many poorly understood aspects of the ecology of economically important small pelagic species would provide a better understanding of their 'volatility' and the risks posed by habitat change (including changes to adjacent catchments) and increasing fishing pressure.

## Author contributions

J.R.: Conducted the great majority of fieldwork, analysed most of the data, and co-wrote the paper; S.F.: Conceived of the project and research design, organized permissions, funded part of the fieldwork (from an internal research account), assisted with the initial stage of the fieldwork, performed some data analysis and co-wrote the paper; M.S.: Provided infrastructural support for JR, advised on literature, fieldwork design and some data analysis, and contributed to late drafts of the paper

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