Ocean and Coastal Management 179 (2019) 104826

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Socioeconomic impacts of a sea cucumber fishery in Papua New Guinea: Is there an opportunity for mariculture?

Cathy Hair[a,b,*], Simon Foale[c], Jeff Kinch[d], Sven Frijlink[e], Daniel Lindsay[f], Paul C. Southgate[a]

[a] Australian Centre for Pacific Islands Research and School of Science and Engineering, University of the Sunshine Coast, Locked Bag 4, Maroochydore, QLD, 4558, Australia
[b] Centre for Sustainable Tropical Fisheries and Aquaculture, College of Marine & Environmental Sciences, James Cook University, PO Box 6811, Cairns, QLD, 4870, Australia
[c] College of Arts, Society and Education, James Cook University, Townsville, QLD, 4811, Australia
[d] National Fisheries College, National Fisheries Authority, PO Box 239, Kavieng, New Ireland Province, Papua New Guinea
[e] Wildlife Conservation Society, PO Box 95, Kavieng, New Ireland Province, Papua New Guinea
[f] College of Public Health, Medical and Veterinary Sciences, James Cook University, Townsville, QLD, 4811, Australia

ARTICLE INFO

Keywords:
Bêche-de-mer
Livelihoods
Small-scale fisheries
Pacific islands
Socioeconomic

ABSTRACT

Small-scale fisheries provide many benefits to coastal communities in the Indo-Pacific region, including food security, improved nutrition and cash income. However, increasing engagement with the global economy is exerting additional pressure on marine resources and opportunities to engage in alternative livelihoods are often limited by remoteness and a lack of land-based farming opportunities. Bêche-de-mer, the dried body wall of sea cucumber, is a valuable marine export commodity in the region, and an important cash-earning activity in Papua New Guinea (PNG). Sea cucumber mariculture (or holothuriculture), based on the high-value species, sandfish (*Holothuria scabra*), is also a promising community livelihood. Overfishing of sea cucumber in PNG led the National Fisheries Authority (NFA) to impose a moratorium on the fishery in October 2009. The fishery was reopened in 2017 for less than two months. This article presents socioeconomic data generated before, during and after the 2017 sea cucumber fishing season in three villages in New Ireland Province, PNG, which are also partners in a community-based sandfish mariculture project. The fishery dominated the economies of all three communities while it was open. Increased income was accompanied by high consumption of store-bought foods and purchase of other assets intended to increase living standards. Drawing on current understandings of local culture and political economy, together with the results from the 2017 wild sea cucumber fishery, we discuss how a livelihood based on holothuriculture could coexist with the wild fishery to increase benefits to coastal communities in PNG.

1. Introduction

1.1. Fisheries livelihoods

Small-scale fisheries provide many benefits to island and coastal communities in developing nations including food security and improved nutrition (Kawarazuka and Béné, 2010; Mills et al., 2011), although the link to poverty alleviation is more complex (Béné et al., 2016). Cash generated from the sale of seafood and marine export commodities is used commonly to purchase food, as well as clothes, housing, household goods, schooling, health needs and cultural obligations (Foale, 2005; Curry et al., 2015; Fabinyi et al., 2017). In maritime regions of Papua New Guinea (PNG), growing human populations and an intensifying engagement with markets have placed pressure on marine resources (Kronen et al., 2010; Barclay and Kinch, 2013) as greater income is sought from a shrinking resource base. Further, many islands have limited arable land area and low soil fertility, increasing their reliance on small-scale fisheries for subsistence and livelihoods.

Commodified marine resources such as sea cucumber support important livelihood opportunities in the Indo-Pacific region. Sea cucumber are rarely consumed in PNG but are exported in their processed form of bêche-de-mer or trepang (Kinch et al., 2008a). Bêche-de-mer (hereafter BDM) production is an attractive livelihood for coastal

* Corresponding author. Australian Centre for Pacific Islands Research and School of Science and Engineering, University of the Sunshine Coast, Locked Bag 4, Maroochydore, QLD, 4558. Australia.
E-mail address: cathy.hair@usc.edu.au (C. Hair).

https://doi.org/10.1016/j.ocecoaman.2019.104826
Received 19 November 2018; Received in revised form 12 February 2019; Accepted 19 May 2019

communities—it is easily processed (gutted, boiled and dried) with simple, inexpensive equipment (Ram et al., 2017), is shelf-stable and has high value to weight and volume (Conand, 1990; Preston, 1993; Barclay et al., 2016). Sea cucumber fisheries are prone to boom-and-bust cycles where heavy fishing precedes depletion (Anderson et al., 2011). However, lucrative returns, escalating demand from Asian markets and well developed market chains incentivise fishers to continue harvesting depleted stocks (Kinch et al., 2008b; Friedman et al., 2011; Eriksson et al., 2015; Purcell et al., 2017). Furthermore, negative social impacts and failure to produce long-term benefits or to increase community well-being have also been reported for sea cucumber fisheries (Christensen, 2011; Rasmussen, 2015; Barclay et al., 2016).

Alternative sources of food and cash are urgently needed to reduce fishing pressure and to maintain ecosystem services and food security in the Pacific Islands region (Bell et al., 2009; Kronen et al., 2010). Worldwide, there is increasing research interest in sustainable livelihood opportunities based on sea cucumber mariculture, or holothuriculture, of the high-value sea cucumber species, sandfish (*Holothuria scabra*) (Juinio-Meñez et al., 2012; Robinson and Pascal, 2012). In this paper, we develop this research focus using data from three PNG island villages that engage in the wild sea cucumber fishery and as well as being partners in a sandfish mariculture project (Hair et al., 2016a).

1.2. New Ireland Province and the sea cucumber fishery

New Ireland Province (NIP) is located in northern PNG (Fig. 1), and consists of two large islands – New Ireland and Lavongai (also known as New Hanover) – plus many smaller islands. The capital Kavieng is located on the northwestern tip of New Ireland. Production and sale of BDM has been an important activity in the study area since the late 1980s, targeting sandfish until they were overfished and the fishery expanded to include other species (Lokani, 1996; Friedman et al., 2008; Hair et al., 2016a).

Severe depletion of wild sea cucumber stocks nationwide led the PNG National Fisheries Authority (NFA) to impose a moratorium on fishing sea cucumber and selling BDM in September 2009. Communities that relied heavily on BDM for income were forced to pursue alternative livelihoods, with most effort shifting to other forms of fishing (Barclay et al., 2016; Purdy et al., 2017; Vieira et al., 2017). The moratorium was in place for more than seven years and reopened on 1 April 2017, despite NFA surveys indicating that populations of many sea cucumber species had not fully recovered (Hair et al., 2018). Resumption of the fishery had been eagerly anticipated by NIP fishers; sea cucumbers were conspicuous again in nearshore fishing grounds and BDM prices had increased greatly during the moratorium. Prior to reopening the fishery nationally, NFA revised their Beche-de-mer Management Plan (Barclay et al., 2016; Hair et al., 2016a; NFA, 2016). A feature of the revised Plan was an annual season from April to September or until a provincial total allowable catch (TAC) of BDM was reached, assessed from exporters' purchase records. In this first post-moratorium season, the TAC for NIP was 43 tonnes (T), which was attained in less than two months of intensive fishing. In fact, the TAC was exceeded by at least 36 T because of the inability to monitor BDM purchases in real time (Hair et al., 2018). More than 20 sea cucumber species were fished in NIP during the 2017 season.

The reopening of the sea cucumber fishery provided an opportunity to describe and quantify its importance and value to New Ireland fishing communities. Changes in occupation, income, spending patterns, diet and fishers' attitudes are compared over three periods: before, during and after the 2017 sea cucumber fishery. Drawing on survey results and current understandings of local culture and political economy, we conclude with an appraisal of the potential contribution a sea cucumber mariculture-based livelihood might make to the well-being of coastal communities and how best to successfully integrate this with the existing wild fishery.

2. Methods

2.1. Ethical statement

This study was carried out under James Cook University Human Research Ethics Committee approval H4930. All interviewees gave consent to participate, verbal consent was usually sought because of low levels of literacy. Prior to being interviewed, each respondent was informed of the purpose of the interview, the confidentiality of information provided and the right to omit questions or end the interview

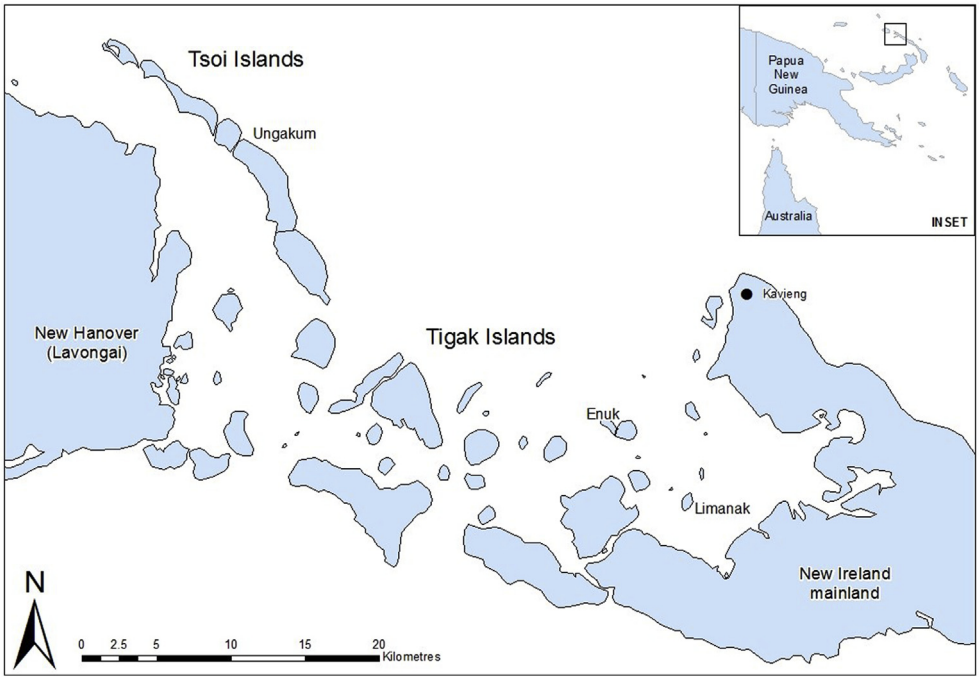

Fig. 1. Location map showing the three villages involved in the study and location of the provincial capital, Kavieng.

at any stage.

2.2. Description of the study area

The study area lies within the Tigak and Tsoi Islands which are located east of New Ireland (Fig. 1). These islands are raised limestone or sand atolls, featuring fringing reefs, sandy seafloors with coral bommies, seagrass meadows in sheltered areas and extensive mangroves on the islands and the nearby mainland areas. Most communities in this area are heavily reliant on marine resources for food and income but also engage other activities to meet subsistence and cash needs (Kaly, 2005). Customary marine tenure in this area gives equal rights to all community members to harvest in their traditional fishing grounds (Otto, 1998). Outsiders are generally permitted to fish for subsistence needs, however, not for high-value commodities such as sea cucumber, trochus, lobster and mangrove crab (Foale et al., 2011). Many islands in the study area have former coconut plantations and copra production is undertaken by clans with entitlement to a 'block' of land.

The study was conducted in three villages: Enuk and Limanak in the Tigak Islands; and Ungakum in the Tsoi Islands (Fig. 1). All three villages were involved with the BDM trade in the boom period of the late 1980s: Limanak and Enuk fishers sold sandfish to a processing company on nearby Limellon Island (Hair et al., 2016a); while middlemen on Enuk also bought fresh sandfish from Ungakum fishers. These villages were selected because they are involved in holothuriculture research using juvenile sandfish that are now produced routinely at NFA's Nago Island Mariculture and Research Facility (NIMRF) (Militz et al., 2018). Although no commercial farming operations have commenced under this program, two trial 'sea ranches', stocked with cultured juvenile sandfish from NIMRF, have been established at Limanak and Ungakum since 2015.

The population of each village fluctuates but at the time of the study was between 250 and 300 residents, as estimated from surveys and available records. Lawless and Fijlink (2016) provides estimates but census figures were not available for all villages, nor were village officials able to provide accurate numbers of residents. Proximity to Kavieng by boat is 15 min from Enuk and Limanak, and 1–1.5 h from Ungakum. A resort near Enuk employs residents from that island but generally levels of formal employment are low. The level of community-based fisheries management (CBFM) relating to sea cucumber was ranged from minimal (Enuk) to well-developed (Ungakum). At Enuk, two households had imposed informal 'tambu' zones (i.e. banned all fishing) in the sea adjacent to their houses. At Limanak, a resource management committee was formed in 2016 and a Fisheries Management Plan ratified (WCS, 2016a). Their plan did not include specific sea cucumber management measures but the committee informally banned all fishing in nearshore areas and prohibited non-residents from sea cucumber fishing, even if they had relatives on the island. Outsider fishing had been a source of conflict since before the moratorium, hence the attempts to control this in the 2017 season. Ungakum established a Marine Management Committee and developed their first resource management plan in the mid-2000s. A revised Ungakum plan stipulated protection of the 5 ha NIMRF sea ranch area (WCS, 2016b), and the committee also informally prohibited harvest in the tidal channel that divides the village.

2.3. Survey and sampling design

We used a mixed-methods approach of: oral, semi-quantitative household socioeconomic surveys; semi-structured interviews with key informants (KIs); informal conversations with fishers and other community members; and participant observation, over a 2.5-year period.

Household socioeconomic surveys were carried out in three periods: *Pre-fishery* (during the moratorium); *Fishery* (2017 sea cucumber season); and *Post-fishery* (closed season) (Table 1, Appendix S1). A team of two to five enumerators worked in study villages for one or two days, accompanied by local assistants. Household heads (male or female, or both) were surveyed and if neither were available on the first attempt, the house was revisited. We attempted to survey every household, no interviews were refused and we accepted a minimum of 35 households per village in each survey period (Table 1). Interviews were conducted in *Tokpisin*, a National *lingua franca*. Local assistants translated questions into local language (Tigak *Tokples*) and provided clarification when required. *Pre-fishery* period data included information on demography, occupation, assets, income, fishing activity and diet. *Fishery* period data included demography, income, purchasing, fishing activity, gender roles and diet. *Post-fishery* period data included income, purchasing, fishing activity, diet and attitude towards the 2017 sea cucumber fishing season.

Table 1
Survey dates and number of household surveys conducted in each village in each Fishery period.

	Enuk		Limanak		Ungakum	
Survey period	Date	No. HH	Date	No. HH	Date	No. HH
Pre-fishery	March 2017	55	April 2015	40	Dec 2014	40
Fishery	May 2017	45	April 2017	45	April 2017	35
Post-fishery	Sept 2017	53	Sept 2017	47	Sept 2017	36

A small number of in-depth interviews were held with key informants (KIs) during each sampling period. Interviews with KIs probed more deeply into aspects of the sea cucumber fishery during pre-moratorium times (with an emphasis on sandfish) and the broader impacts of the 2017 fishery and trade. Enumerators also recorded personal observations and information gleaned from discussions with community members. Following each survey or interview, respondents were invited to volunteer information or ask questions. Information from all sources was examined for recurring key themes (Bernard, 2006).

Data from NIP BDM exporters were summarised for type, quality and value of BDM for the province and for the study villages. Interviews were also held with three BDM exporters who had operated during the pre-moratorium sea cucumber fishery.

2.4. Statistical analysis

Weekly income from all sources and from seafood sales were compared for the three fishery periods for each village. A generalised least square (GLS) analysis was used for total income (data were log+1 transformed prior to analysis to normalise values). A binomial logistic regression was used for seafood sales income where 0 denoted nil income and 1 denoted income from this source. Differences in diet and occupations were analysed for each village in the *Fishery* and *Post-fishery* periods only. The proportion of imported food items consumed was analysed with GLS, while the number of non-BDM related occupations was analysed with a Poisson generalised linear model (GLM). Results of all analyses were considered significant at $P < 0.05$. GLS and GLM coefficient values are presented to indicate goodness of fit between the actual and the fitted values of the dependent variable.

3. Results

3.1. Income and occupation

Reported household weekly income from sale of BDM was divided by three because fishers sold BDM they had stockpiled for three weeks due to delayed issuing of exporter licences. Respondents who did not divulge their income in *Pre-fishery* surveys (15 households) were omitted from analyses, as were households that had collected but not

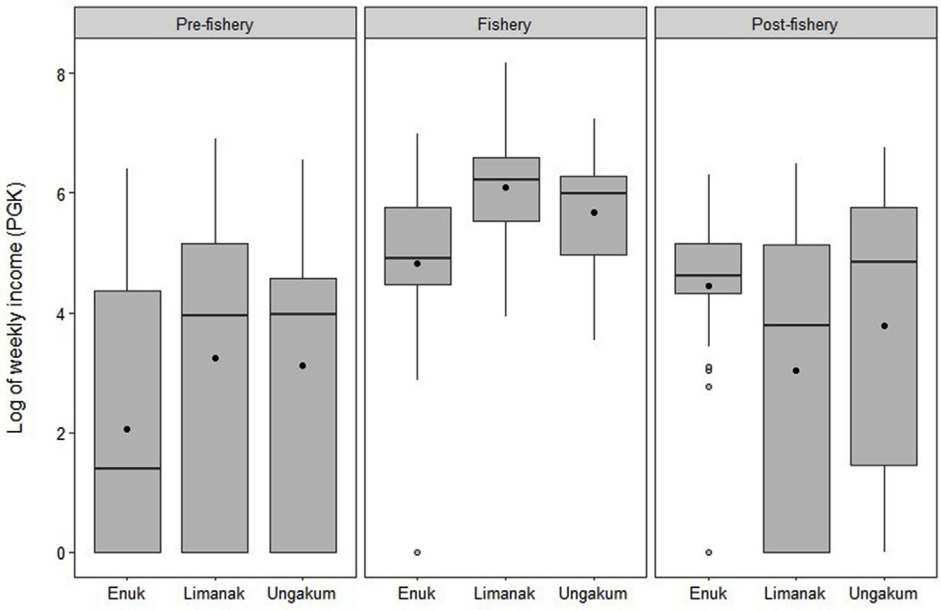

Fig. 2. Box plots of log-transformed average weekly income (PGK) per village for *Pre-fishery*, *Fishery* and *Post-fishery* periods. Closed circle = mean; horizontal line = median; grey bars = 25th and 75th percentiles; whiskers = 5th and 95th percentiles; open circle = outlier.

yet sold BDM in *Fishery* period interviews (eight households). If households provided an income range (ten households over all survey periods), the lower value was used.

Average weekly household income in all villages was significantly higher in the *Fishery* period ($F = 91.981$, $P < 0.001$; Fig. 2). Limanak had higher weekly income than Ungakum and Enuk ($F = 8.99$, $P < 0.001$). Increases in average household income during the *Fishery* period were due to BDM sales which surpassed income from other activities in all villages: average weekly incomes for Enuk, Limanak and Ungakum was PGK 140,[1] PGK 580 and PGK 405, respectively, comprising 82%, 94% and 99% of the total average weekly income for each village. Across sites, weekly household income from BDM sales ranged from PGK 16–2,700, with the greatest change in the lower incomes which rose more than high incomes did (Fig. 2). Analyses revealed that Enuk's *Post-fishery* period income remained relatively high compared the other villages (interaction coefficient value of -2.70, $P < 0.001$ cf Limanak, -1.53, $P < 0.05$ cf Ungakum). Across all villages, more households reported nil income in the *Pre-* and *Post-fishery* periods (31% and 23%, respectively) compared to one (< 1%) in the *Fishery* period (discounting households that were in the process of selling BDM when interviews were held).

Seafood and copra sales were the most common income sources in *Pre-* and *Post-fishery* periods (Fig. 3) but copra production ceased and seafood fishing effort decreased during the *Fishery* period (Fig. 4). Significantly fewer households earned any income from seafood sales during the *Fishery* period (coefficient value 2.68, $P < 0.001$); most fish caught during this period were for subsistence purposes, with anecdotal reports of price increases and reduced supply in the Kavieng market. Many other cash-earning and subsistence activities ceased or were curtailed during the *Fishery* period—sea cucumber were collected every day except Sunday (unpublished data). There were significantly more non-BDM occupations in the *Post-fishery* than the *Fishery* period (coefficient value 1.17, $P < 0.001$) but this also varied between villages with Enuk having a significantly greater diversity of occupations than Limanak and Ungakum (also note relatively higher *Post-fishery* income in Enuk, Fig. 2). Non-BDM livelihoods were diverse and included salaried work, village industries such as selling cooked food and sewing, sale of market produce, handicrafts, trades and petrol sales. Waged employees did not quit their jobs to fish for sea cucumber during the fishing season but many did so in their free time.

We note that some sources of income were under-reported during the *Fishery* period. For example, we know that betelnut sales and boat transport did not cease but these sources were not always mentioned in surveys, possibly because of the collective focus on BDM.

3.2. Spending

Questions on spending were asked during *Fishery* and *Post-fishery* surveys only: household heads were asked specifically what they purchased with income from BDM sales. *Fishery* period surveys recorded purchases with initial BDM earnings and *Post-fishery* period surveys recorded purchases with earnings from the entire 2017 season, although the amount spent on each item was not recorded.

The most common purchases reported for initial BDM earnings (i.e. *Fishery* period surveys) were store-bought food and clothes, reported by at least 50% of households in each village (Fig. 5). Many households also spent BDM income on school items, homewares, fishing gear and electronics. A high proportion of households reported some unspent income, which was probably due to surveys being done soon after such large amounts of cash were earned and would likely be lower if surveys had been conducted later (cf. Foale, 2005; Christensen, 2011). *Fishery* and *Post-fishery* 24-h total diet recall (Kennedy, 2011) confirmed the substantial spending on store-bought food in the *Fishery* period. Store-bought foods also included food cooked and sold in the village using store-bought ingredients (e.g. buns and fried pastries). Locally sourced food came from markets, gardens, the bush or ocean, or was gifted. Households consumed a significantly higher proportion of store-bought food when the fishery was open ($F = 102.44$, $P < 0.001$). Rice was consumed by more than 95% of households and tinned fish was the most common protein (58% of households) during the *Fishery* period. Rice consumption decreased slightly in the *Post-fishery* period (75% of households), but consumption of tubers, plantains, sago and fresh fish increased, while consumption of tinned fish decreased during this period.

A recurring theme from KI interviews was that large, lump sums of money earned from BDM sales allowed people to purchase expensive items that are beyond their means during periods of 'normal' income.

[1] During the study, PGK 1 was approximately equal to USD 0.31.

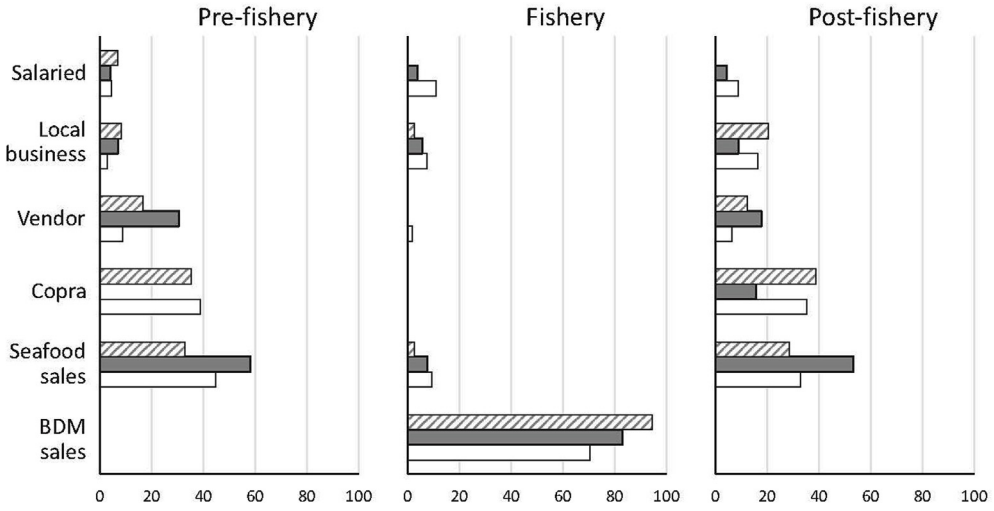

Fig. 3. Selected income source as a proportion (%) of all income sources for Enuk (open), Limanak (solid) and Ungakum (stripes) during *Pre-fishery*, *Fishery* and *Post-fishery* periods.

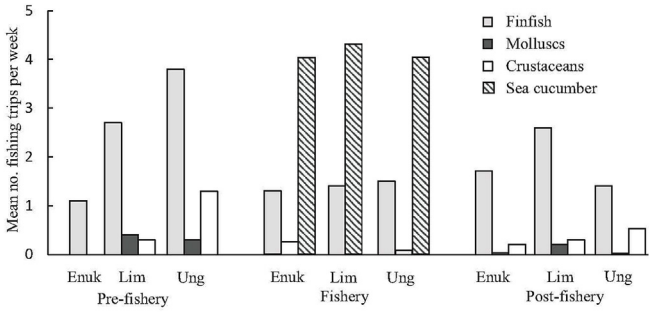

Fig. 4. Fishing effort (mean number of fishing trips per week) for marine resource groups in each village during *Pre-fishery*, *Fishery* and *Post-fishery* periods.

business, e.g. drums of fuel or canteen items to sell in the village. Almost half of all households spent money on house construction (Table 3), with roofing iron, walling, and chainsaw hire reported. Three respondents completed new permanent houses with BDM earnings.

Most households reported that spending decisions were made jointly by male and female (68%, 72%, and 63% in Enuk, Limanak and Ungakum respectively). Men were solely responsible for decisions in 18% of households. When a woman was solely responsible for purchasing decisions (14% of households), she was usually unmarried or the fisher.

3.3. Community attitude towards the 2017 sea cucumber season

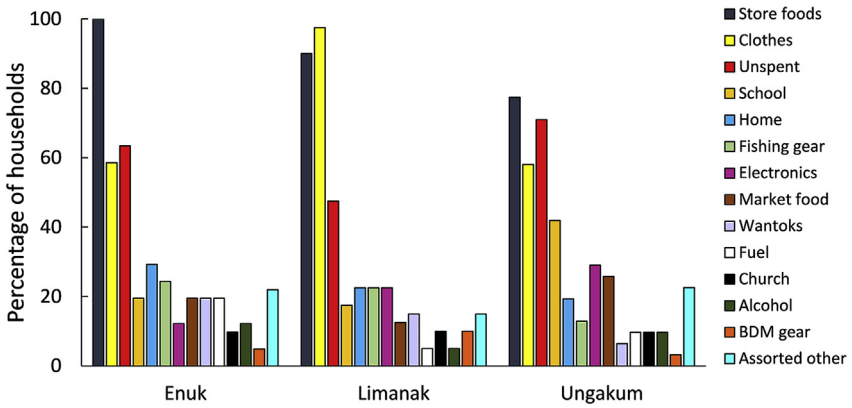

Fig. 5. Percentage of households in each village that reported purchasing selected items using initial bêche-de-mer income.

As such, BDM spending patterns (as reported in the *Post-fishery* period) were typified by asset purchases and items associated with house improvements. Assets were defined as durable and discretionary items, divided into: (i) minor assets: items of value up to PGK 200 (excluding clothing); and (ii) major assets: items of value greater than PGK 200. More than 75% of households bought assets with BDM income (Table 2). The most commonly purchased minor assets were dive torches and snorkeling gear that were used for sea cucumber collection as well as other fishing activities, followed by homewares and tools. The most commonly purchased major assets were solar power cells and lights, mobile phones, electronic equipment and fishing equipment such as nets. Some households invested in alternative income-earning

Household surveys and KI interviews elicited views about personal satisfaction and perceived benefits and costs of the 2017 fishing season, and about what practices fishers would like to change in future seasons. Respondents were overwhelmingly of the opinion that the sea cucumber season had benefited them personally (96%, 98% and 100% from Enuk, Limanak and Ungakum, respectively), either through direct participation in the fishery, or indirectly by receiving benefits from participants in terms of gifts and increased local business. Only three individuals felt they did not benefit from the fishery.

Satisfaction with the 2017 season was also high (77%, 66% and 81% of respondents from Enuk, Limanak and Ungakum, respectively). High income was the primary reason (90% of responses) but social benefits

Table 2
Number and proportion of households who purchased selected assets with BDM income.

Asset category	Enuk (n = 52)	Limanak (n = 43)	Ungakum (n = 35)	Total (n = 130)
Major assets				
Solar kit (light, panel, inverter)	20 (38%)	26 (60%)	14 (40%)	60 (46%)
Phone	11 (21%)	13 (30%)	5 (14%)	29 (22%)
Electronic goods (screen, radio, speaker)	4 (8%)	8 (19%)	4 (11%)	16 (12%)
Major fishing gear (e.g. net, canoe, eskie)	1 (2%)	8 (19%)	3 (9%)	12 (9%)
Generator	3 (6%)	2 (5%)		5 (4%)
Chainsaw		3 (7%)	1 (3%)	4 (3%)
Fuel drum		2 (5%)	2 (6%)	4 (3%)
Power tools		1 (2%)	2 (6%)	3 (2%)
Outboard engine		2 (5%)		2 (2%)
Business investment capital			1 (3%)	1 (1%)
Minor assets				
Minor fishing gear (e.g. torch, mask, fins, handline, spearguns)	21 (40%)	28 (65%)	14 (40%)	63 (48%)
Homewares (e.g. mattresses, plates)	4 (8%)	10 (23%)	7 (20%)	21 (16%)
Tools/hardware	9 (17%)	4 (9%)	6 (17%)	19 (15%)
Parts (generator, chainsaw, outboard)	7 (13%)	4 (9%)	3 (9%)	14 (11%)
Boat repair	1 (2%)			1 (1%)
Nil assets				
No asset purchases	14 (27%)	9 (21%)	7 (20%)	30 (23%)

Table 3
Number and percentage of households from each village who reported spending BDM income on house improvement.

Home improvement category	Enuk	Limanak	Ungakum	All villages
Purchase of materials for house	12 (23%)	28 (59%)	10 (28%)	49 (37%)
Completed a new house		1 (2%)	2 (6%)	3 (2%)
Repair/extension to existing house	3 (6%)	1 (2%)	4 (11%)	8 (6%)
Reported saving for new house	3 (6%)	1 (2%)		4 (3%)
Total any home improvement	***18 (35%)***	***31 (65%)***	***16 (45%)***	***65 (48%)***
No home improvement	35 (65%)	16 (35%)	20 (55%)	71 (52%)

related to a prospering community were also mentioned. Dissatisfied respondents (13%, 30%, and 17% of respondents from Enuk, Limanak, Ungakum, respectively) were unhappy with trade issues (49%), fisheries management (40%) and social problems (5%). Enuk fishers reported more dissatisfaction with the amount of BDM that was rejected because it was undersized or badly processed, underpayment and delays in selling due to late issuance of licences (83%, compared to 29% and 38% for Limanak and Ungakum, respectively). Limanak fishers reported more fishery management issues (e.g. short season, failed CBFM) than the other two villages. All key informants emphasised the positive benefits from the fishery; young men were kept busy, money was earnt to meet daily and long-term needs, standards of living were increased, and debts repaid. Negative aspects were noise and disturbance from drunks but problems such as domestic violence were not reported, purportedly due to the surplus of money which mitigated this conflict. Key informants from Limanak and Ungakum mentioned fishing in protected areas and bemoaned the neglect of gardens and community work. There were also complaints about the irresponsible disposal of rotten sea cucumber and rejected BDM.

Regarding what practices fishers said they would change, the most common was to improve income management (37% of all responses), followed by improving fishing (29%) and processing (21%) methods in order to maximise income. There were some differences among villages: more than half of households in Enuk wanted to improve fishing and processing practices; Limanak had the highest proportion of households who wanted to improve resource management; and Ungakum had the highest proportion who wanted to improve their income management (Fig. 6).

Post-fishery household surveys and KI interviews probed into outsider fishing of sea cucumbers, this being a recurring theme in *Pre-fishery* and *Fishery* surveys. Two common types of outsiders were

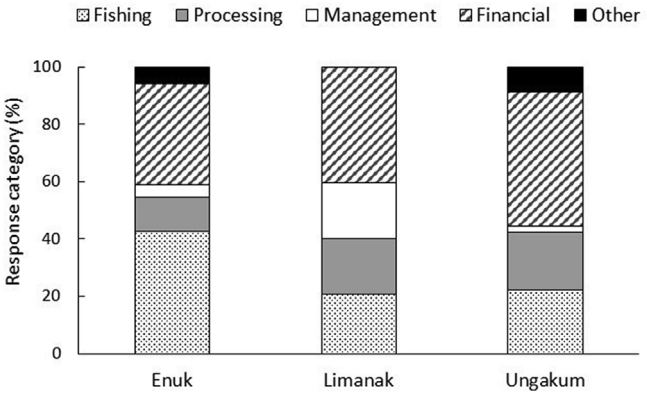

Fig. 6. Percentage of household responses per village for each category of desired changes to practices associated with the sea cucumber fishery and BDM trade.

identified: (i) 'Poachers': fishers who reside outside the community and enter village fishing grounds without permission to harvest sea cucumber; and (ii) 'Insider outsiders': fishers who temporarily relocate to the village during the open season for the purpose of harvesting sea cucumber. Insider outsiders were ex-residents or people who had connections to the village through relatives (*wantoks*) or marriage (*tambus*).

Enuk respondents mostly reported poaching on uninhabited islands within their fishing grounds or were unaware of outsiders (Fig. 7).

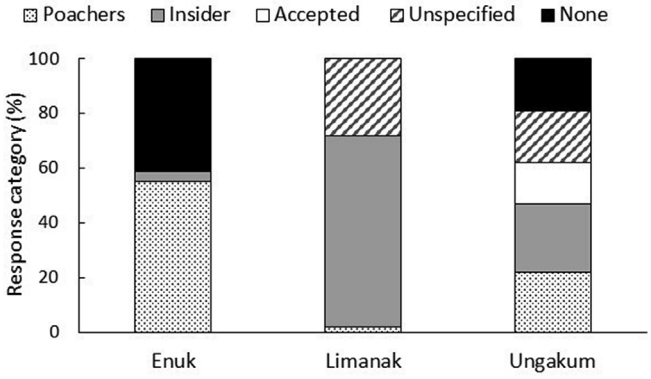

Fig. 7. Percentage of household responses per village for each category of 'outsider fishing'.

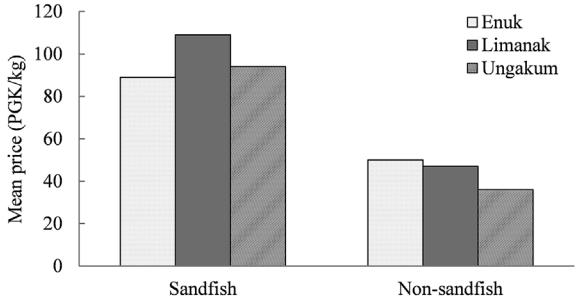

Fig. 8. Mean price (PGK/kg) received for sandfish BDM and non-sandfish BDM by Enuk, Limanak and Ungakum fishers.

There were few concerns raised in *Pre-fishery* surveys and minimal effort made to stop poaching, possibly due to the difficulty of enforcement. Limanak predominantly reported insider outsiders (Fig. 7), an issue of concern since before the moratorium. Ungakum reported roughly equal numbers in all categories, and were the only village to include outsiders with reciprocal rights (some nearby Lavongai villages access Ungakum fishing grounds due to a trading relationship). Outsider fishing in Ungakum was not raised in *Pre-fishery* KI interviews and was of minor concern in *Post-fishery* surveys.

3.4. NIP Bêche-de-mer exports

New Ireland province exporter records indicate that 68 T of bêche-de-mer, valued at PGK 4.2 million (approx. USD 1.26 million) was purchased from thousands of fishers in NIP villages between 1 April and 26 May 2017. Based on recorded village of origin, fishers from Enuk sold 1886 kg of BDM earning PGK 101,700; fishers from Limanak sold 2943 kg of BDM earning PGK 171,000; and fishers from Ungakum sold 1458 kg of BDM earning PGK 100,640. Prices received for sandfish BDM were higher than for non-sandfish BDM (Fig. 8) with Limanak recording the highest mean price. Proportionally more sandfish BDM was sold by Ungakum fishers (52% compared to 9 and 17% for Enuk and Limanak, respectively).

Exporters complained about the quantity of undersized and badly processed BDM that was brought in for sale in the 2017 season, echoing complaints from *Pre-fishery* interviews (Hair et al., 2016a).

4. Discussion

4.1. The 2017 sea cucumber fishery and bêche-de-mer trade

Following the extended moratorium, sea cucumber stocks were partially restored in shallow, nearshore waters in NIP. The re-opening of the fishery with high BDM prices created a bonanza, dominating village life at the expense of other subsistence and income-earning activities. A large cross section of the community participated in the fishery (Hair et al., 2018). However, much undersized and poorly processed BDM received lower prices or was rejected outright, lowering returns for fishers. Nonetheless, the two-month sea cucumber fishing season injected more than PGK 4 million into NIP households, with more than PGK 370,000 earned in the three study villages over the course of the season. This study estimated average weekly household income across the three villages to be PGK 413 during the fishing season, which compares favourably with the minimum weekly wage for paid workers in PNG of around PGK 140[2] and the official weekly income of PGK 111.[3]

Few studies have directly quantified the income of sea cucumber fishers in the Pacific region (Ramofafia et al., 2007; Purcell et al., 2018a). However, numerous reports suggest that communities endure financial hardship when the fishery is closed, due to fewer and less lucrative alternative livelihoods (Foale, 2005; Kinch et al., 2007; Christensen, 2011; Barclay et al., 2016; Vieira et al., 2017). Purdy et al. (2017) found that NIP households compensated for lost BDM income by increasing seafood sales and were not financially disadvantaged by the sea cucumber moratorium (however, note that their income baseline was from a depleted pre-moratorium fishery). Our study quantified the significantly higher incomes resulting from the 2017 post-moratorium sea cucumber season in three NIP villages—many fishers claimed to have earned more money than they had ever seen before. Barclay et al. (2016) suggested that sea cucumber wealth was disproportionately held by young men and resulted in few long-term benefits to the community. Our study suggests that benefits were somewhat better distributed and satisfaction with the fishery was high. A concurrent sea cucumber fishery study also reported that a wide cross-section of the community participated in the NIP fishery (see Hair et al., 2018). Further, most fishers believed that their standard of living was improved by making changes to their diet, clothes, material possessions and housing. Initial spending was unsurprisingly on store-bought foods. The consumption of rice and tinned fish supplanted garden food and fresh fish during the *Fishery* period, highlighting a desire for these foods when income is adequate (Saweri, 2001; Christensen, 2011; Fabinyi, 2017) and less time available for sourcing and preparing 'traditional' foods owing to heightened fishing activity.

As the season progressed and more money was earned, durable assets were purchased, such as gear for general fishing activities (e.g. nets, outboard engines), capital for non-fishing businesses (e.g. fuel sales, canteens) and house construction. The desire for a permanent house is an increasingly high priority in modern Melanesian society (Macintyre and Foale, 2004; Smith, 2018) and was a recurrent theme in our study. It requires significant capital but is long-lasting, has practical benefits (e.g. rainwater collection), while signaling prestige and modernity. During the study, revenue derived from the fishery enabled many fishers to undertake full or partial construction of a permanent house. Conversely, some fishers did spend their income on consumable items and recreation (cf Barclay et al., 2016), while others claimed they were caught off-guard by the brevity of the season, restricting their capacity to purchase assets. Alcohol consumption (despite the difficulty of obtaining unbiased reports, see Foale, 2005) and drunken anti-social behaviour were widely reported. However, other social problems such as domestic conflict and gambling (Barclay et al., 2016) were not reported or observed but we cannot assume that they did not occur.

4.2. Sandfish: a premium marine resource

In contrast to most marine resources harvested for subsistence and artisanal purposes in the community, sea cucumbers are usually exported. It is one of the 'readily profitable' but easily depleted fisheries identified by Barclay and Kinch (2013). While artisanal seafood fishing remains an important livelihood for many villagers (Purdy et al., 2017; our study), financial returns are restricted by proximity to markets (in the absence of refrigeration), plus fluctuating prices owing to local supply and demand. Bêche-de-mer, on the other hand, is non-perishable, has a guaranteed immediate sale and high value ('fast money' as one KI described it). The commodification of sea cucumber has also resulted in communities exerting stronger proprietary rights to this resource (Otto, 1998).

Among traded sea cucumber species, sandfish 'punches above its weight' in income generation. It requires a more complicated and lengthy processing method (Ram et al., 2017), but remains the most valuable tropical species fetching an average retail price of USD 369/kg in China in 2016, with exponentially higher prices for larger individuals (Purcell et al., 2018b). The premium position of sandfish in the study area is confirmed by past harvest levels (Friedman et al., 2008; Hair

[2] https://tradingeconomics.com/papua-new-guinea (accessed 2/2/2019).

[3] Based on per capita income of USD 1790 (PGK 5774) http://www.pg.undp.org/content/papua_new_guinea (accessed 2/2/2019).

et al., 2016a), fishers' declared preference (stated first choice in *Pre-fishery* interviews) and targeted fishing for this species in the 2017 season (Hair et al., 2018Hair et al., 2018). As mentioned, sandfish is also a promising candidate for holothuriculture in the region.

4.3. Wild sea cucumber fishery and community-based mariculture

Our study contributes to understanding the value of the wild sea cucumber fishery in NIP and provides important information for management. The inherent and intractable difficulties in the sustainable management of wild sea cucumber fisheries due to high demand, ease of harvest and various biological characteristics are well known (Uthicke et al., 2009; Anderson et al., 2011; Purcell et al., 2014; Eriksson et al., 2015). Even though the moratorium did effect a partial recovery prior to the 2017 season (Hair et al., 2018), further recovery may be jeopardised if unsustainable fishing practices reported for the 2017 season, including exceeding the TAC and harvesting undersized animals, continue in future seasons (Carleton et al., 2013; Pakoa et al., 2013). Holothuriculture has potential to co-exist with the wild fishery as a complementary and more sustainable mode of exploitation (Hair et al., 2016a; Purcell et al., 2012). The socio-economic parameters described in this study can instruct the development of mariculture-based livelihoods and also provide a baseline for future comparisons.

Alternative livelihoods in developing countries work best with a familiar resource, strong financial incentives, cultural compatibility, low investment and realistic time and labour demands (e.g. Slater et al., 2013; Stevenson and Irz, 2009; Curry et al., 2015). Research in PNG and elsewhere suggests that sandfish mariculture is well-positioned to meet these criteria (Hair et al., 2016a; Juinio-Meñez et al., 2012; Robinson and Pascal, 2012). From a technical perspective, sea ranching is a simple and low-cost mariculture intervention: cultured juveniles are released into an unenclosed area, designated as the community 'ranch', for harvest at market size (Purcell et al., 2012). Key to the success of this activity is the community having sole, exclusive access rights to the ranch and selecting suitable habitat to maximise retention of individuals within sea ranch bounds, given their naturally low dispersal rates (Purcell and Kirby, 2006; Lee et al., 2018). Survival and growth will vary with juvenile release size and habitat quality (Tsiresy et al., 2011; Hair et al., 2016b; Ceccarelli et al., 2018), and small juveniles may require protection against early mortality (Lavitra et al., 2015; Hair et al., 2016b). However, sandfish mortality decreases as they grow and with no need for supplementary feeding, inputs from the community during grow-out to commercial size are minimal. In socioeconomic terms, benefits from a sea ranch must exceed the costs of creating and maintaining it, and opportunity costs must also be considered if fishing grounds are lost through establishment of a ranch. Finally, holothuriculture is unlikely to sustain ongoing individual high incomes but is more likely to contribute to a portfolio of livelihoods, a strategy shown to increase income security and resilience (Allison and Ellis, 2001; Mills et al., 2011). The salient issues around sea cucumber mariculture are, therefore, likely to be in the human dimension: social acceptance and adoption, sensible and effective management, and equitable distribution of both costs and benefits (Krause et al., 2015).

Development and enforcement of sound management measures are equally important for mariculture as for the wild fishery (Purcell et al., 2012). These include measures to ensure optimum value is extracted from the resource and the equitable distribution of benefits. Results from the 2017 sea cucumber fishery season raise concerns for the former. In NIP, poor BDM processing and harvest of undersized sea cucumbers constrained profits for fishers. A lack of awareness underpinned these problems, highlighting an urgent need for information on sustainable harvesting and improved processing practices. These difficulties were exacerbated by the influx of inexperienced fishers, in addition to informed, experienced fishers seeking a fast (low-value) sale. Exporters reported similar problems during pre-moratorium times (Hair et al., 2016a). The persistence of these practices in 2017 suggests that fishers were focused more on catch volume than optimum prices, a version of 'race to fish' behaviour (Gordon, 1954).

Under a sea ranching scenario, it would be expected that community leaders will regulate who has harvest rights, when the ranch can be accessed and which animals can be harvested. It is reasonable to assume that harvest will be restricted to community members. Harvest frequency might be 'never' (i.e., aimed at producing spillover into open areas), 'annual', 'random' (e.g. fundraising events) or 'year-round', all of which require control of access. Issues experienced with outsider fishing in the 2017 wild fishery will therefore affect sea ranch operations, especially if wild sea cucumber catches dwindle and sandfish become depleted, as in the past (Hair et al., 2016a, 2018). Sea ranches should therefore be located close to villages and additional security measures introduced (Juinio-Meñez et al., 2012; Robinson and Pascal, 2012). Although Purdy et al. (2017) recorded an increase in Tigak Island households enforcing access rights to community fishing grounds in 2014, effective CBFM will be harder to enforce for the much higher value sea cucumber fishery (Sulu et al., 2015). Among other things, the capacity to enforce management measures depends on proximity to town, past experiences, local politics and relationships with neighbouring villages (Otto, 1998; Allison and Ellis, 2001; Foale et al., 2011; our study). The unique circumstances of any community engaging in mariculture should therefore be considered in deciding how to mitigate against poaching. Equitable distribution of benefits from communally cultured sandfish must be carefully managed to establish trust in sea ranching as a community activity and to maintain support for the operation. Just as the large individual incomes obtained in the 2017 wild fishery are likely to decline in future fishing seasons, sandfish ranchers must be realistic about financial returns from holothuriculture.

There are obvious ways in which stocking of cultured sea cucumber juveniles into suitable habitat under community control might deliver benefits. Regular releases of juveniles can buffer the effects of irregular recruitment events and overfishing, enabling a predictable harvest and sustaining a modest but regular income stream. In NIP, men and women fish for sea cucumber, although there are often gender differences in harvest method, habitats fished, species harvested and income (Lawless and Frijlink, 2016; Friedman et al., 2008; Purcell et al., 2016, 2018a). Holothuriculture may produce a more egalitarian system if sea ranches are located close to villages in accessible waters (noting high participation by women and the elderly in the 2017 season). Depending on how fisheries regulations are framed, communities might avoid the race to fish, instead harvesting when it can provide most benefit to them (Hair et al., 2016a; Purcell et al., 2018a). Options include a quota system for individuals or family groups (sensu Preston, 1992; Nash et al., 1995) or harvest for whole-of-community benefit. The success of any model, however, relies on the ability to control access to the ranch and a commitment to extract maximum benefit through sale of large, well processed BDM. Unfortunately, these were not features of the 2017 wild fishery.

Various models of community or corporate sea cucumber mariculture operate in other countries. In the Maldives, northern Australia and Madagascar, private hatcheries produce sandfish juveniles that support community livelihoods in addition to wholly commercial grow-out operations (Bowman, 2012; James, 2012; Robinson and Pascal, 2012). In the former, sandfish are either purchased back from individual farmers or resource-owners are paid for their role in the production process. In Vietnam, farmers purchase juvenile sandfish from private hatcheries, then rear them to commercial size in ex-shrimp ponds (Duy, 2012). In the Philippines, sea ranches are leased and managed by a community group, juveniles supplied by public sector hatcheries, and profits distributed to those who work the lease (Juinio-Menez et al., 2012). In some places, failed mariculture ventures have left communities cautious about involvement in holothuriculture (Hambrey et al., 2011; von Essen et al., 2013; Slater et al., 2013). In PNG, routine hatchery production of juvenile sandfish for mariculture research occurs at NIMRF (Militz et al., 2018). This is the responsibility

of the NFA and there is currently no commercial imperative, although this may change in the future should production be scaled up, if cost recovery is sought or if the private sector becomes involved. However, success of this activity in PNG relies on the capacity for 'communities' to function as cohesive social, political and economic units – a goal which may be elusive.

4.4. Conclusions

The 2017 sea cucumber fishing season made a significant financial contribution to coastal villages in New Ireland, and has the potential to do so in future seasons, particularly if management practices are improved (Barclay et al., 2016; Hair et al., 2018). We have emphasised the importance of sandfish in the study area, but the prognosis for wild stocks of this species is dire, given its history of over-exploitation (Hamel et al., 2013; Hair et al., 2016a, 2018). Accordingly, the opportunity to farm sandfish to obtain a modest, consistent income is considered here, but successful uptake will depend on adoption of approaches that optimise financial returns through sound, effective management. Our study suggested a more responsible attitude to spending the large earnings from BDM, which had a positive impact on village life with relatively few negative consequences. However, careless processing, fishing of undersized sea cucumber and ineffectual CBFM are still issues of concern. Mariculture interventions have risks and many externally-supported projects fail (Barclay and Kinch, 2013; von Essen et al., 2013), although sandfish ranching has an advantage in closely mimicking a very high-value wild fishery. Continuing research is aimed at developing a viable model for PNG and the Indo-Pacific region through resolving technical bottlenecks while addressing the social barriers for communities to adopt sandfish mariculture.

Acknowledgements

This study was supported by the National Fisheries Authorityin Papua New Guinea and the Australian Centre for International Agricultural Research as part of ACIAR project FIS/2014/061 'Improving technical and institutional capacity to support development of mariculture based livelihoods and industry in New Ireland, Papua New Guinea', for which the University of the Sunshine Coast is the commissioned organisation. Many thanks to July Kuri and Nelson Sapung (WCS), Terencehill Galiurea, Posolok Kanawi (NIMRF), Mathew Mwapweya, Joshua Noiney, and John Aini (Ailan Awareness) for assistance with surveys, and Esther Sione for data entry. We acknowledge the generosity of Enuk, Limanak and Ungakum communities and Kavieng seafood dealers for providing data associated with the sea cucumber fishery and bêche-de-mer trade. Thanks to Professor Paige West of Columbia University for helpful comments on an early draft of the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2019.104826.

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