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Assessing sandfish population stocks within the south coast of Manus, and a summary report of sandfish connectivity field research

Technical report of a survey conducted from May 19-June 27, 2014

By David A. Feary, Richard Hamilton, Manuai Matawai, Chris Molai, Maunoa Karo and Glenn Almany.

ASSESSING SANDFISH POPULATION STOCKS WITHIN THE SOUTH COAST OF MANUS, AND A SUMMARY REPORT OF SANDFISH CONNECTIVITY FIELD RESEARCH

MAY 19 - JUNE 27, 2014

FINAL REPORT

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Cover Photo: Juvenile sandfish (*Holothuria scabra*).

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SUMMARY

Despite the importance of the sea cucumber trade in terms of foreign revenue generation for PNG and cash income for local fishers, stock collapse nationally led to a nationwide closure coming into force from 2009. There is now increasing interest in examining the role of locally based management strategies in sustaining sea cucumber populations. The present work was undertaken in support of the decentralisation of sea cucumber fisheries within Papua New Guinea, and encompassed two major goals: a rigorous stock assessment of the density and status of a sea cucumber population, and an understanding of larval dispersal between and connectivity among populations.

This work focused on the high value sea cucumber, the Sandfish (*Holothuria scabra*), and accomplished a stock assessment of the populations throughout the southern coast of Manus, while also collecting tissue samples from both adult and juvenile sandfish throughout this region. This project worked closely with the Manus E Ndras Tribal Network within southern Manus Island, Manus Province, with local fishers from the seven Council of Chief areas — Nauna Asi, Polobuli Asi, Mouk Asi, M'buke Asi, Tawi Asi, Pere Asi and Mbunai Asi actively taking part. This represented a significant training and community co-management opportunity.

Sandfish are very high value, being purchased from fishers throughout the western and central pacific at an average of US$90 per kilo and retailing in Hong Kong for up to US$1,668 per kilo. Due to their high value and shallow distribution, populations are estimated to have declined by more than 90% in at least 50% of their range, leading to this species being listed as 'Endangered' on the IUCN Red List in 2010.

Survey results indicate that sandfish populations within the southern Manus region have shown considerable recovery since the 2009 moratorium and were dominated by juvenile size classes. In consultation with fishers from southern Manus that partook in the present study, there was general agreement that heavy fishing pressure on sandfish populations had resulted in sandfish densities being exceptionally low across the southern Manus region prior to the 2009 moratorium.

Although densities of sandfish fluctuated between villages across the southern Manus region, average densities per hectare in shallow seagrass habitat were relatively high (from 192 to 422 individuals per hectare), and are on par with areas that have begun experimental, small-scale fishing (i.e., Warrior Reefs within Torres Strait, Murphy et al 2012).

There was a dominance of immature sandfish individuals (≤21cm TL) throughout surveys, an indication of heavy historical fishing pressure and recovery from 2009 onwards. Any further harvesting of sandfish within this region should be restricted to the harvest of individuals that are larger than the minimum size for maturity.

There was a clear demarcation in the size class of sandfish individuals, associated with habitat availability. The majority of immature sandfish were observed using shallow, seagrass

habitats (~1-2m in depth), whereas the largest mature sandfish (≥30cm TL) were predominantly found in low abundances within sand/silt habitat at depths below ~3m. We recommend that the protection of such mature stocks (which are the primary spawning stock) is vital, and could be implemented by the use of permanent harvesting closures within the deep habitats (sand/silt habitats).

As the majority of historical surveys for sandfish have been accomplished during the day, we undertook and compared densities of sandfish between day and night. We found significantly more individuals – more than twice as many – observed at night. We suggest that night surveys should be included in future sandfish stock assessments, which will improve accuracy in determining stock status.

We estimated the total number of juvenile and adult sandfish in the seagrass within each customary area (Mbunai, Pere, Tawi, Timoenai and M'buke - no sandfish were sighted at Locha or Ndrova) by taking the mean densities sighted on transects in each of these five areas (per m^2) and multiplying this estimate by the total available habitat present in each customary area. Pere and Timoenai had the highest populations of sandfish, with an estimated 91,050 juveniles and 35,771 adults located within the Pere seagrass, and an estimated 56,582 juveniles and 15,166 adults located within the Timoenai seagrass.

This work has shown the importance of stock assessments in quantifying the densities and size structure of sandfish populations within the southern Manus region. We recommend that yearly assessments of the status of sandfish stocks throughout Manus are undertaken, and include both NFA staff members and trained local fishers.

To determine the degree of self-recruitment of sandfish (*H. scabra*) populations within Pere, and larval dispersal out of this area 6,465 individual sandfish were collected and a small 2cm X 2cm piece of body wall tissue collected (all individuals were then replaced in the area collected).

Tissue samples were collected from 57 sites from 15km to the west of Pere (i.e., Pamachau Island), 38km east of Pere (i.e., Timoenai) and 21 km south of Timoenai (i.e., M'buke Island). All samples have been sent to the King Abdullah University of Science and Technology (KAUST), Saudi Arabia for on-going genetic parentage analysis.

SECTION 1: SEA CUCUMBER ASSESSMENTS, CONNECTIVITY RESEARCH AND FISHERIES MANAGEMENT WITHIN PAPUA NEW GUINEA

1. INTRODUCTION

The combination of high value and ease of capture has meant that the majority of sea cucumber fisheries in Papua New Guinea are now severely overfished (Kinch et al. 2008b). There were signs of overfishing, and 'boom and bust' cycles within the PNG sea cucumber fishery from the beginning of the latest boom period in the late 1980s. For example, Lokani (1989) found only a single species of sea cucumber (*Holothuria scabra*; sandfish) was harvested for the first seven months of the Tigak Island bêche-de-mer fishery, before stocks of this species steeply declined and then crashed over a 4-month period. As sandfish catches declined other high value sea cucumber species, followed by progressively lower value sea cucumber species were added to the catch, and these species also followed the same 'boom and bust' cycles of high catch production followed by a precipitous and quick decline in stocks (Lokani 1989). In addition, surveys (reported in Kinch et al. 2008b) showed that sea cucumber stocks were relatively depleted throughout Papua New Guinea. In the Milne Bay Province, Skewes et al. (2002) reported low densities of commercial holothurians (average of 21 ind. ha^{-1}), while low survey densities and a comparison of historical and recent catch data indicated that *H. scabra* and *H. whitmaei* populations were grossly overexploited by 2008 (Kinch et al. 2008b). In New Ireland Province, sparse populations were observed of *H. scabra* up to 2008. More recently, Hamilton and Lokani (2011) compared changes in populations of sea cucumbers on reef flats around Buka Island in the Autonomous Region of Bougainville in 1992 and 2008 and found that the abundances of the six most dominant sea cucumber species had declined to 1-5 percent of former abundances over this 16-year period. This trend in stock collapse was repeated throughout all other coastal provinces within PNG, and led to a nationwide closure coming into force from 2009.

1.1 DECENTRALIZATION OF SEA CUCUMBER MANAGEMENT

Despite the importance of the sea cucumber trade in terms of foreign revenue generation for PNG and cash income for local fishers, this fishery faces many management and monitoring issues. Within PNG there is now increasing interest in examining the role of locally based management strategies in sustaining sea cucumber populations, with such interest buoyed by the relatively ineffective top-down management that has permeated management of sea cucumber stocks. Such changes would decentralise the management of the sea cucumber fishery to the provinces, Local Level Governments (LLGs) and communities within PNG.

Papua New Guinea's seascape is suitable for developing more effective management of sea cucumbers. Customary Marine Tenure - the informal rights-based framework for site-based fisheries management in Papua New Guinea - evolved rapidly in response to the need to control access to valuable commodities such as sea cucumbers several hundred years ago (Kinch et al 2008b). The vast majority of community-based marine protected areas in Papua

New Guinea have been established as a fisheries management tool, with the primary goal being to allow sea cucumber stocks the chance to recover (Kinch 2004).

Decentralisation of sea cucumber management must also be supported by rigorous and regular stock assessments of the density and health of sea cucumber populations at both the community and regional levels. Such stock assessments provide managers with a rapid overview of the current state of sea cucumber populations within their regions, while also allowing the evaluation of resources in selected sites, populations and species. By undertaking regular assessments, managers are also able to actively compare stock sizes and densities between management regions, allowing for an evaluation of current community management measures against national and provincial measures. Lastly, regular assessments result in local and regional capacity building through the training of surveyors to undertake sea cucumber stock assessments.

One of the major impediments to the decentralisation of management to sustain sea cucumber populations is an understanding of larval dispersal between and connectivity among populations. Genetic studies indicate that large-scale larval dispersal exists for some species (*Holothuria nobilis* and *H. scabra*: Uthicke and Benzie 2001; *Stichopus chloronotus*: Uthicke and Conand 2005). However, such work suggests that the same species can also show quite low dispersal ability, with restricted connectivity between populations, and high genetic differences between populations separated by relatively short distances (Uthicke and Purcell 2004). However, all these studies have examined the connectivity of sea cucumber populations using traditional population genetics, which provide insight into dispersal over many hundreds to thousands of generations (i.e., evolutionary time), but do not provide information on the dispersal of populations over one or a few generations (i.e., demographic/ecological timescale); it is the later information that is the most relevant to management, and can only be resolved using techniques such as parentage analysis (Almany et al 2013).

1.2 Main Aims of Work

The present study has worked closely with the Manus E Ndras Tribal Network within southern Manus Island, Manus Province, to provide data and support for decentralization of sea cucumber fisheries management within this region. The Network unites the Manus E Ndras Sea Faring Titan Tribal Communities to collaborate on issues affecting livelihoods, climate change and tribal governance. Extending across the entire south coast of Manus Island, the Network includes seven Council of Chief areas — Nauna Asi, Polobuli Asi, Mouk Asi, M'buke Asi, Tawi Asi, Pere Asi and Mbunai Asi. The development of local community networks, such as Manus E Ndras, could provide the proof of concept for how decentralized marine resource management can work in Papua New Guinea. Such decentralization would revolutionize sea cucumber management by giving communities, tribal groups, and provinces the power to manage and trade in their sea cucumber stocks, as they deem appropriate. This scenario should provide local incentives for improved management of sea cucumber stocks back at the community and provincial level (Purcell et al. 2012).

Despite support for decentralization of sea cucumber fisheries at the National level, there are a number of key ecological questions that need to be answered before we can provide advice on whether or not the fishery should be reopened, and at what ecological scale decentralized management should be supported. The goal of the present work is then to provide a proof of concept for local management of sea cucumber. Therefore, the main aims of the present work were to:

1. Undertake a stock assessment of sea cucumber populations throughout the southern Manus region – within this work we focus on one of the most commercially important sea cucumber within Papua New Guinea - Sandfish, (*Holothuria scabra*).

2. Examine the genetic connectivity of sandfish populations throughout the southern Manus Region, and determine the level of larval dispersal within and away from a natal source.

PART 1: STOCK ASSESSMENT OF SANDFISH POPULATIONS ACROSS THE SOUTHERN COAST OF MANUS

2. AIM OF WORK: UNDERTAKE A RIGOROUS STOCK ASSESSMENT OF SANDFISH POPULATIONS THROUGHOUT THE SEVEN CUSTOMARY MARINE TENURE AREAS WITHIN THE MANUS E NDRAS TRIBAL NETWORK.

In order for provincial and local management of sea cucumbers to succeed, fisheries managers need up-to-date information on the density and health of local sea cucumber populations. Without this basic information fisheries may be opened well before they have had the chance to recover from their over-exploited state, therefore perpetuating the 'boom-and-bust' scenario seen in sea cucumber fisheries throughout Papua New Guinea. Despite this there has been a paucity of surveys across the Manus coastline examining the density of sea cucumber populations.

2.1 HIGH VALUE SEA CUCUMBER SPECIES USED WITHIN THIS STUDY - SANDFISH (*HOLOTHURIA SCABRA*)

The sandfish (*Holothuria scabra*) is widespread in the tropical Indo-Pacific (excluding Hawaii) between latitudes 30N and 30S, with this species never found further east than Fiji (Purcell et al. 2012). Despite its wide geographical distribution, this species has a narrow habitat range and is only found in low-energy environments that have muddy or sand substrates (IUCN Red List, 2014). Sandfish are most abundant in intertidal seagrass beds that are in close proximity to mangroves; however, they also can be found on inner sand reef flats and in sand and silt lagoon habitats. In Papua New Guinea sandfish are distributed between depths of 0-12 metres, with most individuals found in less than 10 metres of water (Kinch et al. 2008b). Larvae of this species are planktonic, settling in shallow seagrass habitats at between 13-16 days. Recently settled juveniles (<10 mm in length) preferentially settle on seagrass such as *Thallassia hemprichi*, while larger juveniles (> 50 mm) and adults inhabit both shallow seagrass areas and deep sand/silt habitats. This species (and predominantly all *Holothuria* species) are site attached, slow moving and aggregate as adults and juveniles.

Sandfish support subsistence, artisanal, and commercial fisheries throughout the Indo-Pacific and is one of the most commercially important target species for the Papua New Guinea bêche-de-mer industry (Purcell et al. 2014). Sandfish are very high value, being purchased from fishers throughout the western and central Pacific at an average of US$90 per kilo and retailing in Hong Kong for up to US$1,668 per kilo (Purcell et al. 2012, Table 1). Due to their high value and shallow distribution, populations are estimated to have declined by more than 90% in at least 50% of their range, leading to this species being listed as Endangered on the IUCN Red List in 2010 (IUCN Red List, 2014).

2.3 Methods of Population Assessment

Between May and June 2014, the density and size structure of sandfish populations were examined at a minimum of 2 sites within each of 7 villages encapsulating the southern Manus coastline (Mbunai Village (hereafter termed "Mbunai"), Ndrova Island (hereafter termed "Ndrova", Pere Village (hereafter named "Pere"), Locha Village (hereafter termed "Locha"), Tawi Island (hereafter termed "Tawi", Timoenai Village (hereafter termed "Timoenai"), and M'buke Island (hereafter termed "M'buke") (Fig. 1a, 1b). The survey sites were predominantly chosen within shallow seagrass (~1-2m depth). In Pere sandfish populations were surveyed within both the shallow seagrass and deep sand/silt habitats (≥3m depth). Sandfish populations were surveyed with a minimum of 4 transects per site, with each transect 50 m long by 2 m wide (representing 100m^2 area per transect). A total of 364 transects were surveyed (Table 2).

Table 1 Common Name, Scientific Name, the estimated average Purchase Prices that were paid for various grades of dried sea cucumber across the western and central Pacific over the past decade (Adapted from Crick et al. 2013). Purchase prices are shown in USD per kg, (dried form), the Product Value is grouped by price bracket (H = high; M = medium; L = low; VL = very low).

Common name	**Scientific name**	**Purchase price USD kg^{-1} (dried)**	**Value group**
Sandfish	*Holothuria scabra*	90	H
White teatfish	*Holothuria fuscogilva*	84	H
Golden sandfish	*Holothuria lessoni*	60	M
Black teatfish	*Holothuria whitmaei*	53	M
Greenfish	*Stichopus chloronotus*	50	M
Prickly redfish/Pineapple fish	*Thelenota ananas*	45	M
Deepwater blackfish/Panning's blackfish	*Actinopyga palauensis*	45	M
Deep water redfish	*Actinopyga echinites*	45	M
Surf redfish	*Actinopyga mauritiana*	39	M
Blackfish/Hairy blackfish	*Actinopyga miliaris*	20	L
Curryfish	*Stichopus herrmanni*	20	L
Stonefish	*Actinopyga lecanora*	20	L
Tigerfish / leopardfish	*Bohadschia argus*	20	L
Snakefish	*Holothuria coluber*	16	L
Peanutfish/Dragonfish/Warty	*Stichopus horrens*	14	L
Chalkfish/Brownspotted sandfish	*Bohadschia marmorata*	14	L

Brown sandfish	*Bohadschia vitiensis*	14	L
Flowerfish/Orangefish/Ripple fish	*Pearsonothuria graeffei*	14	L
Amberfish	*Thelenota anax*	14	L
Lollyfish/Reef lollyfish	*Holothuria atra*	11	VL
Elephant trunkfish	*Holothuria fuscopunctata*	11	VL
Pinkfish	*Holothuria edulis*	6	VL

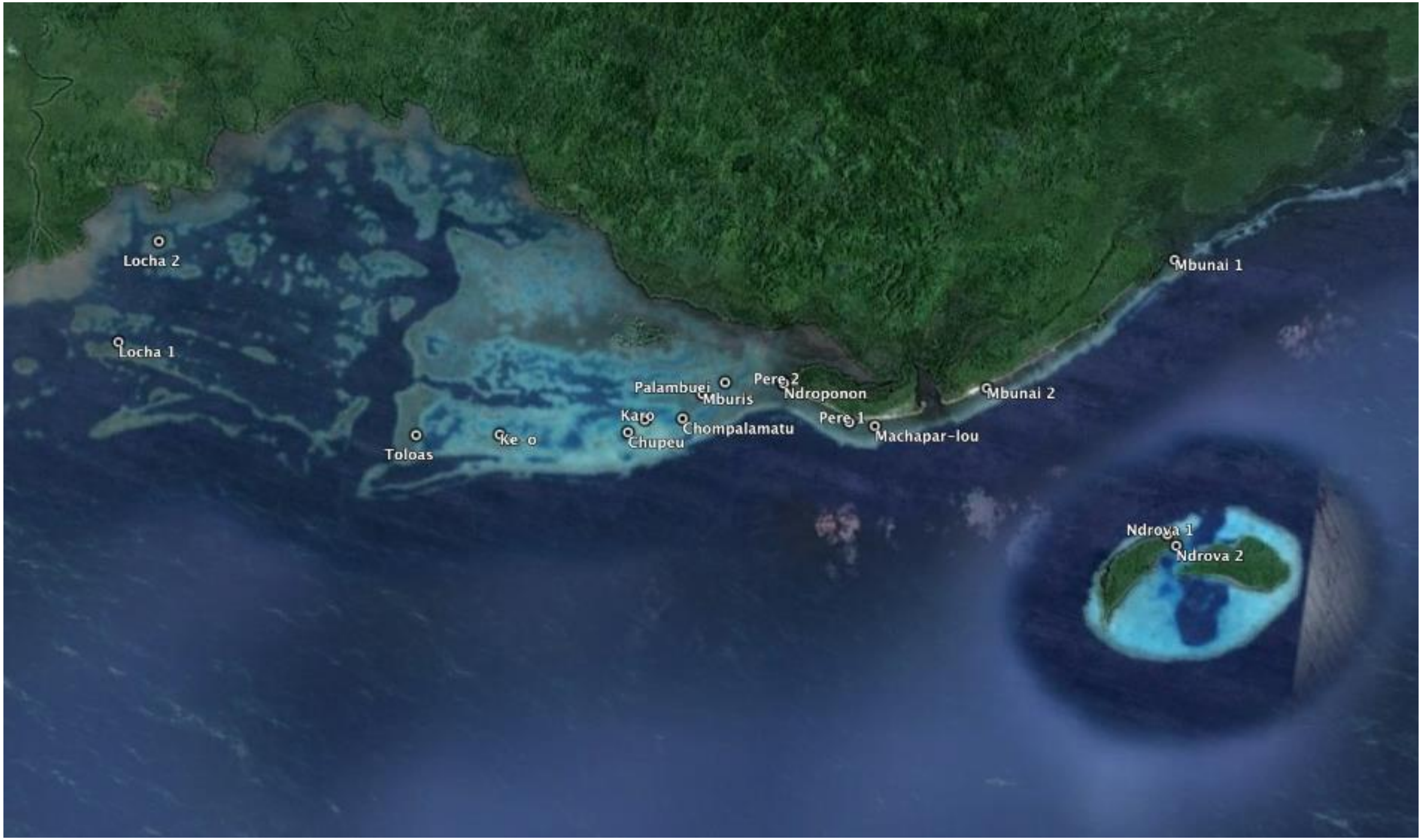


Fig 1a Survey sites for stock assessments undertaken within the eastern part of Southern Manus, with site names listed in white.

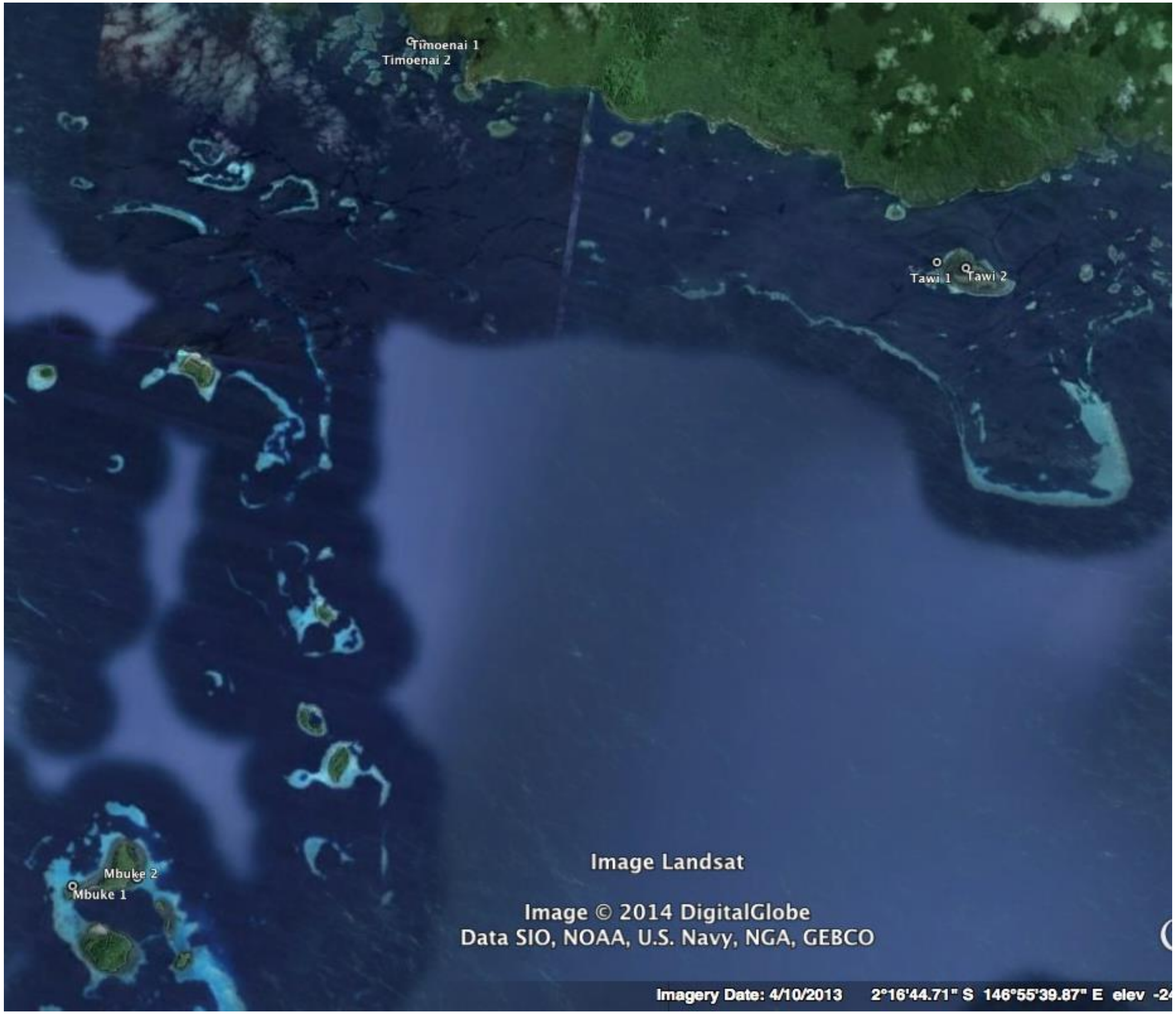


Fig 1b Survey sites for stock assessments undertaken within the western and southern parts of Southern Manus, with site names listed in white.

Table 2 Date, Local-Level Government, Village, Site, Habitat, Depth (m), Visibility (m) and the number of $100m^2$ visual transects surveyed for Sandfish (*Holothuria scabra*) across the southern Manus coastline.

Date	Local Level Government	Village	Site	Habitat	Depth (m)	Visibility (m)	Number of Transects
24-May-2014	Penabu-Nalisopat	Mbunai	Mbunai 1	Seagrass flat	<1	3	16
24-May-2014	Penabu-Nalisopat	Mbunai	Mbunai 2	Seagrass flat	2	3	24
25-May-2014	Penabu-Nalisopat	Pere	Ndroponon	Seagrass flat	<1	2	16
25-May-2014	Penabu-Nalisopat	Pere	Macharpar-lou	Seagrass flat	<1	3	12
27-May-2014	Penabu-Nalisopat	Pere	Mburis	Seagrass flat/sand	<1	5	4
27-May-2014	Penabu-Nalisopat	Pere	Chompalamatu	Seagrass flat/sand	<1	5	4
27-May-2014	Penabu-Nalisopat	Pere	Mburis	Seagrass flat/sand	<1	5	4
27-May-2014	Penabu-Nalisopat	Pere	Cholah	Seagrass flat/sand	<1	5	4
27-May-2014	Penabu-Nalisopat	Pere	Ke-o	Seagrass flat	<1	5	8
27-May-2014	Penabu-Nalisopat	Pere	Toloas	Seagrass flat/sand	<1	6	16
27-May-2014	Penabu-Nalisopat	Pere	Karo	Seagrass flat	1.8	10	4
28-May-2014	Penabu-Nalisopat	Pere	Ndroponon	Silt and sand	2 to 7	<1	24
29-May-2014	Penabu-Nalisopat	Pere	Chupeu	Deep sand/silt	7.2	3	12
29-May-2014	Penabu-Nalisopat	Pere	Karo	Deep sand/silt	5	5	4
29-May-2014	Penabu-Nalisopat	Pere	Palambuei	Deep sand/silt	5.8 to 7.8	5	12
30-May-2014	Penabu-Nalisopat	Pere	Ndroponon	Seagrass flat	<1	5	24
30-May-2014	Penabu-Nalisopat	Pere	Macharpar-lou	Seagrass flat	<1	5	20
03-June-2014	Bobuma	Tawi	Tawi 1	Seagrass flat	<1	2	24
03-June-2014	Bobuma	Tawi	Tawi 2	Seagrass flat	1.8	2	24
06-June-2014	Bobuma	Timoenai	Timoenai 1	Seagrass flat	1	5	8

06-June-2014	Bobuma	Timoenai	Timoenai 2	Seagrass flat	1	5	16
08-June-2014	Bobuma	M'buke	M'buke 1	Seagrass flat	1	3	12
08-June-2014	Bobuma	M'buke	M'buke 2	Seagrass flat	1	3	16
10-June-2014	Bobuma	Locha	Locha 1	Seagrass flat	1	<1	16
10-June-2014	Bobuma	Locha	Locha 2	Seagrass flat	1	<1	16
20-June-2014	Penabu-Nalisopat	Ndrova	Ndrova 1	Seagrass flat	1	<1	12
20-June-2014	Penabu-Nalisopat	Ndrova	Ndrova 2	Seagrass flat	1	<1	12

Within each transect all sandfish encountered were counted, with each individual's length visually estimated and placed within 50 mm size classes (total length, TL). To determine the density of sandfish in juvenile versus adult phases all individuals were split into ≤21cmTL (juvenile) and ≥22cm TL (mature [adult] phase) (following Lokani 1990) for later conversion to density (per area) estimates. The depth of each transect determined the method used to survey sandfish: all transects <1 to 3m in depth were surveyed on snorkel, while all transects ≥4m were surveyed using SCUBA.

All visual surveys were conducted at night to coincide with the highest density of sandfish (as sandfish will burrow during the day and emerge during the night, Hamel et al. 2001; Purcell 2010). However, as the majority of surveys that have examined sea cucumber populations have been undertaken during the daytime (Kithakeni and Ndaro 2002; Al-Rashdi et al. 2007, but see Mercier et al. 2000; Purcell 2010), we visually surveyed and compared the density and size structure of sandfish populations using shallow seagrass habitat within 2 villages during both day and the night (Pere and M'buke). At each site between 12 and 16 transects (representing 1200m^2 to 1600m^2 area) were surveyed between daytime (44 transects in total) and night (64 transects in total) (Table 3). All sandfish were counted visually by snorkel along 2m * 50 m belt transects, with each individual categorized into 50 mm interval size classes (total length, TL) for later conversion to density (per area) estimates.

Table 3 Comparison of sandfish (*H. scabra*) densities between day and night surveys. Date, Village, Site, Survey time (Day or Night), Depth, Visibility and the number of 100m^2 visual transects surveyed for sandfish (*H. scabra*) across the southern Manus coastline.

Date	**Village**	**Site**	**Survey for**	**Depth**	**Visibility**	**Number transects**
30-May-14	Pere	Pere Point 1	Night Baseline	<1m	5	12
30-May-14	Pere	Pere Point 1	Night Baseline	<1m	5	12
30-May-14	Pere	Pere Point 2	Night Baseline	<1m	5	12
8-Jun-14	M'buke	M'buke 1	Night Baseline	1m	3	12
8-Jun-14	M'buke	M'buke 2	Night Baseline	1m	3	16
8-Jun-14	M'buke	M'buke 2	Day Baseline	1m	3	16
8-Jun-14	M'buke	M'buke 1	Day Baseline	1m	2m	16
12-Jun-14	Pere	Pere Point 1	Day Baseline	1m	2m	12

2.4 Results

There were substantial differences in the average density of sandfish populations in the seagrass habitat across villages (Fig 2). Pere (8.62 ± 2.34 SE), Timoenai (7.5 ±1.25 SE) and Tawi (4.45 ± 1.33 SE) held the highest densities of sandfish per $100m^2$, with lower densities of sandfish recorded at Mbunai (2.16 ± 0.48 SE) and M'buke Island (hereafter 'M'buke') (2.06 ± 0.91 SE) (Fig 2). No sandfish were recorded in transects at both Ndrova and Locha (Fig 2). Within the deep sand/silt habitat surveyed within the Pere there were exceptionally low average densities of sandfish, with 0.87 (± 0.32) individuals found per $100m^2$ (Fig 2).

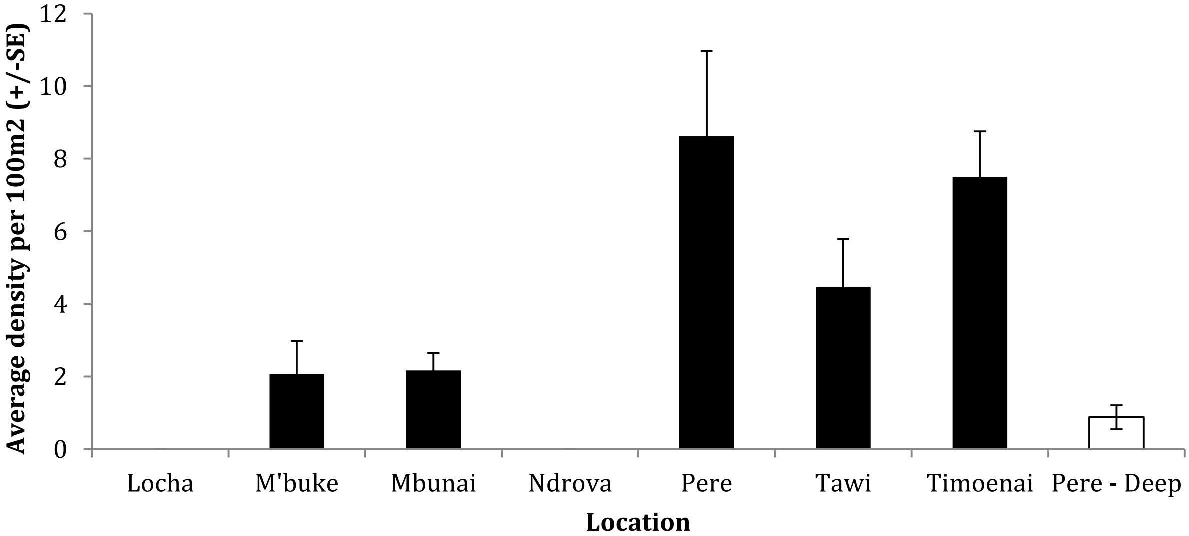


Fig 2 Average density of sandfish (± SE) per $100m^2$ at seven villages in the Manus E Ndras Tribal Network within shallow seagrass habitats (≤2m) (⍰), within deep sand/silt habitats in Pere (☐) (≥3m). Note: no sandfish were found within transects at both Locha and Ndrova.

We then separated sandfish densities per $100m^2$ into juvenile (≤21 cmTL) and adult (≥22 cmTL) size classes between shallow and deep habitats. This showed that the majority of sandfish recorded in shallow habitats were juveniles (Fig 3). Within Mbunai adult sandfish comprised 36.53% of the total number of sandfish surveyed, while within M'buke adult sandfish comprised 30.3% of the total sandfish surveyed. However, within both villages there were low densities of sandfish recorded, both villages having between 1 and 2 individuals per $100m^2$ (Fig 3). At Pere, Tawi and Timoenai adult sandfish comprised <25% of the total individuals observed on transects. Within the deep habitats, there were very low densities of both juvenile and adult sandfish (Fig 3).

Further examination of the size structure of sandfish populations between villages and habitats showed that within the shallow habitat (≤2m) the majority of 'juvenile' sandfish were between 15-20cmTL, while the majority of 'adult' sandfish surveyed were 22-23cm TL (Fig 4). The smallest individual surveyed was 9cmTL (M'buke), while the largest was 33 cm TL (Pere). When examining the size structure of sandfish populations within the deep habitat (≥3m), only two 'juvenile' sized sandfish were recorded, while the majority of individuals recorded were ‘adult’ sized individuals. The majority of adult individuals were between 25TL and 37TL (Fig 5)

At all villages sandfish populations within the shallow seagrass were dominated by juveniles (Fig 6). The average densities of juvenile sandfish in the seagrass were: Pere (666 juveniles per hectare ± 175.1 SE), Timoenai (606 juveniles per hectare ± 105.07 SE), Tawi (383 juveniles per hectare ± 117.7 SE), M’buke (143 juveniles per hectare ± 66.4 SE), and Mbunai (137 juveniles per hectare ± 31.1 SE) (Fig 6). The average density of adults within the shallow seagrass habitat was substantially lower than juvenile densities; Pere (195 adults per hectare ± 65.5 SE), Timoenai (143 adults per hectare ± 35.3 SE), Mbunai (79 adults per hectare ± 21.6 SE), M’buke (62 adults per hectare ± 28.6 SE), and Tawi (62 adults per hectare ± 23.9 SE) (Fig 6). Within the deep sand silt habitat (surveyed within Pere), juvenile sandfish showed densities of 12 individuals per hectare (± 8.5 SE), while adults showed densities of 75 individuals per hectare (± 29.5 SE).

There was a substantial difference in sandfish densities between day and night time surveys (Fig 7). Across all villages the average density of sandfish during the daytime was 0.63 individuals per $100m^2$ (± 0.16 SE), while this more than doubled during the night to 1.98 individuals per $100m^2$ (± 0.52 SE). At the village level there were substantial differences in the density per $100m^2$ of sandfish within both Pere and M’buke between night and day (Fig 7). Sandfish within the daytime at Pere were in densities of 0.50 individuals per $100m^2$ (± 0.16 SE), while during the night sandfish densities increased to 2.91 individuals per $100m^2$ (± 0.98 SE). Such substantial differences in sandfish densities between night and day were not as pronounced within M’buke, but also showed higher densities of sandfish within the night than daytime surveys (Daytime: 0.68 individuals per $100m^2$ ± 0.21 SE; Night time: 1.17 individuals per $100m^2$ ± 0.44 SE) (Fig 7).

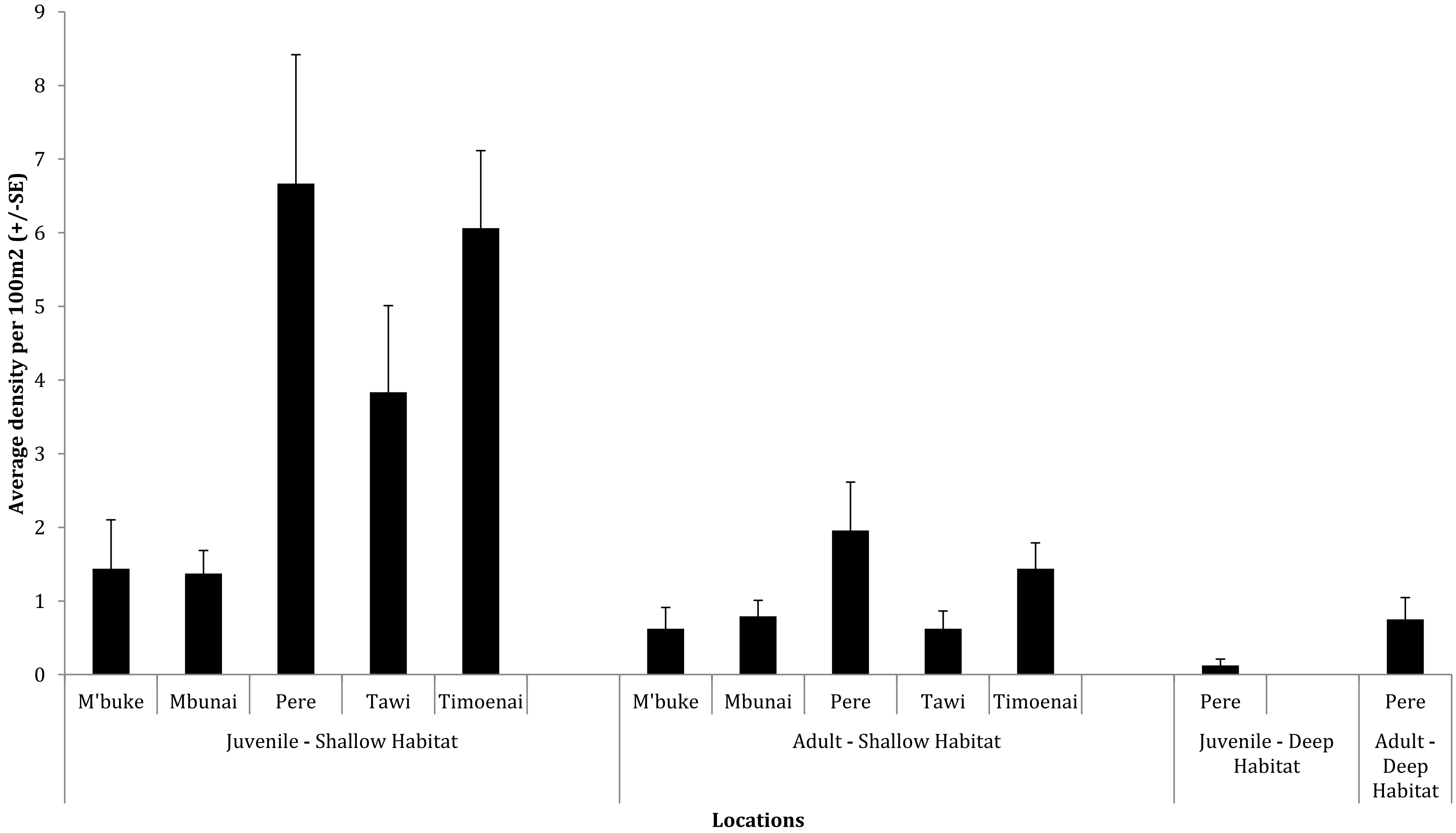
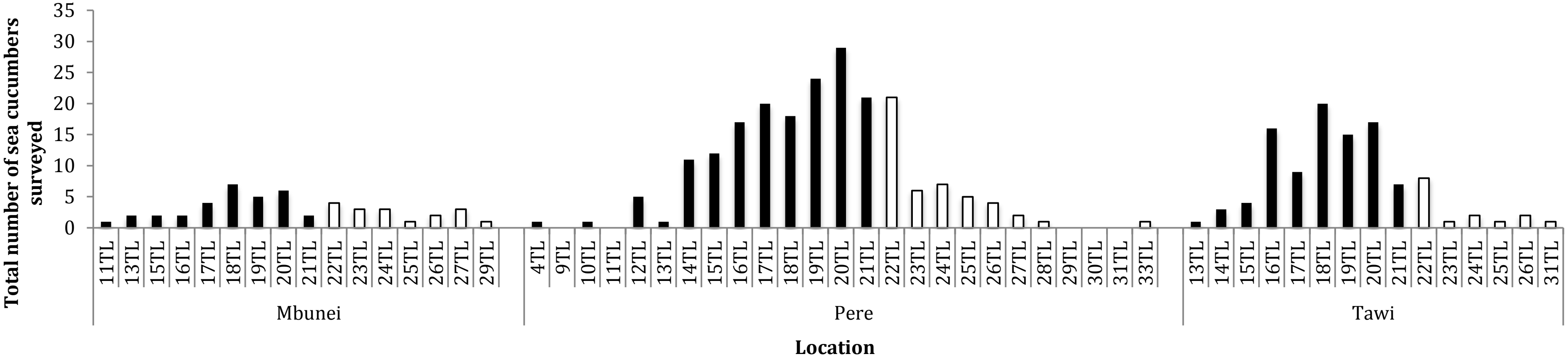


Fig 3 Average density of juvenile (≤21cmTL) and adult (≥22cm TL) sandfish (± SE) within 100m^2 transects within shallow seagrass habitats (≤2m) and within deep sand/silt habitats (≥3m). Black bars signify juvenile sized individuals (≤21cmTL); white bars signify adult sized individuals (≥22 cmTL). Note: no sandfish were found within transects at both Locha and Ndrova.

(a)



(b)

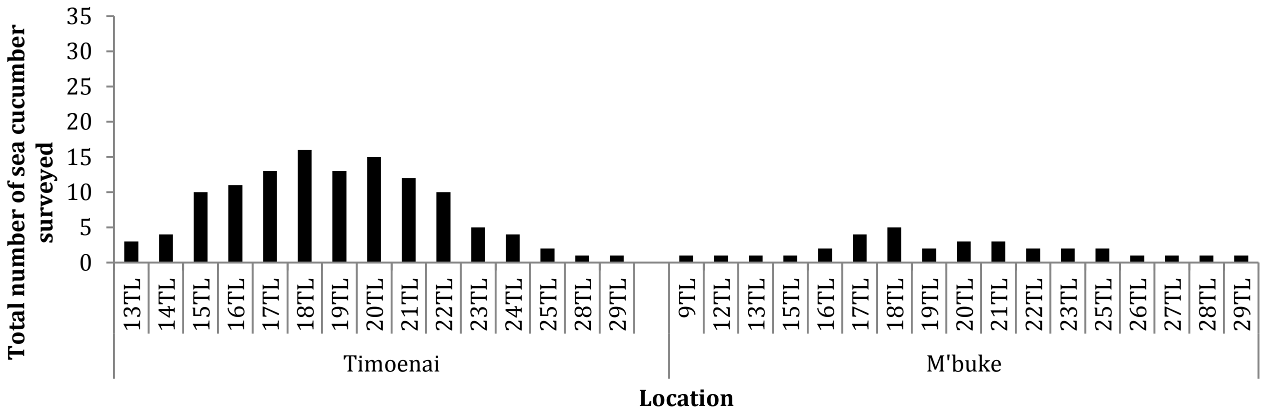


Fig 4 Size structure of sandfish populations within shallow seagrass habitat (≤2m depth) across 5 villages (a) Mbunai, Pere, Tawi and (b) Timoenai, M'buke. Black bars signify juvenile sized individuals (≤21cmTL), white bars signify adult sized individuals (≥22 cmTL) Please note: No sandfish were present in transects at 2 villages, Locha and Ndrova. Data presented is abundance of sandfish pooled across all transects at each village.

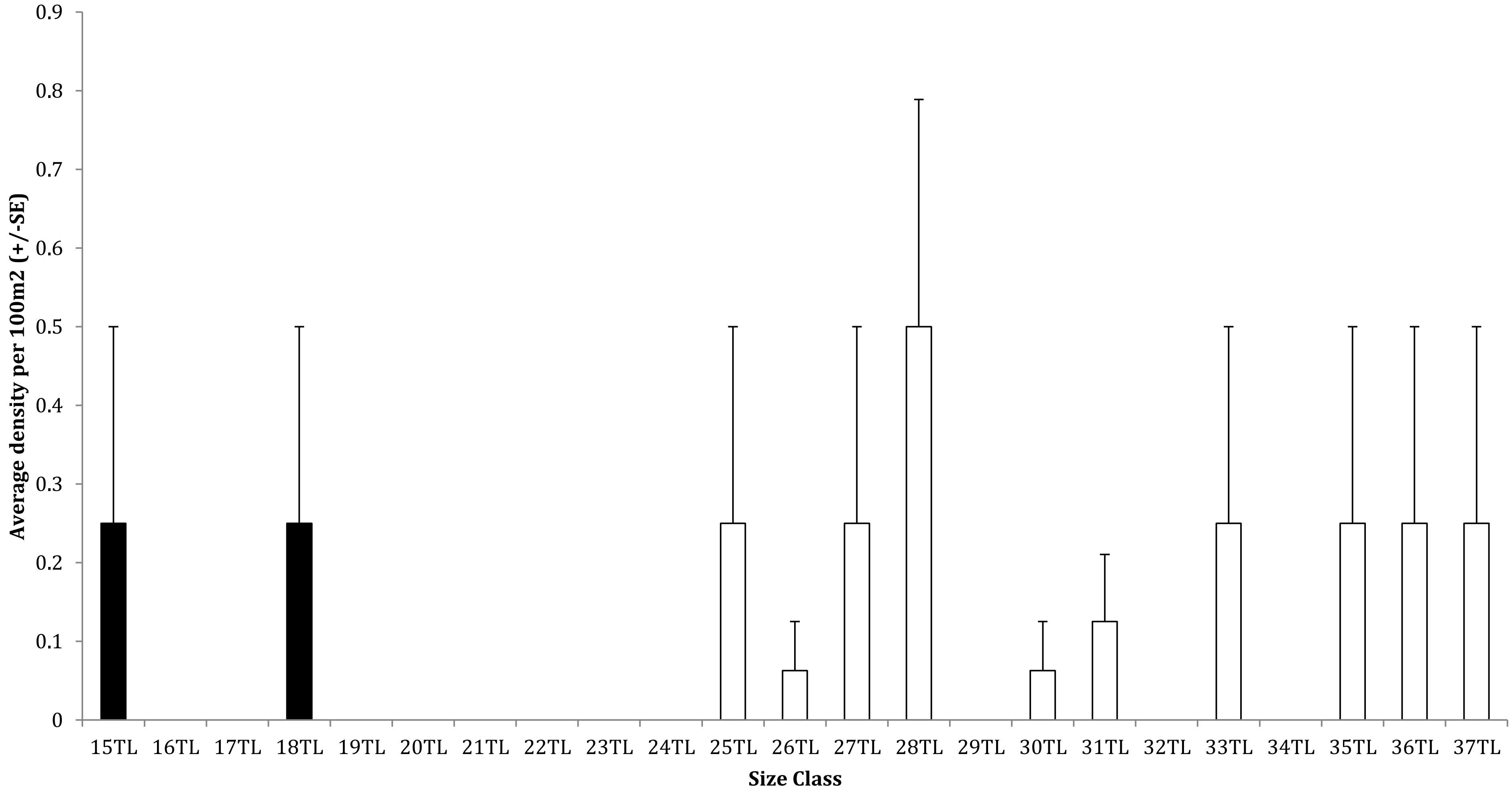


Fig 5 Average density of sandfish size classes within 100m^2 transects in deep sand/silt habitat (≥3m). Black bars signify juvenile sized individuals (≤21cmTL); white bars signify adult sized individuals (≥22 cmTL). Juvenile (≤21cmTL) and adult (≥22cm TL) sandfish (± SE) Black bars signify juvenile sized individuals (≤21cmTL); white bars signify adult sized individuals (≥22 cmTL). Note: no sandfish were found within transects at both Locha and Ndrova.

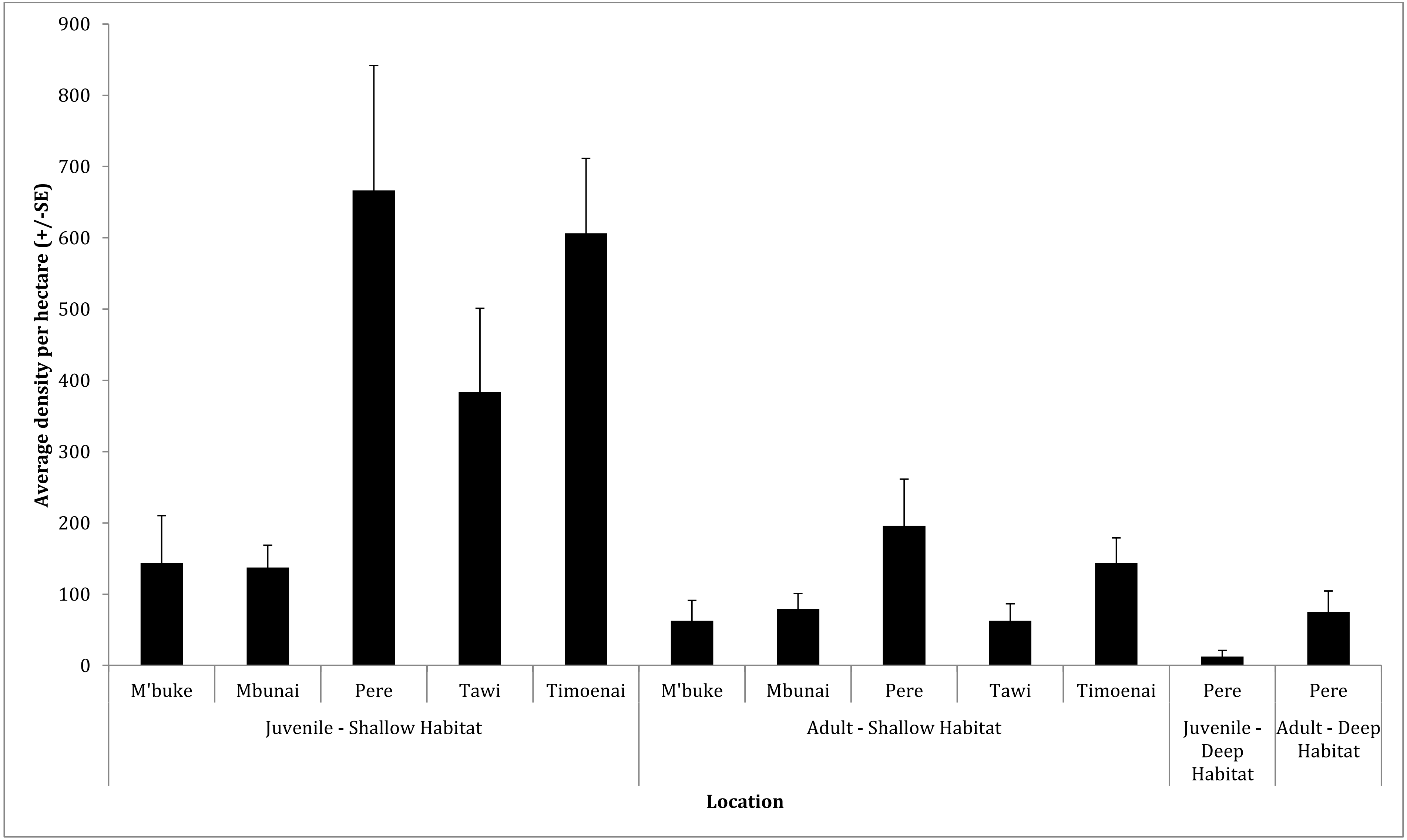


Fig 6 Density per hectare (± SE) of juvenile (≤21cmTL) and adult sandfish (≥22cm TL) within shallow seagrass habitats (≤2m) and deep sand/silt habitats (≥3m). Note: no sandfish were found within transects at both Locha and Ndrova.

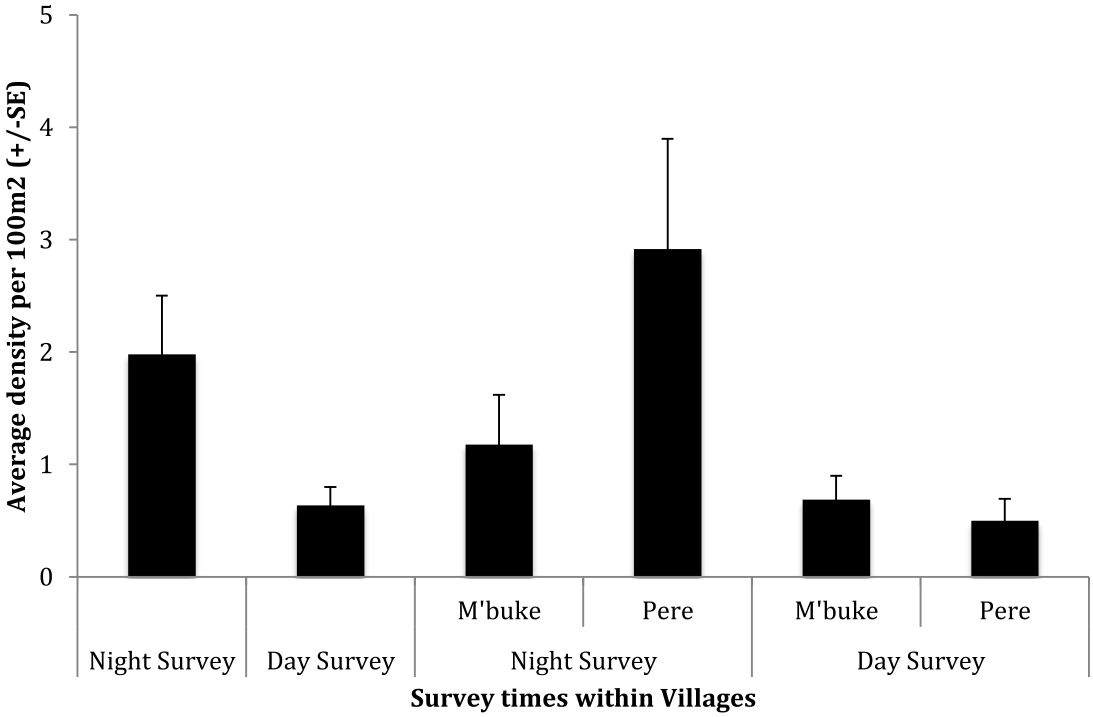


Fig 7 Average density of sandfish (± SE) in shallow seagrass habitat within 100m^2 transects during both night-time (i.e., surveyed between 2000 and 0100) and day time (i.e., surveyed between 1500 and 1600). Note: 'Night Survey' and 'Day Survey' correspond to the average density per 100m^2 across all transects when lumped, while 'M'buke Night Survey', 'Pere Night Survey', 'M'buke Day Survey' and 'Pere Day Survey' correspond to the average density per 100m^2 of sandfish within each village.

2.5 Estimate of total population

To provide an estimate of the total populations of sandfish within each village, we quantified the total area (per m^2) of suitable sandfish habitat present within each village. We did this by having fishers use their local knowledge to demarcate seagrass and deep sandfish habitat on satellite images of their reefs, a process known as 'participatory mapping'. These locally identified features were then digitised in Arc GIS, enabling the total area of habitat(s) to be calculated for each village (Fig 8). Within each village 'suitable' habitat encompassed areas of "shallow seagrass" (dense seagrass habitat predominantly holding juvenile individuals, with sparse densities of adults), "sparse seagrass" habitats (which were areas predominantly holding sparse juvenile and adult sandfish densities) and "deep silt/sand" habitat (which predominantly held adult sandfish).

We estimated that within Pere there was over 4 million m^2 of shallow seagrass (4,628,175.09 m^2), over 3 million m^2 of sparse seagrass (3,987,971.01 m^2) and over 1 million m^2 of deep sand/silt habitat (1,130,571.80 m^2) (Table 4). Timoenai and Mbunai also held a substantial area of suitable habitat for sandfish, encompassing over 1.5 million (1,532,091.10 m^2) and 1.1 million m^2 (1,000,752.93 m^2) of shallow seagrass, respectively (Table 4). Shallow seagrass habitat was also estimated for Tawi (791,301.98 m^2), M'buke (781,064.28 m^2) and Locha

(260,141.14 m^2). Deep sand/silt habitat was estimated for Mbunai (30,963.32 m^2), Timoenai (1,051,769.26 m^2) and Tawi (527,204.34 m^2).

Using the estimates of total suitable habitat within each village, we then estimated the total number of juvenile and adult sandfish in the total available habitat (i.e., Shallow seagrass, Sparse seagrass and Deep sand/silt habitats) within each village (Fig 9, Table 4). This showed that the highest numbers of juvenile sandfish were found in the shallow seagrass habitats in Pere (179,341 juveniles across total area ± 39,329 SE) and Timoenai (61,922 juveniles across total area ± 14,000 SE). A large number of juvenile sandfish were also estimated within the total area of sparse seagrass habitat at Pere (61,632 juveniles across total area ± 22,772 SE), while a low number of juveniles were estimated to be in the deep sand and silt habitats within Pere (2,826 juveniles across total area ± 2,826) (Fig 9, Table 4). Estimates of total juvenile numbers within the shallow seagrass throughout all other villages were substantially smaller: M'buke (6,415 juveniles across total area ± 3,034 SE), Mbunai (8,256 juveniles across total area ± 1,958 SE), Tawi (15,166 juveniles across total area ± 4,980 SE) (Fig 9, Table 4).

Estimates of the number of adult sandfish in the seagrass were considerably lower than those for juvenile sandfish (Fig 9, Table 4). Pere (2,472 adults across total area ± 854 SE) and Timoenai (14,682 adults across total area ± 3,743 SE) held the highest estimated numbers of adults in the shallow seagrass, while low numbers of adult sandfish were also apparent within M'buke (2,789 adults across total area ± 1,283 SE) and Mbunai (4,753 adults across total area ± 1,340 SE). Sparse seagrass habitats within Pere held moderate numbers of adult sandfish (9,139 adults across total area ± 2,966 SE), while low numbers of adults were apparent within the deep sand/silt habitat within Pere (4,441 adults across total area ± 1,575) (Fig 9, Table 4).

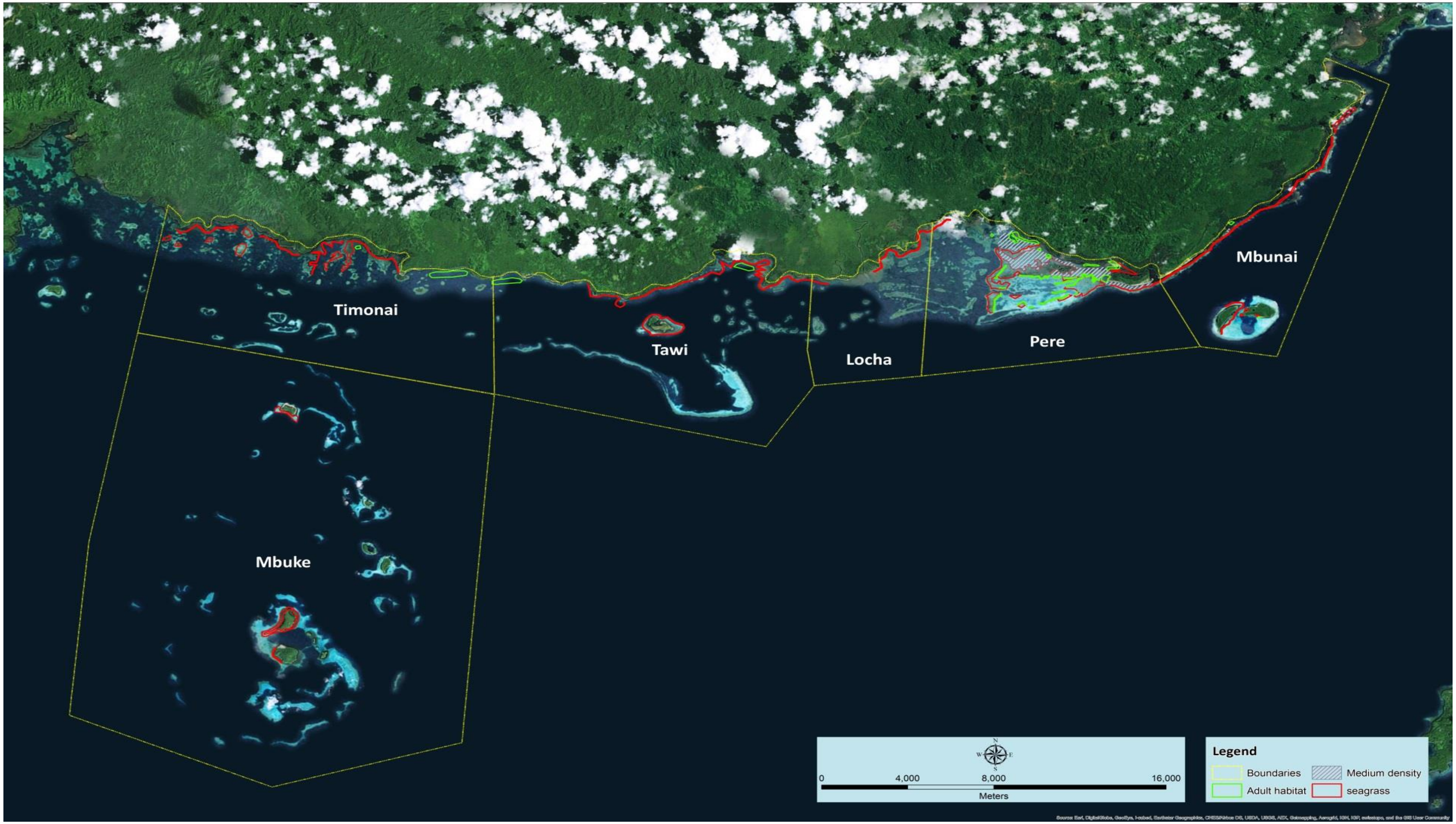


Fig 8 Satellite map of suitable habitat for sandfish throughout the southern Manus coastline. See legend for details of each habitat quantified.

Table 4 Estimate of total suitable sandfish habitat within each village across the southern Manus coastline and total number of juvenile and adult sandfish in the total available habitat (encompassing Shallow seagrass, Sparse seagrass and Deep sand/silt habitats where surveyed).

Village	Habitat Type	Area m^2	Total estimated number of juvenile sandfish	Total estimated number of adult sandfish
Locha	Shallow seagrass	260,141.14	-	-
M'buke		781,064.28	6,415 ± 3,034 SE	2,789 ± 1,283 SE
Mbunai		1,000,752.93	8,256 ± 1,958 SE	4,753 ± 1,340 SE
Pere		4,628,175.09	179,341 ± 39,329 SE	46,595 ± 12,878 SE
Tawi		791,301.98	15,166 ± 4,980 SE	2,472 ± 854 SE
Timoenai		1,532,091.10	61,922 ± 14,000 SE	14,682 ± 3,743 SE
Pere	Sparse seagrass	3,987,971.01	61,632 ± 22,772 SE	9,139 ± 2,966 SE
Mbunai	Deep sand and silt	30,963.32	-	-
Pere		1,130,571.80	2,826 ± 2,826	4,441 ± 1,575
Tawi		527,204.34	-	-
Timoenai		1,051,769.26	-	-

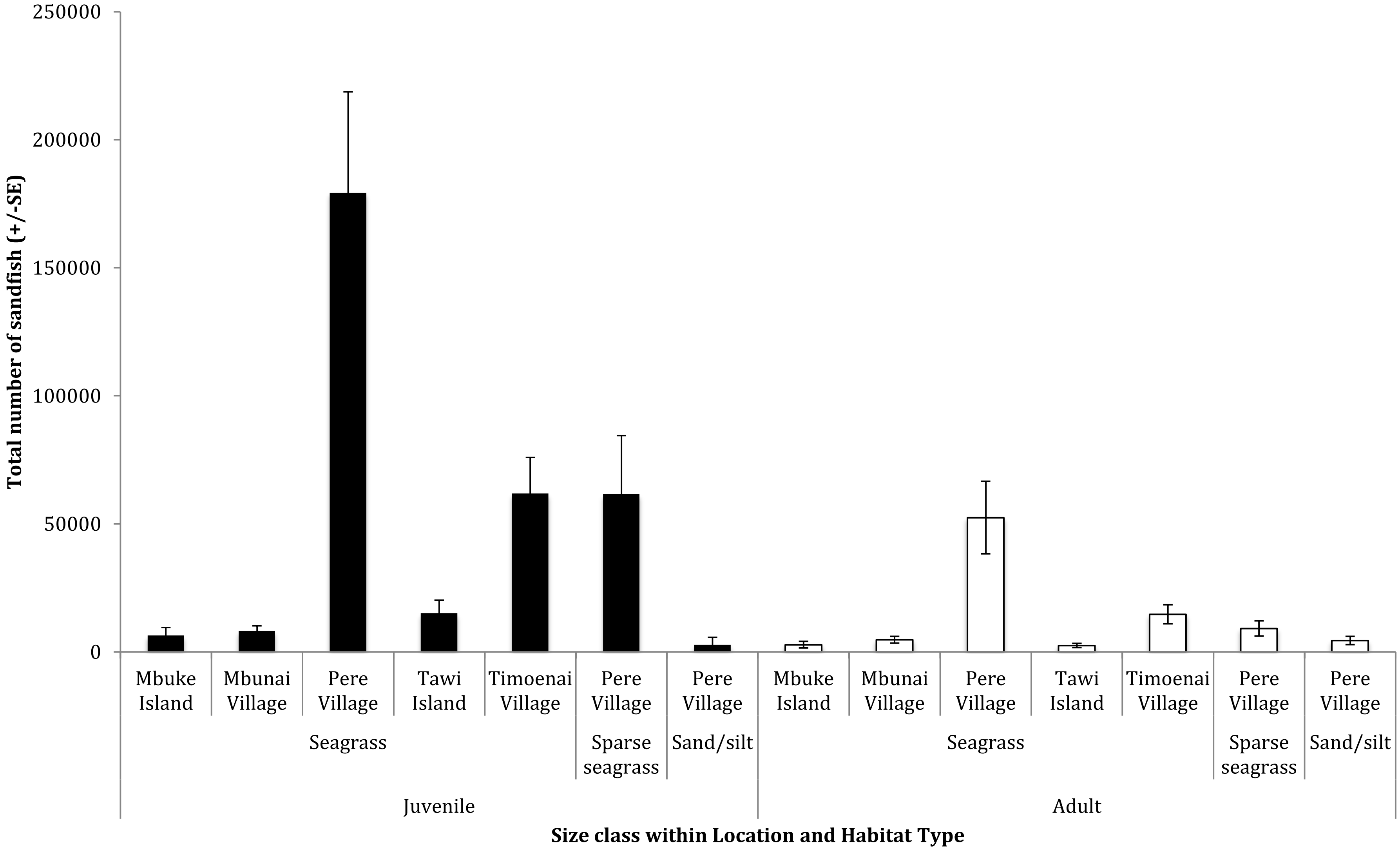


Fig 9 Estimate of total number (± SE) of (Juvenile [black box], Adult [white box]) sandfish across full extent of suitable area within each village (M'buke, Mbunai, Pere, Tawi, Timoenai), within each of three Habitat types (Shallow seagrass, Sparse seagrass, Deep sand/silt). Note: no sandfish were found within transects at both Locha and Ndrova.

2.6 AVERAGE MARKET VALUE OF ADULT SANDFISH WITHIN PERE: SHORT CASE STUDY

To estimate the total legal value of adult sandfish throughout Pere we did the following. Firstly, we determined the total number of adults sized individuals (individuals ≥22 cmTL, Grade A) within shallow seagrass, sparse seagrass and deep sand/silt habitats. To convert these population estimates to total sea cucumber wet weights (kg), we developed a length (mm) to weight (g) conversion for *H. scabra* by collecting and measuring length (mm) and weight (g) of 415 individual sea cucumber from Pere, encapsulating individuals from shallow seagrass and deep sand/silt habitats (Fig 10). The minimum and maximum lengths of individuals measured were 110mm and 430mm, respectively, with an average length of 218mm (± 3.08SE)

The quadratic equation developed was in the form of:

$f = y0+a*x+b*x^2$, where f = weight (g), y0 = 25.8394. a = -1.7615, b = 0.0129.

This conversion factor was calculated for each individual sandfish surveyed, with all estimated weights then divided by 1000 to convert to kg. In order to convert total wet weights (kg) of adults per habitat to processed (i.e., bêche de mer) BDM weights (kg) we divided by a factor of 20, since processed sandfish are 5% of their wet live weight (Purcell et al 2009a). Finally, we multiplied the total processed BDM weights by US$90, that being the mean price paid (per kg) to fishers for this processed product in the Pacific (Crick et al 2013).

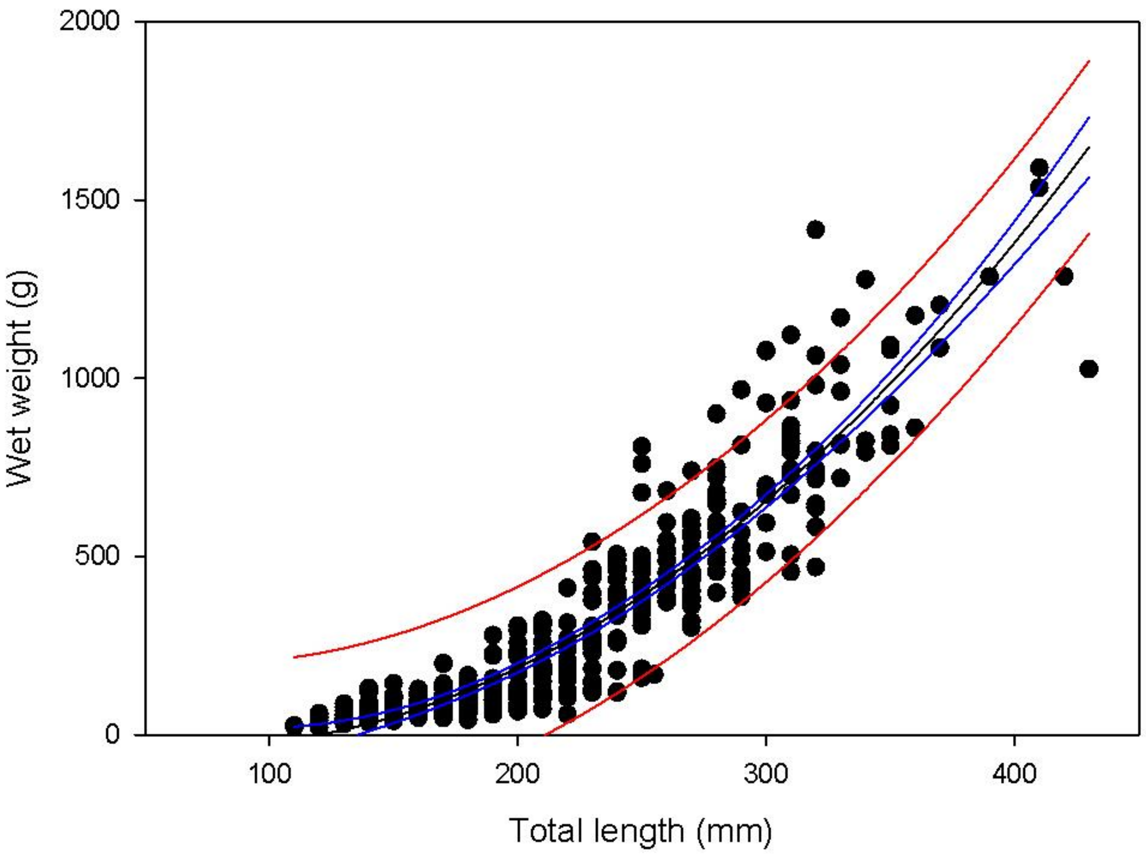


Fig 10 Relationship between total length (mm) and wet weight (g) for unprocessed sandfish within Manus coastline (n = 415 individuals, adjusted R^2 = 0.86). Blue lines are 95% CI around mean, red lines are 95% prediction values.

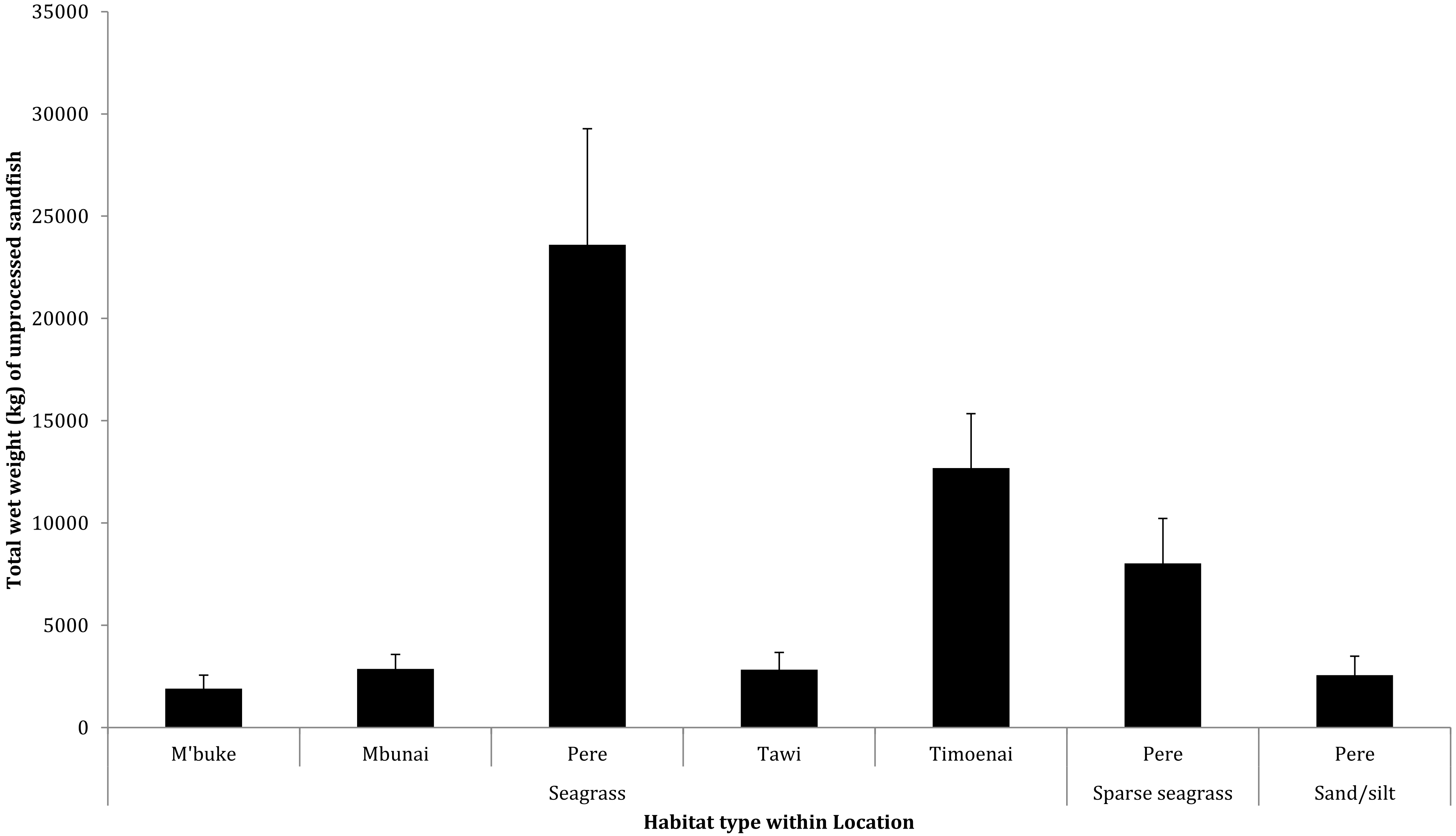


Fig 11 Estimate of total wet weight (unprocessed) of adult sandfish (≥22cm TL) found throughout total suitable habitat within villages, between each of three habitats types (Shallow seagrass, Sparse seagrass, Deep sand/silt). NB. No sandfish were found within Locha Village or Ndrova Island.

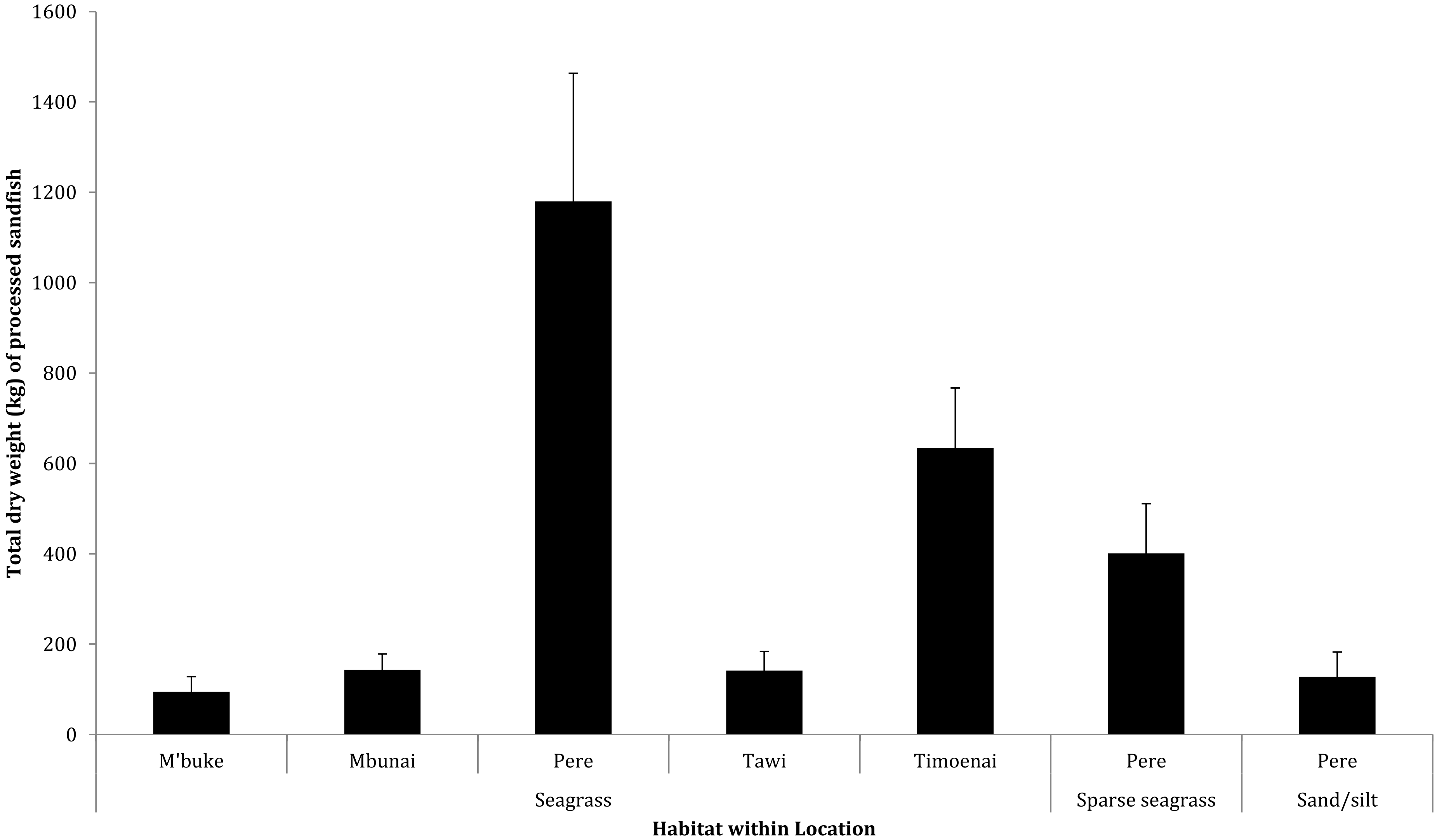


Fig 12 Estimate of total dry weight (processed) of adult sandfish (≥22cm TL) found throughout total suitable habitat within villages, between each of three habitats types (Shallow seagrass, Sparse seagrass, Deep sand/silt). NB. No sandfish were found within Locha Village or Ndrova Island.

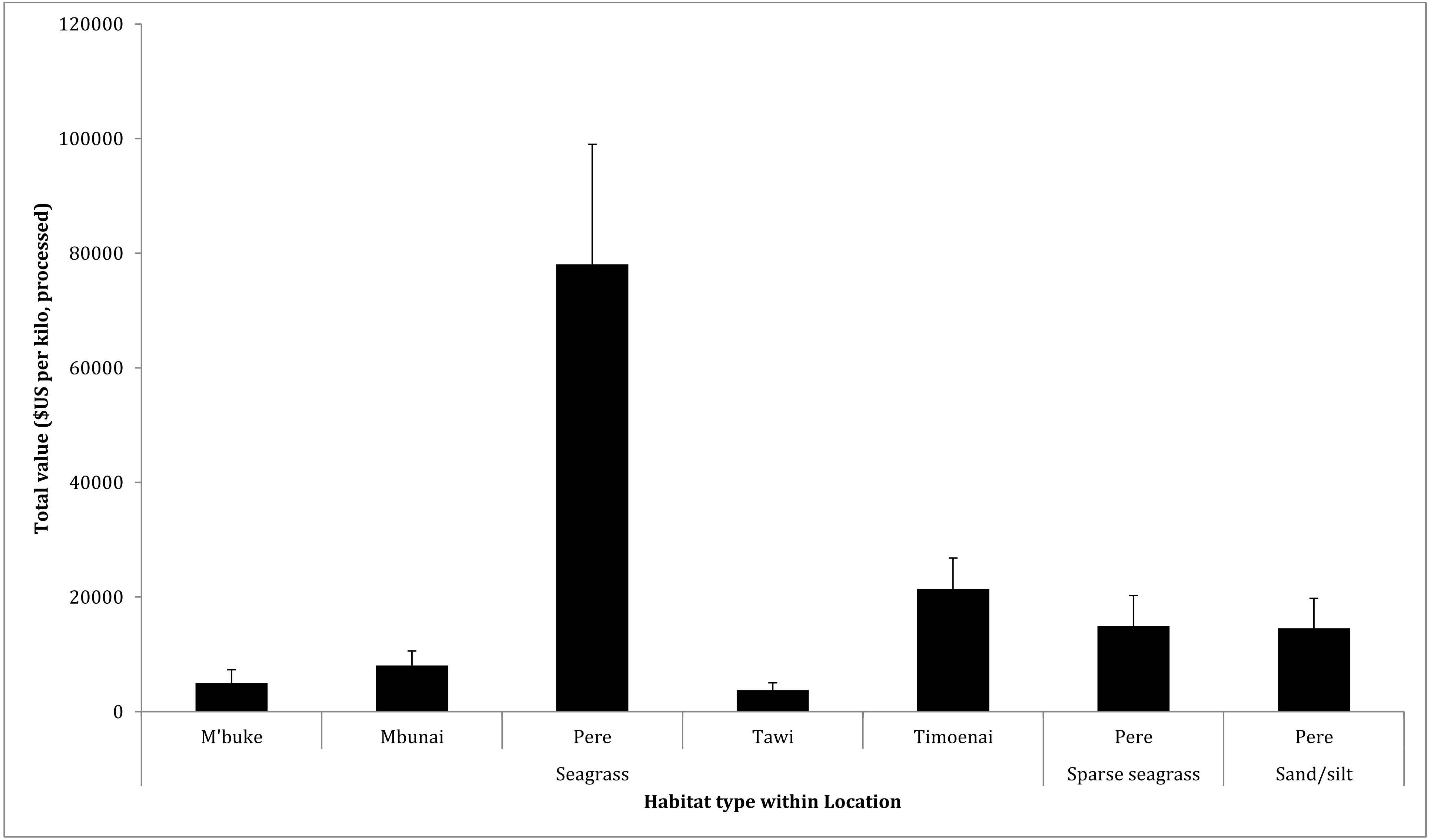


Fig 13 Estimate of total value (USD per kilo processed) of adult sandfish (≥22cm TL) found throughout total suitable habitat within villages, between each of three habitats types (Shallow seagrass, Sparse seagrass, Deep sand/silt). NB. No sandfish were found within Locha Village or Ndrova Island.

There were substantial differences in estimates of total wet weight (kilogram [kg] unprocessed adult sandfish), total dry weight (kg, processed adult sandfish [bêche de mer]) and the approximate retail value of processed adult sandfish (using US$90 per kilo: Crick et al 2013) between villages and habitat types (Figs 11, 12, 13). The largest harvestable populations were estimated to be present within the shallow seagrass within Pere (23,596 kg wet weight of sandfish ± 5,674 SE), which represents approximately 1,179 kg of processed bêche de mer (± 284 SE) and is estimated to be worth US$78,058 (± 20,945 SE). Pere also held the only area of sparse seagrass surveyed, which held an estimated 8,017 kg wet weight of sandfish (± 2,199 SE), which represents approximately 400 kg of processed bêche de mer (± 110 SE) and is estimated to be worth US$14,916 (± 5,368 SE). Lastly, the deep sand/silt habitats were also only surveyed within Pere, and held an estimated 2,554 kg wet weight of sandfish (± 932 SE), which represents approximately 127 kg of processed bêche de mer (± 54.7 SE) and is estimated to be worth US$14,547 (± 5,216 SE). Although all other villages and habitat types held substantially lower densities of harvestable populations, relatively high densities of sandfish were apparent within the shallow seagrass in Timoenai (12,677 kg of sandfish ± 2,664 SE), which represents 633 kg of processed bêche de mer (± 133 SE) with an estimated total worth of US $21,413 (± 5,394 SE). M'buke held 1,894 kg of adult sandfish (± 668SE) within the shallow seagrass habitat, which represents 94 kg of processed bêche de mer (± 33 SE) with an estimated total worth of US $5,007 (± 2,291 SE), Mbunai held 2,860 kg of adult sandfish (± 710 SE) within the shallow seagrass habitat, which represents 143 kg of processed bêche de mer (± 35 SE) with an estimated total worth of US $8,081 (± 2,487 SE), while Tawi held 2,830 kg of adult sandfish (± 842 SE) within the shallow seagrass habitat, which represents 141 kg of processed bêche de mer (± 42 SE) with an estimated total worth of US $3,774 (± 1,272 SE) (Figs 11, 12, 13)

2.7 Discussion

Survey results demonstrate that sandfish populations were dominated by small size classes; that is, small juveniles (adults that are presumed to be sexually immature, Lokani 1990). Therefore, because harvesting of sea cucumber has not occurred since (at least) 2009, there is sign of substantial recovery in small size classes. Furthermore, discussions with local fishermen suggested that all major exports of sandfish within the surveyed area had been undertaken in 2007 – no major collections and export of sandfish products had occurred since at least this time. This then suggests that the size structure of sandfish surveyed within this work may be dominated by individuals that have not been subjected to harvest since 2007/2008 (7 to 8 years post harvesting). Although there is still little available evidence on the growth rates of sandfish (and the majority of commercial sea cucumber species), we predict that the relative dominance of the 15-20cmTL sizes throughout the villages may be associated with the impact of harvesting of sea cucumbers within this region.

2.8 Density and size structure of sandfish populations

The density of sandfish identified in this survey between villages should not be considered exhaustive, but provides a good indication of the relative abundance of this species and the structure of populations across the across the seven Customary Marine Tenure areas within the Manus E Ndras Tribal Network. Within this work we showed that there are substantial differences in the average density per hectare of sandfish between villages. However, within several locations (i.e., Pere, Timoenai and Tawi), average densities per hectare of juveniles are relatively high (from 383 to 666 individuals per hectare), and are on par with areas that have begun experimental, small scale fishing (i.e. Warrior Reefs), where the estimated average density for legal sized (>18 cm) sandfish was 388.3 (± 48.3 SE) sandfish per hectare (Murphy et al 2012).

The survey results show the impact of high levels of historical harvesting of sandfish prior to 2009. The average density of sandfish for several villages was reasonably high (when compared to historical surveys of sandfish in Papua New Guinea, Lokani 2001), but much of the sandfish remaining on the reefs of Manus are young adults, and are considered recently recruited into the fishery. As in historical surveys within the region (Lokani 2001) the dominant sizes of sandfish surveyed was approximately 20 cm TL, with very low densities of large sandfish (>30cmTL). Such population structure will be associated with the relatively slow growth of sandfish (Hamel et al. 2001), in addition to fishing practices that preferentially target large sizes of sandfish. Such results are in parallel with both Lokani (1995) and Skewes et al. (1998) who found that sea cucumber harvesting within the Warrior Reefs (Torres Strait area) initially targeted large sizes of sandfish, moving to smaller sizes as larger sizes were depleted.

There were substantial differences in the density of sandfish observed in day and night surveys, with significantly more individuals – more than twice as many – observed at night. This difference in density is expected to be due to the burrowing nature of sandfish; both juvenile and adult sandfish are known to burrow during the daytime, and re-emerge at night to feed. Although there is a substantial primary literature that has documented the nocturnal behaviour of sandfish (Purcell 2010), we could find no ecological surveys of sandfish (or any other sea cucumber species) that have quantified individual densities throughout night hours. Although night surveys can present logistical difficulties, we suggest that their inclusion into stock assessments would improve accuracy in determining stock status. For example, combining day and night surveys of the same area would allow for a correction factor to be applied to day surveys to obtain a truer measure of sandfish density in an area.

2.9 Recommendations

1. Based on the positive indication for stocks within Manus, small levels of fishing could occur in the future.
2. We recommend that there is an implementation of some permanent closures in deep habitats (sand/silt habitats) to protect the largest and most productive of the primary spawning stock
3. We recommend that fishing of sea cucumbers should be restricted to only harvesting individuals that are larger than the minimum size for (estimated) maturity (21cmTL) (following Lokani 1990)

4. We recommend that the NFA re-impose seasonal harvesting rules, which only allow harvesting to occur periodically.
5. We recommend that the estimates of adult abundances (reported within the present study) are utilised when harvesting resumes within Manus, and not more than 50% of this adult abundance is removed annually
6. We recommend that before harvesting resumes within Manus, sandfish density surveys are undertaken again by locally trained surveyors, and undertaken on a regular basis once harvesting is underway. Once density fall below 50% of the pre harvest densities then all harvesting should be stopped. Harvesting should then only be resumed once density estimates reach above 50% of the pre harvest densities.
7. We recommend that there is an increase in the number of surveys of sandfish at night (to balance and adjust daytime averages)
8. Assessments of the status of sandfish stocks throughout Manus should be undertaken yearly or bi-yearly utilising both NFA staff members and trained local fishers.

Part 2: Connectivity Research – Preliminary results of fieldwork

3. Aim of Work: Determine the spatial scale of larval dispersal and its role in replenishing local stocks of the commercially important sea cucumber, sandfish (*Holothuria scabra*), within and across tribal boundaries along the southern coastline of Manus Island.

Fisheries replenishment depends on juvenile recruitment, however sea cucumber populations produce planktonic larvae that have the potential to disperse widely before recruiting to benthic habitats. Despite this, throughout PNG fisheries management is beginning to be decentralized, with management now focusing on the spatial scale of small Customary Marine Tenure areas, often consisting of just a few hundred hectares of habitat. Therefore, a key concern for PNG fishers is the degree to which their local actions may (or may not) contribute to the replenishment of their own stock, but also how actions in adjacent (neighbouring) areas may impact their stock. A local- or provincial-level network of communities that cooperatively make management decisions across an area encompassing several Customary Marine Tenure areas, such as the Manus E Ndras Tribal Network, could – depending on patterns of larval dispersal – solve the problem of unequal burdens and benefits on communities.

The focus of this work will be to determine the spatial scale of larval dispersal—the dispersal kernel— of sandfish throughout the seven tribal regions that make up the Manus E Ndras Tribal Network at southern Manus Island, Manus Province. This work utilizes recent advances in genetic parentage analysis and will provide the first direct measurements of larval dispersal, and the first direct estimates of how the probability of larval dispersal varies as a function of distance, in a commercially important invertebrate (see Almany et al. 2013 for detailed methods). This work will play a critical role in determining the spatial scale over which decentralized management strategies are likely to be effective in sustaining viable sea cucumber populations, who benefits from such management strategies, and the degree of cooperation necessary among neighbors within the southern Manus Province for the fishery to be sustainable.

3.1 Methods and preliminary results of sampling

We examined the degree of self-recruitment into, and larval dispersal out of, sandfish (*H. scabra*) populations resident within Pere (Patusi Bay) across the southern Manus coastline (Fig 11). Between May 19 and June 22, 6,465 individual sandfish were collected and a small (2cm X 2cm) piece of body wall tissue collected. Within Pere both adult (i.e., ≥ 22cmTL: 2,094 individuals) and small juvenile individuals (i.e., ≤15 cmTL: 1,294 individuals) sandfish were collected and tissue excised (Table 5). Juvenile sandfish were similarly sampled from 57 sites from a broad area around the source population (Pere, where adults were sampled) stretching 15km to the west of Pere (i.e., Pamachau Island), 38km east of Pere (i.e., Timoenai) and 21 km south of Timoenai (i.e., M'buke).

Although juvenile (non-mature) sandfish within Papua New Guinea have been categorized as being ≤21cm TL (Lokani 1990), maturity can occur within sandfish from 17cmTL to 21cmTL

(Hamel et al 2001). As the goal of the present work was to sample juveniles that were highly unlikely to have matured, we chose to restrict all juveniles' samples to individuals' ≤15 cmTL.

Each sandfish collected was measured (mouth to anus), and all tissue samples were preserved in 98% ethanol. All individual sandfish were then placed back within the habitat from which they were collected. Tissue samples were sent to the King Abdullah University of Science and Technology (KAUST), Saudi Arabia for genetic parentage analysis. This analysis is on-going and we estimate that the connectivity data will be available by the middle of 2016.

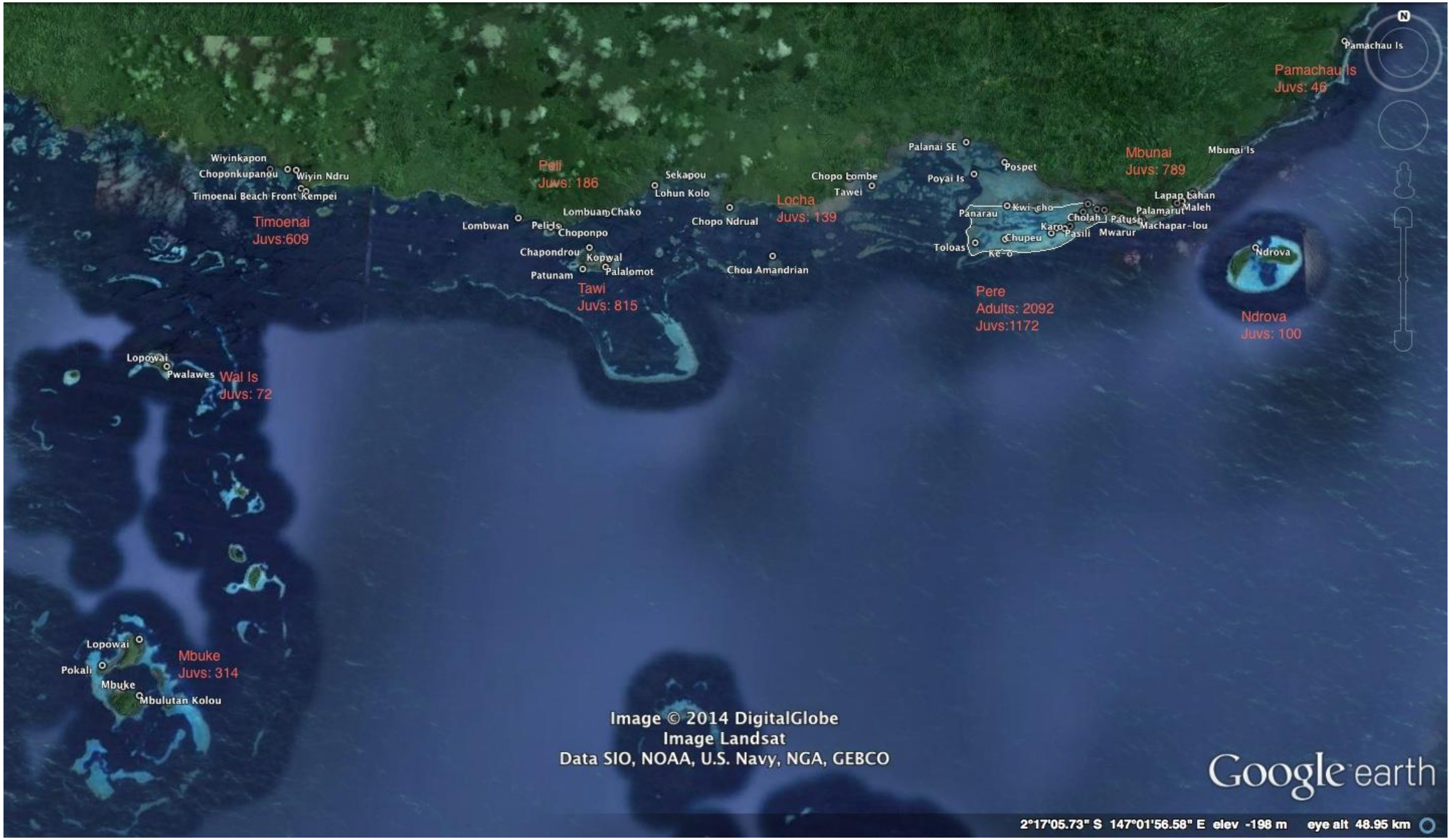


Fig 14 Map of sampled areas for sandfish (*H. scabra*) tissue, with village and site names. The village name and the numbers of both adult and juvenile samples collected from each village are given in red. Sites within each village from which individuals were sampled are in white.

Table 5 Village, Site, Site GPS coordinates and Total number of tissue samples collected for adult and juvenile sandfish.

Village	Site	GPS coordinates of site	Total adult tissue samples	Total juvenile tissue samples
Pamachau Island	Pamachau Island	S 02°08' 10.7", E 147°15' 48.2"		47
Mbunai	Lapap Lahan	S 02°11' 56.6", E 147°12' 07.5"		33
	Lowaya	S 02°11' 51.1", E 147°12' 11.8"		11
	Maleh	S 02°12' 02.6", E 147°11' 57.8"		175
	Mbunai 2	S 02°12' 05.8", E 147°11' 50.7"		35
	Mbunai Island	S 02°10' 52.0", E 147°13' 12.4"		72
	Mbunai Village Front	S 02°12' 04.9", E 147°11' 49.5"		173
	Palamarut	S 02°12' 18.7", E 147°11' 34.1"		290
Ndrova	Ndrova	S 02°13' 04.6", E 147°13' 31.5"		100
Pere	Cholah	S 02°12' 30.0", E 147°09' 52.8"	230	6
	Chompalamatu	S 02°12' 40.1", E 147°09' 27.8"	10	
	Chupeu	S 02°12' 50.2", E 147°09' 02.7"	3	
	Kaloundroponon	S 02°12' 16.0", E 147°10' 04.0"	36	
	Karo	S 02°12' 43.1", E 147°09' 09.9"	6	

	Ke-o	S 02°12' 59.6, E 147°08' 01.8"	95	
	Kwi-cho	S 02°12' 17.4", E 147°08' 45.6"	309	
	Machapar-lou	S 02°12' 31.2", E 147°10' 59.8"		95
	Mburis	S 02°12' 27.1", E 147°09' 35.7"	9	4
	Mwarur	S 02°12' 27.8", E 147°10' 37.2"	1	272
	Ndroponon	S 02°12' 16.8", E 147°10' 13.8"	63	30
	Palambuei	S 02°12' 20.1", E 147°09' 45.7"	3	
	Palanai SE	S 02°10' 46.1", E 147°07' 12.0"	3	
	Panarau	S 02°12' 13.5", E 147°08' 05.2"	254	
	Pasili	S 02°12' 43.7", E 147°09' 20.6"	23	
	Patusi	S 02°12' 31.1", E 147°10' 47.4"	24	230
	Pere Village Front	S 02°12' 26.3", E 147°10' 33.5"	601	336
	Poanchal	S 02°12' 30.4", E 147°11' 03.2"		321
	Pospet	S 02°11' 13.4", E 147°08' 02.7"	1	
	Poyai Island	S 02°11' 30.3", E 147°07' 21.9"	1	
	Toloas	S 02°13' 05.3", E 147°07' 22.1"	422	
Locha	Chopo Lombe	S 02°11' 36.91", E 146°04' 41.18"		3
	Chopo-Ndrual	S 02°12' 22.99", E 147°01' 57.68"		64

	Chou Amandrian	S 02°13' 28.45", E 147°02' 55.37"		71
	Tawei	S 02°11' 49.27", E 147°05' 05.99"		1
Tawi	Chapondrou	S 02°13' 21.4", E 146°58' 54.0"		271
	Kopwal Tawi	S 02°13' 36.5", E 146°59' 20.4"		32
	Lohun Kolo	S 02°11' 54.2”, E 147°00' 17.7”		91
	Lombuan Chako	S 02°12' 34.5", E 146°59' 15.3"		97
	Lombwan	S 02°12' 43.2", E 146°57' 18.8"		153
	Palalomot Tawi	S 02°13' 47.5", E 146°59' 16.1"		4
	Patunam	S 02°13' 50.9", E 146°58' 46.3"		67
	Sekapou	S 02°11' 42.2", E 147°01' 04.9"		100
Peli	Choponpo	S 02°12' 53.8”, E 146°58' 11.9”		89
	Peli Island	S 02°12' 55.0", E 146°58' 02.1"		100
Timoenai	Choponkupanou	S 02°11' 40.57", E 146°52' 07.92"		166
	Kempei	S 02°12' 06.7", E 146°52' 27.7"		150
	Kupanou	S 02°11' 40.7", E 146°51' 44.6"		172
	Timoenai Beach Front	S 02°12' 10.9", E 146°52' 34.8"		77
	Wiyin Ndru	S 02°11' 41.6", E 146°52' 19.6"		7
	Wiyinkapon	S 02°11' 28.0", E 146°51' 07.9"		40

Wal Island	Lopowai	S 02°16' 02.1", E 146°49' 32.1"		29
	Pwalawes	S 02°16' 11.0", E 146°49' 52.3"		43
M'buke	Lopowai	S 02°21' 58.99", E 146°49' 50.80"		65
	M'buke	S 02°22' 56.82", E 146°49' 36.32"		2
	Mbulutan Kolou	S 02°23' 07.39", E 146°49' 57.60"		10
	Pokali	S 02°22' 31.6", E 146°49' 07.7"		237

SECTION 2 REVIEW OF THE LITERATURE ON FISHERIES OF SEA CUCUMBER GLOBALLY AND WITHIN PAPUA NEW GUINEA

4. THE GLOBAL IMPORTANCE OF THE SEA CUCUMBER FISHERY

Sea cucumbers are harvested in over 70 countries, particularly in tropical regions, and encompass approximately 3 million fishers (FAO 2008; Toral-Granda et al. 2008; Purcell et al. 2013). Globally, 66 sea cucumber species are commonly exploited (Purcell 2010) and they are of particular importance in the Indo-Pacific (Conand and Byrne 1993; Choo 2008a; Conand 2008; Kinch et al. 2008a). Within Pacific island countries sea cucumber have historically been one of the major export commodities, worth up to USD20–50 million/year collectively and providing income to over 500,000 small-scale fishers in the western Pacific (Purcell et al. 2012). In New Caledonia and Tonga, sea cucumber export earnings recently surpassed finfish and other marine resources (Purcell et al. 2009b) and elsewhere are the leading invertebrate fishery export (Anderson et al. 2011b). The importance of sea cucumbers as sources of income for community fishers in remote villages is essentially due the ease at which they can be processed and stored. As with other coastal products (i.e., shark fin and trochus), sea cucumbers can be processed with relatively little logistic difficulties, with boiling and salting of the skin the main processes underlying processing (Purcell et al 2014). In addition, the processed tissue (in their dried bêche-de-mer form) is one of the few products that can be stored without refrigeration until they can be brought to a buyer (Purcell et al 2014).

Sea cucumbers have been utilized as food and medicinal products by the Chinese and other Asian cultures for centuries (Conand 1990, 2006a, 2006b). Markets within China, the Hong Kong Special Administrative Region (SAR), Singapore and the Taiwan Province of China are the predominant importers of sea cucumbers and sea cucumber products (Conand 2004, 2006b, 2008). Within these regions sea cucumbers have historically only been eaten by wealthy Asians, or served as delicacies during festive periods such as the Chinese New Year (Purcell et al. 2014). However, owing to their increased affluence and greater disposable income for luxury foods Chinese and other Asians have recently started to eat sea cucumbers more regularly (Purcell et al. 2014). Such changes in global demand have resulted in rapid inflation of prices for sea cucumbers globally, and concomitant increases in the exploitation of natural stocks (Purcell et al. 2014, see Table 1). As sea cucumbers are a luxury food item and one that is believed to have curative benefits, it is unlikely that the global market will wane over time, particularly if consumer affluence in China continues to rise (Purcell et al. 2014).

Although the prices for particular species of sea cucumber (in their dried bêche-de-mer form) are relatively hard to find, an internet search (31July2014) found prices of dried sea cucumber ranging from a minimum of US$30 per kg to a maximum of US$1,800 per kg (source: http://www.alibaba.com/showroom/sea-cucumber-price.html).

4.1 General impacts of fishing on sea cucumbers

Globally, sea cucumber fisheries have a history of being boom-and-bust fisheries (Conand 1990; Uthicke 2004; Uthicke et al. 2009). The latest fisheries boom started during the 1980s and 1990s, leading to a high number of countries exporting sea cucumbers (Conand 1997, 1998) and substantial development in global harvesting (Purcell et al. 2012). However, this trend has resulted in the rapid decrease of stocks globally, especially within tropical nations (Purcell et al. 2012), forcing recent moratoria (fishery closures) in the majority of tropical exporters, including Costa Rica, mainland Ecuador, Egypt, India, Mauritius, Mayotte (France), Panama Papua New Guinea, Solomon Islands, mainland Tanzania, Tonga, Vanuatu and Venezuela (Purcell 2010). Moratoria have in turn given rise to a globally prevalent practice of illegal harvesting (Conand 2006), resulting in a number of species being listed as threatened (Purcell et al. 2014), with increasing evidence of local extinctions (Uthicke and Conand 2005; Friedman et al. 2011). Urgently needed are substantially different management paradigms and new tools to conserve and sustain the reproductive capacity of stocks globally.

Wild caught populations of sea cucumber are susceptible to rapid overfishing for two major reasons. First, the majority of sea cucumbers are found within shallow intertidal and subtidal habitats, making them easy to capture by a range of fishers, both novice and experienced (Uthicke and Benzie 2001; Bruckner et al. 2003). Second, sea cucumbers are predominantly slow growing and have relatively low recruitment rates, resulting in slow population replenishment (Uthicke et al. 2004; Bruckner 2005). In addition, at low population densities their method of reproduction (broadcast spawning), where individuals simply release gametes into the water column and fertilization is a chance event, may induce an Allee effect (Allee 1938; Courchamp et al. 1999; Uthicke et al. 2009), resulting in low or even no fertilization, population collapse and inhibition of recovery (Uthicke and Benzie 2001; Bruckner 2005). Owing to these issues, overfishing has severely decreased the global biomass of sea cucumber populations (e.g. Skewes et al. 2000; Conand 2004; Lawrence et al. 2004). Even with harvesting closures, sea cucumber stocks seem slow to recover (D'Silva 2001; Uthicke et al. 2004; Ahmed and Lawrence 2007), with time to population recovery potentially on the order of decades (Uthicke et al. 2004). Other broadcast spawning invertebrate populations that have been severely depleted, such as pearl oysters in the South Pacific, have not recovered even 50–100 years after severe overexploitation and following protection (Dalzell et al. 1996).

4.2 Management measures for sea cucumber fisheries globally

Many sea cucumber populations grow relatively slowly, and there is an increasing awareness that the majority of species populations will not support high rates of fishing, nor will they be amenable to rotational harvest-closures. For instance, growth of species like the teated sea cucumber (*H. whitmaei*) appear slow, in the order of 80–170 g yr^{-1}, with large animals able to shrink during certain periods of resource scarcity (Uthicke and Benzie 2002; Uthicke et al. 2004). For this species populations are likely to be slow to recover from moderate to high rates of exploitation (Uthicke et al. 2004). In fact, recent work has shown that a fishing rate of just 5 percent of virgin biomass per year can still lead to depletion of breeding stocks of this species (Uthicke 2004).

The majority of sea cucumber fisheries occur in tropical countries, where regulations pertaining to sea cucumber harvest are often hard to enforce (Purcell et al. 2014). However, there are some sea cucumber fisheries that have been managed successfully, including within Japan, southeast Alaska (USA) and British Columbia (Canada). Within these countries a number of management measures have been enforced which have effectively restricted the biomass of sea cucumber being harvested, including introducing fisheries laws, permits and fishery co-operatives (Japan: Akamine 2004), fishing on a 3-year rotation schedule with separate areas being left closed as controls (southeast Alaska: Clark et al. 2009), reduced quotas, added license restrictions and implemented adaptive management (British Columbia: Hand et al. 2008). However, throughout the majority of areas where sea cucumbers are fished (predominantly tropical areas) overexploitation has left stocks depleted and fishers have shifted to low-value species, leading to serial depletion. Furthermore, fisheries agencies of tropical countries often lack the technical capacity and resources to develop and adapt complex management regulations and/or to enforce them, as has been the case in the Japan, USA and Canada examples.

4.3 The importance of sea cucumbers to Papua New Guinea

With at least 26 species of sea cucumber harvested, Papua New Guinea's sea cucumber fishery was one of the most valuable inshore fisheries in the country. Up to 2007-2008 (before the current moratorium was enforced) Papua New Guinea was the third largest producer of sea cucumbers supplying the China Hong Kong Special Administration Region (SAR) and other Asian markets (Conand 2004; Kinch 2004) and accounted for roughly 10 percent of all bêche-de-mer (processed and dried sea cucumber) entering the global market.

Papua New Guinea has a long history of involvement in the sea cucumber fishery and bêche-de-mer trade, with written accounts dating exports back to the early 1800s (Kinch et al. 2007). Throughout the 1800s and into the early 1900s bêche-de-mer production for British New Guinea (later named the 'Territory of Papua' comprising the south-eastern quarter of the island of New Guinea from 1883 to 1949) and the Trust Territory of New Guinea (consisting of the north-eastern part of the island of New Guinea and a number of outlying islands) ranged from an average export of 37 to 60 tons, with peak exports between 96 to 98 tons (Kinch et al. 2007). Although bêche-de-mer production slowed between 1960 and 1985, production increased significantly from 2000 to 2008, with annual production averaging annually 556 tons, with an average value of PGK 30 million per year. Production peaked in 2007, when 795 tonnes of bêche-de-mer valued at PGK 52 million were exported.

In terms of the species being harvested, Shelley (1981) reported that seven species were being traded throughout the 1980s: *Actinopyga echinites*, *Actinopyga mauritiana*, *Actinopyga miliaris*, *Holothuria scabra*, *Holothuria whitmaei*, *Holothuria fuscogilva* and *Thelenota ananas*. In 1989, the high-valued *H. scabra* accounted for 70 percent of total bêche-de-mer exports from Papua New Guinea (Lokani, 1990). More recently, catches have shifted to mostly low-value species, particularly *Bohadschia vitiensis* and *Holothuria atra* (Kinch, 2004).

4.4 Management measures within Papua New Guinea

The need to effectively manage Papua New Guinea's sea cucumber fishery was recognized from the inception of the fishery in the nineteenth century. A closed season was attempted by the colonial government in 1881, while the 1911–1934 pearl, pearl shell and bêche-de-mer ordinance was enacted in the early twentieth century in order to prohibit the sea cucumber harvesting between the high water mark and a line drawn parallel to and 800 m distant from the high water mark (Hyndman 1993; Kinch 2004; Kinch et al. 2007; Tom'tavala 1990, 1992). In addition, in 1992, a 'Prohibition of Taking Sedentary Resources' was gazetted under the Continental Shelf (Living Natural Resources) Act, which enacted minimum legal dry size limits, as well as developing prohibitions on the use of SCUBA and hookah, as well as the use of nightlights and ships to harvest sea cucumbers.

Under the 1998 Fisheries Management Act the National Fisheries Authority (NFA) of Papua New Guinea is now responsible for the management of the country's sea cucumber fisheries. The 2001 National Bêche-de-mer Management Plan gazetted by the NFA has been developed to regulate and manage the sea cucumber fishery. This management plan superseded all previous provincial management plans, including those previously developed for Milne Bay (1998), the Western Province and Torres Strait (1995), Manus (1997) and New Ireland (2000). This plan limited the harvest of sea cucumbers and the export of bêche-de-mer from Papua New Guinea by imposing a Total Allowable Catch (TAC) within each Province and a compulsory closed season, which related to presumed peak spawning periods for the majority of species (1 October to 15 January). TACs were developed to allow the extraction of 70% of the total harvestable estimate by dry weight (converted) within each province across a single season. Sea cucumber species were divided into two groups, high and low value, with a TAC set for both groups (Kinch et al. 2008b).

Following a range of surveys throughout the country, and the high proportion of undersized bêche-de-mer being purchased by exporting companies (Friedman and Gisawa 2008), the NFA imposed a three-year moratorium on the sea cucumber fishery, with the bêche-de-mer fishery being closed in October 2009.

4.5 Current national policy framework

Under the Fisheries Management Act 1998, the National Bêche-de-mer Fishery Management Plan has now been revised (amended in 2012, endorsed by the National Management Advisory Committee in 2013, but not yet gazetted) to encompass three main goals:

1. Manage the sea cucumber fishery for the long-term economic benefit of coastal and island communities throughout Papua New Guinea;
2. Ensure the use of sea cucumber stocks is biologically sustainable and that sea cucumber populations are maintained at levels that will allow them to continue to play their role in the marine ecosystem.
3. Ensure the co-operative implementation of this Management Plan and associated governance involves the support and input from relevant government, industry, resource owners, other civil society actors and research institutions.

Although a range of changes to the management plan have occurred to endorse these three goals, the most predominant change has been the decentralization of management to the provinces, Local Level Governments (LLGs) and communities. In detail, the following management principles will be applied to the Management Plan:

1. Resource owners will be involved in the management of the sea cucumber fishery.
2. Relevant government, industry, other civil society actors and research institutions will also be involved in the management of the sea cucumber fishery and the bêche-de-mer trade.
3. The ecosystem approach to fisheries management will inform the implementation of the Management Plan.
4. Conservation of non-target species and the protection of habitats of special concern will also be taken into account.
5. Implementation of the Management Plan at all levels will take into account the latest scientific and other relevant information to refine management actions.

In such a decentralised management scheme, each partner has been designated a particular role in sustainably managing Papua New Guinea's sea cucumber resources. Firstly, the National Fisheries Authority will be responsible for formulating and implementing the revised management plan, providing resources for obtaining and analysing survey and catch data (see below, detailing such plans) and determining management measures necessary to sustain sea cucumber resources. The revised management plan lists several management measures which may be used by the NFA, including minimum size limits (see Table 6 for further details), utilising closed seasons (which have been ratified within this revised management plan to occur from 1 October to 31st March), use of total allowable catches (TAC) at the province level, capping the maximum number of exporters and buyers per province, utilising licensing criteria and having strict guidelines for licences as well as establishment of a National Management Advisory Committee (NMAC).

Table 6 Value Grade, common name, scientific name and minimum size restrictions for Papua New Guinea sea cucumbers. (From PNG National Bêche-de-mer Fishery Management Plan - Final Draft (2013) National Fisheries Authority October 2013-National Marine Advisory Council Endorsed).

Value Grade	**Common Name**	**Scientific Name**	**Live Length (cm)**	**Dry Length (cm)**
High	Sandfish	*Holothuria scabra*	22	10
High	Black teatfish	*Holothuria nobilis*	22	10
High	White teatfish	*Holothuria fuscogilva*	35	15
High	Greenfish	*Stichopus chloronotus*	20	10
High	Prickly redfish	*Thelenota ananas*	25	15

High	Surf redfish	*Actinopyga mauritiana*	(20)	(8)
High	Blackfish	*Actinopyga miliaris*	15	10
High	Curryfish	*Stichopus hermanni*	25	10
High	Stonefish	*Actinopyga lecanora*	15	10
High	Tigerfish	*Bohadschia argus*	20	10
High	Brown sandfish	*Bohadschia vitiensis*	20	10
Low	Amber fish	*Thelenota anax*	20	10
Low	Lollyfish	*Holothuria atra*	(30)	(15)
Low	Chalk fish	*Bohadschia similis*	(25)	(7)
Low	Elephant trunkfish	*Holothuria fuscopuntata*	(45)	(15)
Low	Pink fish	*Holothuria edulis*	(25)	(10)
Low	Snake fish	*Holothuria coluber*	N/A	N/A
Low	Flower fish	*Pearsonothuria graeffei*	N/A	N/A
Low	Deepwater red fish	*Actinopyga echinites*	(25)	(15)

Note: Figures in the brackets are provisional estimates only

Associated with the decentralisation of the sea cucumber management is the development of responsibility of both the Maritime Provincial Governments and Maritime LLGs in sustainably managing Papua New Guinea's sea cucumber resources. Such responsibilities include the ability to set lower TACs within each province, the development of more restrictive and longer closed seasons, as well as the option to establish Management Advisory Committees at either or both the Provincial and LLG level.

Within the revised guidelines resource owners take considerable responsibility for managing their own sea cucumber resources. In particular, resource owners will be responsible for implementing the Management Plan at their respective levels, as well as developing management strategies at their level or with the support of the LLG and Provincial governments or other civil society actors.

4.6 DATA COLLECTION IN SUPPORT OF THE REVISED MANAGEMENT PLAN

Within the revised management plan are distinct plans to conduct yearly stock assessment surveys of sea cucumber populations throughout the provinces, as well as undertake detailed socio-economic research. Such research will be undertaken at the Provincial Fisheries level, with assistance from relevant stakeholders or research organisations, and with technical support from the National Fisheries Authority. All stock assessment data will be used to refine annual Provincial TACs levels.

In addition, against baseline stock assessment and socio-economic assessments, Provincial Fisheries Administrations and the National Fisheries Authority will commission, or encourage research to identify negative environmental impacts of the sea cucumber fishery and the bêche-de-mer trade, and develop mitigation methods against them, while also monitoring the changing socio-economic profiles of the coastal and island communities as a result of the fishery and management actions.

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