FIJI'S SEA CUCUMBER FISHERY

Advances in Science for Improved Management

MINISTRY OF FISHERIES & FORESTS
"Our Forests, Our Ocean, Our Future"

Wildlife Conservation Society

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Front cover image: Staff from the Ministry of Fisheries and the Wildlife Conservation Society working with communities to monitor sea cucumber stocks inside and outside tabu areas. Photographer: Sangeeta Mangubhai/WCS

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Editors
Sangeeta Mangubhai, Watisoni Lalavanua and Steven W. Purcell

Abstract

The sea cucumber fishery in Fiji has been operating intermittently for 200 years and has incurred intense fishing pressure in the past two decades. A recent change to fishery regulations now prohibits the issuance of exemptions for the use of Underwater Breathing Apparatus (UBA) for collecting sea cucumbers. Ecological, socioeconomic, genetic, and trade studies undertaken in Fiji over the past five years reveal new insights for decisions to further improve management of the fishery. Data collected on products for export, underwater population surveys and socioeconomic surveys corroborate previous reports that sea cucumber populations in Fiji are seriously over-exploited. Abundances are very low for many species (with potential local species extinctions), the body sizes of wild stocks and harvested animals are below legal size limits and reproductive age, and fishers believe they are collecting much less per day than they did decades ago. Serious accidents of UBA divers have come at a high cost to rural communities and the national health system.

Sea cucumbers were shown to be beneficial to reef sediments, and their removal appears to diminish ecosystem health. Gene flow for one species appears to be in an east-to-west direction, so conservation of populations in the eastern islands of Fiji will likely benefit genetic diversity across the fishery. Overall, the recent studies validate the new ban on UBA in the fishery, but urge for further reforms to management. The studies provide evidence for the introduction of better minimum legal size limits, shortlists of permissible species, and limited entry requirements to reduce the number of fishers permitted to collect sea cucumbers. At the same time, management actions are needed to strengthen enforcement of the regulations, support better postharvest processing and value chains, and develop nation-wide standards for pricing of raw and dried sea cucumbers. Prompt action on these management needs will give hope to reversing the perilous status of the fishery. Inaction will likely result in loss of biodiversity and some local species extinctions, erosion of ecosystem benefits of sea cucumbers, diminished long-term performance of the fishery, and a long-term loss of a valuable livelihood resource for current and future generations of Fijians.

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Executive summary

Sea cucumbers have been harvested in Fiji for 200 years as an export commodity, and their trade is linked to the nation's history of political shifts and access to resources. Exploitation of sea cucumbers in Fiji has followed a boom-and-bust pattern, in which trade has been intense for a number of years followed by further years of comparative inactivity. Since the mid-1980s, exploitation has been intense. While Fiji's fishery has remained open, numerous sea cucumber fisheries in the Pacific Islands have been closed due to rampant overfishing. A combination of information from exports, underwater population surveys and socioeconomic surveys indicates that the current boom cycle in Fiji is nearing an end. Whether or not sea cucumbers stock will recover and provide income opportunities for future generations of Fijians will depend on decisions about resource management now.

Although the exploitation of sea cucumbers can be classified as small-scale and artisanal, the scale of harvesting in Fiji is vast and there are many thousands of fishers nationally. The long-term sustainably of the sea cucumber fishery in Fiji is of great importance to coastal communities, from both socioeconomic and ecological perspectives. Sea cucumbers play vital ecological roles in the functioning of coral reef and soft-bottom lagoonal systems.

The status and management of Fiji's sea cucumber fishery was previously reported by Pakoa et al. (2013). In that report, 27 species were recorded to be fished and exported. For many years, one of the few regulations has been a minimum legal size limit of 7.6 cm for dried products across all species. In addition, the export of high-valued sandfish, *Holothuria scabra*, has been prohibited by law. The use of Underwater Breathing Apparatus (UBA) has been banned for collecting sea cucumbers except for certain fishers operating under exemptions issued by the Ministry of Fisheries. One issue highlighted in the report was the increasing number of exemptions issued, resulting in continued intense fishing of sea cucumbers in deep waters and an unacceptably high rate of diving accidents. The report painted a grim picture of sea cucumber stocks in Fiji by revealing that some species have been effectively fished to extinction in some areas, and population densities for many other species were unnaturally very low. In order to avoid collapse of the fishery, the report urged for immediate management action consisting of a complete ban on the use of UBA (no exemptions) and a moratorium across the fishery for 5–10 years.

During the past few years, further research has been conducted in Fiji to further understand the nation's sea cucumbers and their ecological roles, value chains, perceptions and postharvest practices of fishers, societal costs of UBA, genetic connectivity and sizes of dried products in exports. This report presents this recent research and key recommendations for management actions arising from the scientific findings.

Over-exploitation of Fiji's sea cucumbers has now been corroborated from several independent studies. Firstly, underwater visual censuses of sea cucumber populations from eight locally managed marine areas (LMMAs) in Bua, Cakaudrove, Lomaiviti and Ra Provinces show that abundances of sea cucumbers in LMMAs are critically low, including in *tabu* areas (Lalavanua et al. 2017). A majority of censused *H. scabra* were immature, suggesting that over-exploitation is occurring even for this species which is supposed to be for domestic consumption only. Similarly, inspections of dried products ready for export also found that immature sea cucumbers are being harvested, suggesting that large animals are becoming difficult for fishers to find (Tabunakawai-Vakalalabure et al. 2017a). Questionnaire-based interviews of sea cucumber fishers across Fiji revealed that most fishers believe that stocks are declining or depleted (Purcell et al. 2017). Fisher knowledge suggested that catch rates have declined by one-half to three-quarters in the past decades.

There has been an alarming frequency of serious diving accidents in the fishery (Tabunakawai-Vakalalabure et al. 2017b). That study shows that around one dozen sea cucumber fishers have been admitted for hyperbaric recompression therapy annually over the past few years. An estimated annual cost to the national health system of FJ$515,000 is additional to subsequent loss income earning opportunities and social disruption in communities.

The sea cucumber fishery can also indirectly affect lagoon and coral reef ecosystems and genetic biodiversity. Since sea cucumbers eat large quantities of sediments and turn over sediment layers through daily burying, their removal from reef flats can negatively impact reef sediments, for example, through declines in oxygen availability in the sediments (Lee et al. 2017). Low densities of sea cucumbers after intense fishing appears to reduce the health of reef sediments and ultimately other reef animals. A genetic study of lollyfish (*Holothuria atra*) indicated that populations can be genetically different between different islands, and that gene flow (and hence, larval dispersal) is likely from east to west in Fiji through the Bligh waters (López et al. 2017). Therefore, over-exploitation of sea cucumber populations in eastern Fiji might affect the genetic diversity and recovery of stocks in western Fiji.

A number of key management actions are supported by the results of the recent studies. A complete ban on UBA is supported by the high incidence of diving accidents (Tabunakawai-Vakalalabure et al. 2017b), and a belief by many fishers that the use of UBA is a major cause of declining stocks (Purcell et al. 2017).

Area-based management measures could be beneficial. The genetic study by López et al. (2017) indicated that a network of marine reserves and regulations to limit overfishing will be needed in order to safeguard genetic biodiversity within the fishery. However, data from the underwater censuses by Lalavanua et al. (2017) suggest that LMMAs alone are insufficient for safeguarding viable populations. Therefore, other management measures need to be implemented to control fishing effort.

Shortlists of permissible species are a new management measure of interest to other Pacific Island sea cucumber fisheries. These could help to protect species threatened with extinction and allow fishing only for species with healthy populations (Lalavanua et al. 2017). Limited entry requirements would be the logical regulation to address concerns by a majority of fishers that the problem of declining stocks is too many fishers (Purcell et al. 2017). For example, only current fishers could be issued with a license, which would be permanently cancelled for compliance breaches or through inactivity.

Size limits need to be specific to groups of species, and not pertain to all species in the fishery. As there are at least 27 species harvested, with differing biology and body size, the current regulation of 7.6 cm for dried specimens is inadequate to protect immature individuals of all species. Better enforcement is needed for all regulations, and this has been shown to be a key determinant of sustainability in sea cucumber fisheries globally. A value-chain analysis by Mangubhai et al. (2017) suggested that enforcement of size limits at processing and exporting warehouses would have a 'trickle-down' effect throughout the fishery. There was clearly a lack of compliance by fishers and exporters on current size limits (Tabunakawai-Vakalalabure et al. 2017b), so greater investment is needed in this area.

In tandem with more robust regulations, the recent studies also urge that management institutions need to support postharvest processing and value chains in order to make the most benefit from what is removed from the sea. Middlemen, in particular, are sometimes offering unfairly low prices to fishers, and fishers do not always have access to all of the materials to process sea cucumbers using best-practice methods (Purcell and Lalavanua 2017). Mangubhai et al. (2017) found that many fishers did not know best-practice methods, and would benefit greatly from further investments in village-based training workshops on post-harvest processing. Both of these two studies concluded that the Ministry of Fisheries should develop nation-wide standards for pricing of raw and dried sea cucumbers to help ensure that fishers and local processors receive a fair price for their product.

In conclusion, the recent studies concur with the previous report by Pakoa et al. (2013) that sea cucumber stocks are over-harvested in Fiji. Fiji should consider either a long-term moratorium on fishing (e.g. 5–10 years) or will need to promptly impose more robust regulations, including more appropriate size limits, shortlists of permissible species, a complete ban on the use of UBA, and a licensing system that will slowly reduce the number of exporters and fishers in the fishery. Alongside these regulations, more investment is needed in enforcement and support to improving value chains in order that stocks are not further diminished and that current fishers make the most of what they catch.

Oneata fishers with their catch. © Watisoni Lalavanua/WCS

1 | Sea cucumber species richness and densities within locally managed marine areas

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Abstract

Sea cucumber fisheries are an important income source across the Pacific and the fishery in Fiji is the second most valuable after oceanic tuna in terms of export earnings. Previous studies found sea cucumber stocks were overexploited and depleted, highlighting the need for better management and enforcement. This study quantified stock densities and species richness in 8 locally managed marine areas (LMMAs) in Bua, Cakaudrove, Lomaiviti and Ra provinces to inform community management decisions within their customary fishing grounds. Underwater visual census surveys in 2014 and 2015 found 17 species of sea cucumbers. There were notable differences in sea cucumber densities between closed (tabu) and open areas and between study years. Most sea cucumber densities in district fishing grounds were low compared to theoretical regional reference densities suggesting that LMMAs alone are inadequate for managing local stocks. The population size structure for *H. scabra* revealed a population primarily composed of sexually immature juveniles suggesting that management measures, which include export bans, have not been adequate to ensure the recovery of this high-value species in Fiji.

Introduction

Fiji was the second largest sea cucumber export country in the Pacific after Papua New Guinea from 1998 to 2012, and is currently the second most economically valuable coastal fishery in Fiji after the oceanic tuna (Carleton et al. 2013). Sea cucumber fisheries in the Pacific have a long history of boom-and-bust exploitation driven by the high value of sea cucumbers in Asian markets (Kinch et al. 2008). Despite efforts by the Fijian government to control the trade with a 7.6 cm minimum (dried) size limit and a ban on export of *Holothuria scabra* (sandfish) since 1988, the sea cucumber stocks continue to decline with current densities largely below regional averages (Pakoa et al. 2013), including in more remote islands such as the Lau group (Jupiter et al. 2013). Over-exploitation in the sea cucumber fishery is mostly due to increasing market demand, uncontrolled exploitation and inadequate fisheries management arrangements including lack of enforcement (Purcell et al. 2013).

Many coastal communities have implemented local-scale management to try to improve their sea cucumber stocks within customary fishing grounds (*qoliqoli*). Seasonal fishery closures known as *tabu* areas are one of the most commonly used management tools within locally managed marine areas (LMMAs) to ensure a ready supply of fish and invertebrates for village events or fundraisers (Jupiter et al. 2014). Although pulse harvests benefit fishers in the short term, these can lead to depletion when opened if there are inadequate controls on harvests. In a multi-species fishery, such as the sea cucumber fishery, understanding changes in species richness and densities over time and between managed and open areas is essential for effective management. Conservative thresholds for stock density need to be established, communicated and enforced effectively so that stock depletion can be avoided and stocks can be maintained with sufficient breeding capacity (Pinca et al. 2010).

Baseline densities are largely unknown for most species in Fiji. There are reports of densities of the *Actinopyga miliaris* (hairy blackfish) and an unknown *Actinopyga* sp. from lagoonal habitats in Vanua Levu, ranging between 250–78,900 individuals/ha from 1998 (Friedman et al. 2011). In the absence of in-country baseline data, theoretical "regional reference densities" proposed by the Pacific Community are useful to gauge the health of the fishery in Fiji (Pakoa et al. 2013)[1].

To assess how effective *tabu* areas are as a tool to increase abundance of sea cucumber populations, in-water surveys of species richness and density were conducted both inside and outside *tabu* areas in LMMAs across Bua, Cakaudrove, Lomaiviti and Ra provinces. Where the data were available, comparisons between managed and open areas, between years and against regional reference densities were made (Pakoa et al. 2013). The results of this study can be used by communities to adapt management strategies within LMMAs to improve their fishery stocks.

Methods

Surveys of sea cucumber populations were conducted from 31 March 2014 to 21 February 2015 across Bua, Cakaudrove, Lomaiviti and Ra Provinces (Fig. 1), using a standardized protocol developed by the Pacific Community (SPC 2014). To clearly understand the stock status (i.e. species richness, density and size structure) of this multi-species fishery, assessments were conducted in open (fished) and *tabu* (closed) areas in 2014 and in *tabu* areas in 2015 using manta tow, snorkel, and SCUBA (Table 1). Where the data were available, comparisons were made between years, open and *tabu* areas and with regional reference densities.

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1 Assessments conducted by the Pacific Community (SPC) in 2002–2012, generated threshold densities for 17 species of sea cucumber, by averaging the 25% highest densities from the Pacific. These can be used as a baseline for comparison or as a reference in the case that a site has no specific site density available.

Table 1. Survey methods used in each district, the year(s) data were collected and the management status of the areas surveyed.

Province	District	Method/Year/Management Status		
		Snorkel	Manta Tow	SCUBA
Bua	Bua	2014: open, tabu	2014: tabu	
	Kubulau	2014: open, tabu 2015: tabu		2014: open, tabu
	Nadi	2014: tabu 2015: tabu	2014: open, tabu	
	Vuya	2014: open, tabu		
	Wainunu	2015: tabu		
Cakaudrove	Wailevu	2015: tabu		
Ra	Nakorotubu	2014: open, tabu		
Lomaiviti	Levuka		2014: open, tabu	2014: open, tabu

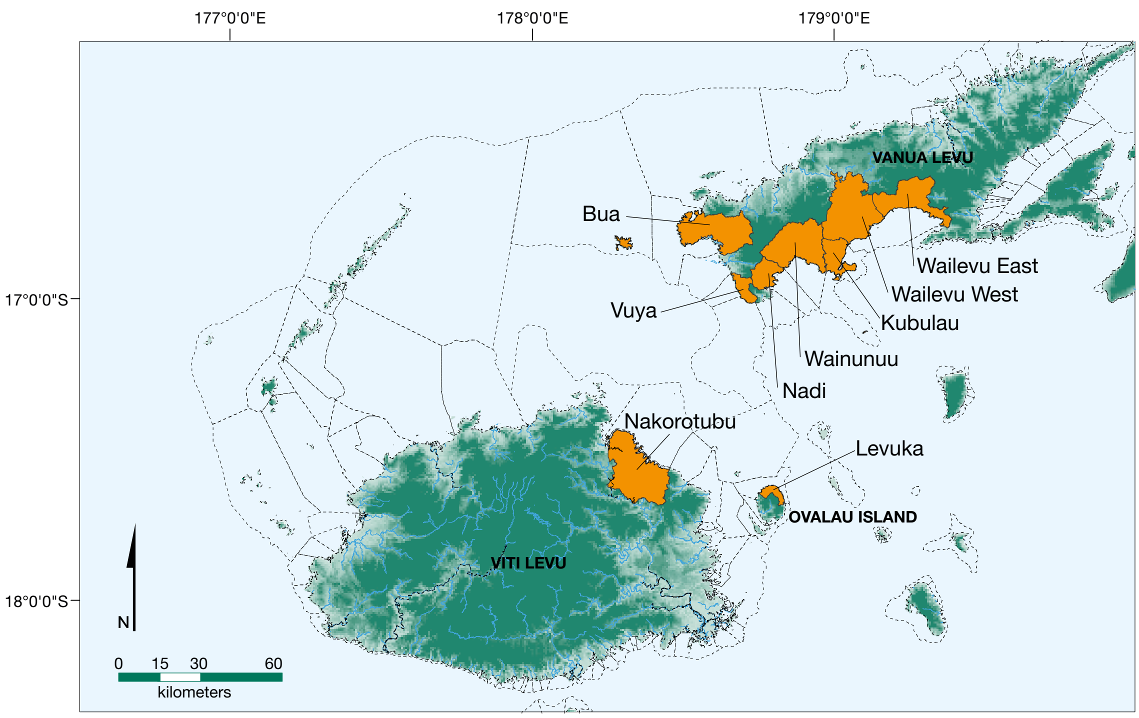

Figure 1. Districts (orange) and adjacent customary fishing grounds where sea cucumber assessments were conducted from 2014–2015.

Manta tows were used at Bua, Nadi and Levuka Districts to assess sea cucumber populations, as this method can be used for large sedentary invertebrates and habitats over a large area (SPC 2014). It involved towing a surveyor behind the boat at a low speed of less than 2.5 km/hour. The surveys were conducted in depths of 1–10 m covering coral substrates, sand and reef edges. Six manta-tow belt transects (300 m x 2 m) covering 3600 m^2 were conducted per site and the number and species of sea cucumber within transects recorded. Each transect was placed roughly parallel to the reef edge, and a handheld GPS (global positioning system) was used to calculate transect length.

Shorter belt transects were used at the majority of sites to collect data on the numbers, species and size of sea cucumbers (measured to the nearest 0.5 cm) on snorkel or SCUBA, using methods described in SPC (2014). These sites were mainly closer to shore with higher densities of sea cucumbers. Six benthic transects (40 m x 1 m) covering a total area of 240 m^2 was completed per site (Table 1).

Results

Species richness

Despite finding a total of 17 species across the four provinces of Bua, Cakaudrove, Ra and Lomaiviti, the majority of sites had less than 10 species present. Species richness was highest in Kubulau and Nadi, each with 10 species, and lowest in Nakorotubu with only 5 species (Table 2). In general, with the exception of *H. scabra*, low and medium-value species were more commonly found across all districts compared to high-value species. Changes in species richness were observed in Nadi District which recorded 7 species in 2014 and 10 species in 2015, while Kubulau District recorded 8 and 4 species in 2014 and 2015 respectively.

Density

Given that three different methods were used to measure density, these are presented separately (Tables 3–7). For sites surveyed on snorkel, the highest density recorded was for *H. atra* (lollyfish) in the *tabu* area in Vuya District (1250 animals/ha, Table 3). This species was well below regional reference density of 5600 animals/ha across all sites. In Kubulau, species densities were higher in *tabu* areas compared to open areas. However, there were mixed results for the districts of Bua, Nakorotubu and Vuya, with some species having higher densities within *tabu* areas and others in the areas open to fishing. All species densities in Bua District were below SPC regional reference densities. However, for other districts the results varied, with some species recording higher or lower densities compared to regional reference densities.

For sites surveyed on SCUBA, the study found *tabu* areas in both Kubulau and Ovalau had mostly higher densities of sea cucumber species when compared to open areas (Table 4). The two exceptions were *S. chloronotus* (greenfish) in the open area of Ovalau, and *Pearsonothuria graeffei* (flowerfish) in the open area of Kubulau; both species of which were not present in *tabu* areas. All densities calculated from the manta-tow data were below the regional reference densities (Table 5). Nakorotubu was the only site with a *tabu* and open area comparison; species in the *tabu* area had higher densities than in the open area.

Data for comparison between years were only available for *tabu* areas in Kubulau and Nadi (Table 6). In Kubulau species densities were higher in 2014 compared to 2015. Just over half the species had densities below regional reference densities. In Nadi, the average density increased for some species between years (e.g. *H. scabra*, *Bohadschia marmorata* chalkfish), while decreased for other (e.g. *H. coluber* snakefish, *Stichopus herrmanni* curryfish). Species such as *H. scabra* were found to have densities higher then regional densities in some years, and in other years lower (Table 6). *H. atra* decreased between years in both Kubulau and Nadi, and densities were well below the regional reference density of 5600 animals/ha.

Size structure

The only species with sufficient size data available to assess size structure were *H. scabra* from the Wailevu District and *S. horrens* (dragonfish) from Nadi District. The *H. scabra* population was dominated by juvenile, sexually immature *H. scabra* and 74% of the animals recorded were below the size-at-first-sexual-maturity of 16 cm (Conand 1990) (Fig. 2).

Table 2. Sea cucumber species present in *tabu* (T) and open fishing areas (F) across all sites and methods in 2014–2015. Blanks indicate no individuals of that species recorded. H, M, L = High, Medium, Low-value species.

Species	Common name	Local name	Value	Bua	Kubulau	Nadi	Vuya	Wailevu	Wainunu	Nakorotubu	Ovalau
Holothuria fuscogilva	White teatfish	Sucuwalu	H								
Holothuria scabra	Sandfish	Dairo	H		T	T	T F	T	T		
Holothuria whitmaei	Black teatfish	Loaloa	H								T
Thelenota ananas	Prickly redfish	Sucudrau	H								T
Holothuria lessoni	Golden sandfish	Dairo kula	H								
Actinopyga mauritiana	Surf redfish	Tarasea	H								
Stichopus herrmanni	Curryfish	Laulevu	M	T	T	T		T			
Stichopus horrens	Dragonfish	Katapila	M			T		T			
Stichopus chloronotus	Greenfish	Dri-votovoto, Barasi	M	T	T					F	T F
Bohadschia argus	Leopardfish	Vula wadrawadra	M		T		F				
Actinopyga echinites	Deepwater redfish	Tarasea, Dri Tabua	M		T			T			
Bohadschia vitiensis	Brown sandfish	Vula	M	T F		T					T
Bohadschia marmorata	Chalkfish	Mudra	M		F	T	F	T			
Thelenota anax	Amberfish	Basi	M								
Actinopyga miliaris	Hairy blackfish	Dri, Driloa	M			F					
Actinopyga lecanora	Stonefish	Dri vatu	M								
Pearsonothuria graeffei	Flowerfish	Senikau	M		F					T F	T
Holothuria coluber	Snakefish	Yarabale	L		T F	T	F			T	
Holothuria fuscopunctata	Elephant trunkfish	Tina-ni-dairo	L								T
Holothuria edulis	Pinkfish	Loli piqi	L	F	T F	T				T F	T
Holothuria atra	Lollyfish	Loliloli	L	T F	T F	T	T F	T		T F	
Synapta maculata				F		T	F				
TOTAL SPECIES				**6**	**10**	**10**	**6**	**6**	**1**	**5**	**7**

Table 3. Average sea cucumber species densities (animals/ha) recorded in *tabu* and open areas in belt transects collected by snorkel in 2014. Standard deviations are provided in parentheses. Regional reference densities across the Pacific Islands are sourced from Pakoa et al. (2013), where available. Species densities above the regional reference density is in bold text.

Species	Bua		Kubulau		Nakorotubu		Vuya		Regional density
	Tabu	Open	*Tabu*	Open	*Tabu*	Open	*Tabu*	Open	
Holothuria atra	833 (1120)	56 (24)	292 (125)	0	594 (250)	250 (295)	1250	167	5600
Stichopus chloronotus	0	0	0	0	167 (125)	167	0	0	3500
Bohadschia marmorata	0	0	0	0	0	0	0	125	1400
H. coluber	42	0	0	0	83	0	0	42	1100
H. scabra	0	0	**1042**	0	0	0	**1000**	250	700
H. edulis	0	42	0	0	167	208 (59)	0	0	260
Actinopyga mauritiana	0	0	0	0	0	0	0	0	200
A. miliaris	0	0	0	0	0	0	0	0	150
B. argus	0	0	83	0	0	0	42	0	120
S. herrmanni	63 (29)	0	0	0	0	0	0	0	100
B. vitiensis	**1000**	83	0	0	0	0	0	0	100
Pearsonothuria graeffei	0	0	0	0	**333** (118)	**333**	0	0	100
H. whitmaei	0	0	0	0	0	0	0	0	50
Thelenota ananas	0	0	0	0	0	0	0	0	30
H. fuscogilva	0	0	0	0	0	0	0	0	20
A. lecanora	0	0	0	0	0	0	0	0	10
H. fuscopunctata	0	0	0	0	0	0	0	0	10
A. echinites	0	0	0	0	0	0	0	0	
A. palauensis	0	0	0	0	0	0	0	0	
H. lessoni	0	0	0	0	0	0	0	0	
S. horrens	0	0	0	0	0	0	0	0	
S. monotuberculatus	0	0	0	0	0	0	0	0	
Synapta maculata	0	42	0	0	0	0	0	83	

Table 4. Average sea cucumber species density (animals/ha) recorded in *tabu* and open areas in belt transects collected by SCUBA in 2014. Standard deviations are provided in parentheses. Regional reference densities across the Pacific Islands are sourced from Pakoa et al. (2013), where available. Species density above the regional reference density is in bold text.

Species	Kubulau		Ovalau		Regional density
	Tabu	Open	*Tabu*	Open	
Holothuria atra	708	42	0	0	5600
Stichopus chloronotus	0	0	0	42	3500
Bohadschia marmorata	0	0	0	0	1400
H. coluber	375	42	0	0	1100
H. scabra	0	0	0	0	700
H. edulis	**333**	42	63 (29)	0	260
Actinopyga mauritiana	0	0	0	0	200
A. miliaris	0	0	0	0	150
B. argus	0	0	0	0	120
S. herrmanni	0	0	0	0	100
B. vitiensis	0	0	0	0	100
Pearsonothuria graeffei	0	42	52 (15)	0	100
H. whitmaei	0	0	31	0	50
Thelenota ananas	0	0	0	0	30
H. fuscogilva	0	0	0	0	20
A. lecanora	0	0	0	0	10
H. fuscopunctata	0	0	42	0	10
A. echinites	0	0	0	0	
A. palauensis	0	0	0	0	
H. lessoni	0	0	0	0	
S. horrens	0	0	0	0	
S. monotuberculatus	0	0	0	0	
Synapta maculata	0	0	0	0	

Table 5. Average sea cucumber species density (animals/ha) recorded in *tabu* and open areas by manta tow in 2014. Standard deviations are provided in parentheses. Regional reference densities across the Pacific Islands are sourced from Pakoa et al. (2013), where available.

Species	Bua *	Nakorotubu		Ovalau *	Regional density
		Tabu	Open		
Holothuria atra	60 (2)	61 (12)	6	0	2400
Stichopus chloronotus	3	0	0	8	1000
H. coluber	0	8	0	0	350
H. edulis	0	0	0	3	250
Bohadschia vitiensis	50 (31)	0	0	3	160
S. herrmanni	6 (4)	0	0	0	130
B. argus	0	0	0	0	50
Pearsonothuria graeffei	0	0	0	6	50
Actinopyga mauritiana	0	0	0	0	20
Thelenota anax	0	0	0	0	20
T. ananas	0	0	0	3	10
H. whitmaei	0	0	0	0	10
H. fuscopunctata	0	0	0	0	10
H. fuscogilva	0	0	0	0	
B. marmorata	0	0	0	0	
A. miliaris	0	0	0	0	
A. palauensis	0	0	0	0	
H. lessoni	0	0	0	0	
S. horrens	0	0	0	0	
S. monotuberculatus	0	0	0	0	
Synapta maculata	0	0	0	0	

* denotes surveys only conducted inside *tabu* areas.

Table 6. Average sea cucumber species density (animals/ha) recorded in *tabu* areas in belt transects collected by snorkel in 2014 and 2015 for sites where temporal data were available. Regional reference densities across the Pacific Islands are sourced from Pakoa et al. (2013), where available. Species densities above the regional reference density are in bold text.

Species	Kubulau	Kubulau	Nadi	Nadi	Regional density
	2014	2015	2014	2015	
Holothuria atra	292	214	2604	1694	5600
Stichopus chloronotus	0	42	0	0	3500
Bohadschia marmorata	0	0	42	354	1400
H. coluber	0	0	135	83	1100
H. scabra	**1042**	**833**	438	**2021**	700
H. edulis	0	0	0	42	260
Actinopyga mauritiana	0	0	0	0	200
A. miliaris	0	0	0	**208**	150
B. argus	83	0	0	0	120
S. herrmanni	0	83	**188**	**139**	100
B. vitiensis	0	0	0	83	100
Pearsonothuria graeffei	0	0	0	0	100
H. whitmaei	0	0	0	0	50
T. ananas	0	0	0	0	30
H. fuscogilva	0	0	0	0	20
A. lecanora	0	0	0	0	10
H. fuscopunctata	0	0	0	0	10
A. echinites	0	0	0	83	
A. palauensis	0	0	0	0	
H. lessoni	0	0	0	0	
S. horrens	0	0	29,042	83,917	
S. monotuberculatus	0	0	0	0	
Synapta maculata	0	0	1042	0	

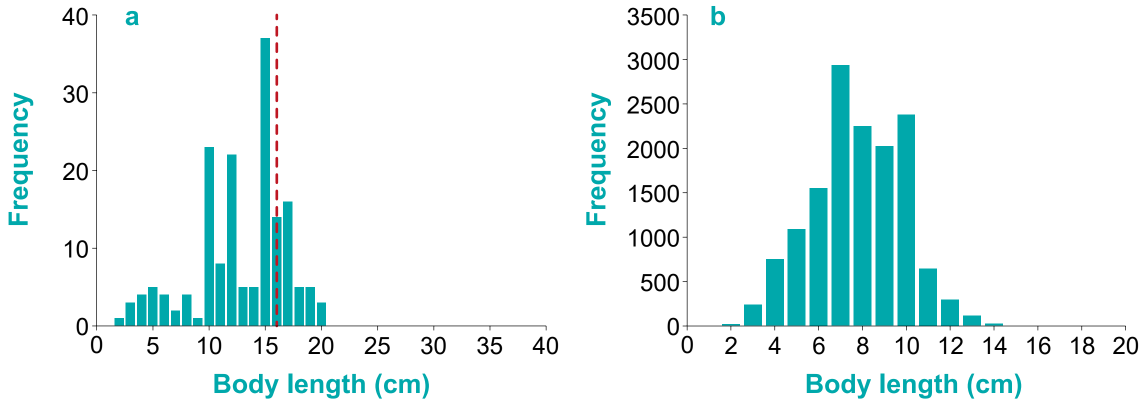

Figure 2. Population size structure of (a) *Holothuria scabra* in Wailevu District in 2015, and (b) *Stichopus horrens* in Nadi District in 2015. Red line indicates size at maturity of sandfish at 16 cm (Conand 1990). The legal size limit in Fiji is currently 7.6 cm.

Discussion

In-water assessments conducted between 2014 and 2015, across four provinces in Fiji, recorded very low species richness and densities of sea cucumber species suggesting management actions are urgently required to avoid collapse of these sea cucumber stocks. The low richness of species at all sites suggests that local depletions of some species, particularly high-value species, have occurred.

For the shallow-habitat species *H. atra*, densities were well below the regional reference density. This is of concern since *H. atra* has a life history characterised by fast growth, and reproduction at a relatively early age or by fusion (Pakoa et al. 2013), and therefore a good indicator of exploitation levels. The severe depletion of *H. atra* and other similar species is a strong indicator that the sea cucumber fishery in the surveyed area has shifted towards low-value species as high- and medium-value species are depleted.

While densities were generally higher inside *tabu* compared to open areas within community LMMAs, most species had densities below the regional reference densities (Pakoa et al. 2013), suggesting that *tabu* areas alone are insufficient to maintain or restore depleted populations. Although threshold densities for successful reproduction of sea cucumbers are generally unknown, it is recommended to maintain populations and avoid 'depensation', where the breeding population is unable to maintain itself by producing enough eggs or offspring. Experts recommend that densities should be in the range of at least 10–50 individuals/ha (depending on the species) over large enough areas with some groups of sea cucumbers of >10 separated by no more than 5–10 m, to avoid reproductive failure (Bell et al. 2008).

Management measures implemented to date have been ineffective at managing Fiji's sea cucumber stocks and the fishery. *H. scabra*, which was banned for export in 1988 due to its importance as a local food item and is listed as Endangered with Extinction under the IUCN Red List of Threatened Species, continues to have densities lower than the regional reference densities for all sites except two. The population size structure of *H. scabra* revealed that the population is largely composed of juveniles, below the size of reproductive maturity.

The results of this study and other recent studies by Tabunakawai-Vakalalabure et al. (2017) and Purcell et al. (2017) concur with earlier work by Pakoa et al. (2013), and highlight the impact of fishing pressure and the pressing need for effective management to avoid further localised extinctions and the complete collapse of the fishery in Fiji.

Recommendations

A management plan should be finalised and adopted for the sea cucumber fishery that has adequate measures in place to ensure its recovery. Specifically this study recommends:

- A major shift in management strategy is needed to safeguard the sea cucumber fishery for the future. The new management plan should impose a shortlist of permissible species (which are the only ones that can be collected and exported), which excludes species at low current abundance and those recognized as being threatened. In order to keep the fishery active, the Ministry of Fisheries should consider reducing fishing effort by quickly bringing in more restrictive regulations such as very short fishing seasons (e.g. 2 months per year until stock abundance recovers), or greatly reduce the number of fishers permitted to collect sea cucumbers by imposing 'limited-entry rules' that reduce the number of fishers to no more than one thousand in the whole country. If the Ministry cannot impose such regulations rapidly (i.e. within the coming year), then it may wish to consider imposing a 10-year moratorium on all collection and exporting, and plan to only open fishing after this period and for species that have been shown by underwater censuses to be well above regional reference densities and their size at maturity.
- The management plan should include more robust regulations, including more appropriate size limits, shortlists of permissible species, a complete ban on the use of UBA, and a licensing system that will reduce the number of exporters and fishers in the fishery.
- Enforcing the ban on the export of *H. scabra*, with strong penalties (e.g. fines, cancelling of licences) for non-compliance.
- Prohibiting the collecting of sea cucumbers species from areas with populations below regional reference densities.

Acknowledgements

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2 Fisher perceptions about abundance and catch rates of sea cucumbers in Fiji

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Abstract

Data on fisher perceptions from interview surveys can help to validate findings from underwater visual census (UVC) of fishery stocks. We conducted questionnaire-based interviews with 235 sea cucumber fishers in 8 locations around Fiji. In all but one location, fishers on average perceived stocks as declining or worse. Most fishers thought the reason for the decline was too many fishers participating in the fishery. One-quarter of fishers believed fishing gears (i.e. SCUBA) were a main problem. Based on fisher knowledge, current catches for an average day of fishing have declined by one-half to three-quarters in the past decades. Our study on fisher perceptions reinforces findings from UVC that sea cucumber stocks are in an over-harvested state across most locations in Fiji. Socioeconomic surveys offer a cost-effective approach to diagnosing changes in sea cucumber stocks. A ban on SCUBA will help protect deeper water stocks and minimise diving injuries, but will unlikely curb exploitation to a sustainable level. To achieve sustainability in the long term, our findings suggest that resource managers in Fiji and other Pacific fisheries should consider limited-entry rules in the fishery as a means to reduce the overall annual catch.

Introduction

A sound understanding the current abundance of wild stocks is among the most fundamental requirements for responsible fisheries management. Management decisions for fisheries should be based on the best scientific evidence available, also taking into account traditional knowledge of marine resources (FAO 1995). Estimations of stock abundance of marine resources such as sea cucumbers can come from fishery-dependent and fishery-independent methods (Purcell 2010). Underwater visual census (UVC) of sea cucumber populations are needed from time to time, but UVCs are generally expensive and time-consuming, and most management institutions in the Pacific Islands lack the financial resources to do them regularly (Purcell et al. 2014). UVCs also only give a 'snapshot' of the current resource state at one time and place, thus overlooking potentially important information about past and recent changes in fishery stocks.

Several simple questions can be answered by social science research, which indicate the health of fishery stock. For example, fishers could be asked their perceptions about current trends in stock abundance, any perceived reasons for declines, and how different catches were in past years (Friedman et al. 2008). Some caution is needed because perceptions are subjective and sometimes biased (Daw et al. 2011, O'Donnell et al. 2012). Nonetheless, fishers have an intimate knowledge of the marine resources and many of them have years of experience to understand changes in population abundance.

This chapter presents research results from questionnaire-based surveys of fishers in Fiji, conducted in a project funded by the Australian Centre for International Agricultural Research (ACIAR), in collaboration with Partners in Community Development Fiji (PCDF). That project operates in Fiji, Kiribati and Tonga, but only the data from Fiji are presented here. The research findings from several important questions to fishers furnish a clear picture about recent trends in sea cucumber stocks in Fiji and fishers' perceptions about the reasons why stocks appear to be declining.

Methods

The study was conducted in 8 locations in Fiji as follows, with number of surveyed villages in brackets: Ra province (3), Bua Province (3), Yasawa group (4), Kadavu (5), Cakaudrove (4), Taveuni (5), southern Lau Group (5) and Vanua Balavu (5) (Fig. 1). In consultation with the Fiji Ministry of Fisheries, villages were selected within each location that had sea cucumber fishers. Within each location, we generally visited 3–5 villages where sea cucumber fishing took place. Questionnaire-based interviews were held with fishers from February to September 2014. On average, 7 fishers (±2 SD) were interviewed per village, and 235 fishers were interviewed in total across all locations. After presenting the customary *sevusevu* in each village, we consulted village elders or the *turaga ni koro* (village headman) to find sea cucumber fishers and then proceeded to ask interviewees for the whereabouts of other fishers to interview ('snowball' technique). We interviewed women fishers where possible. Otherwise, our sampling of fishers was irrespective of whether fishers were young or old, part-time or full-time, or how they collected sea cucumbers.

Interview surveys of fishers in Fiji using questionnaires. © Watisoni Lalavanua/WCS and Steven Purcell

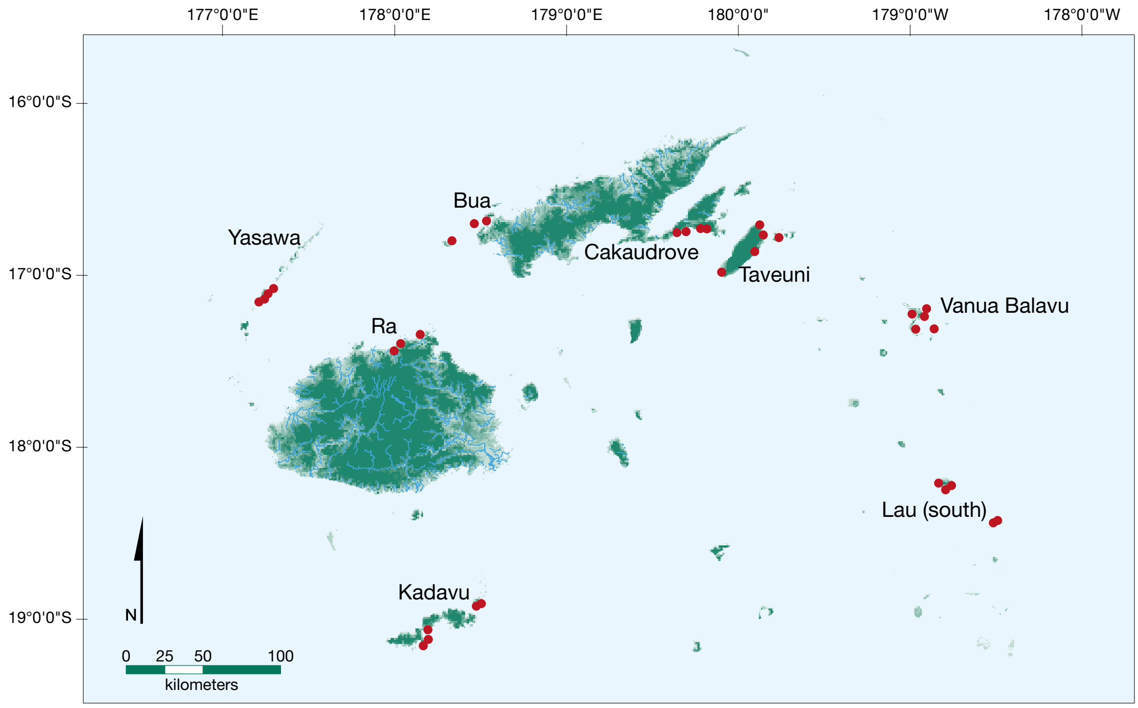

Figure 1. Map of Fiji Islands with the study locations (regions) for socioeconomic surveys annotated. The geographic locations of villages are indicated by red dots.

During interviews, we asked questions from a structured questionnaire (see Purcell et al. 2016, Supplementary material S1). We asked fishers whether they thought sea cucumber stocks have been increasing, stable, declining or are depleted. If fishers believed stocks were declining or depleted, we asked them for their view on the main reasons why they think stocks would have declined. The reasons given by fishers were recorded into one of six categorical responses: too many fishers, fishing intensity in the past, a change in fishing gears, natural change, pollution, or other reasons. Some fishers gave more than one response, hence the percentages across response categories should not add up to 100 (see Fig. 2). We also asked fishers how many sea cucumbers they caught in the past on a 'good' day, as a means to help improve reliability of memory about an average day's catch (O'Donnell et al. 2012), and then asked how many they would catch on an average day of fishing. Data on the number of sea cucumbers caught on an average day at a specified time in the past were then compared to answers from fishers about their current (last 12 months) average-day catch rate. We pooled data from fisher surveys among villages within locations. This approach is also appropriate for management implications, since management regulations in Fiji would generally operate at the national or provincial scale.

Results

Perceptions about current stock status

We had good replication of fishers across locations. Perceptions by fishers about the current stocks were congruent across most locations — fishers generally believed that stocks of sea cucumbers are declining or worse (depleted) (Fig. 2). The exception was in Taveuni, where fishers believed on average that stocks of sea cucumbers were currently stable in their fishing grounds.

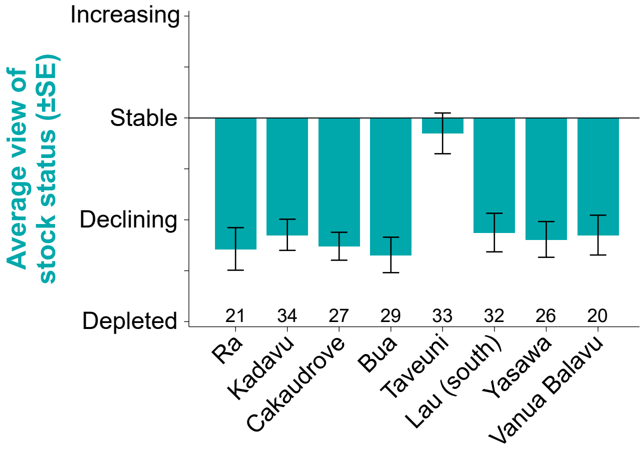

Figure 2. Bar graph of average views of fishers about current status of sea cucumber stocks in 8 locations in Fiji. Responses of fishers were pooled among the villages in each location. Numbers along the x-axis are the sample sizes (*n*) of fishers for each location. SE=standard error. Adapted from Purcell et al. (2016).

The error estimates on our average ranks for stock status were relatively small, with precision ranging from 0.11–0.17 (s.e./mean) across all locations except Taveuni. This means that the perceptions about the status of sea cucumber stocks were in harmony among fishers within almost all locations, and that the exception in Taveuni can be attributed to varying views of fishers.

Perceptions about reasons for declining stocks of sea cucumbers

The most common reason why fishers thought stocks were declining or depleted was "too many fishers" (Fig. 3). Apart from past fishing intensity, changes in fishing gear was also perceived by fishers as another major contributor to declining stocks, especially the use of SCUBA gear for harvesting sea cucumbers in deep water. Pollution was the least-common reason.

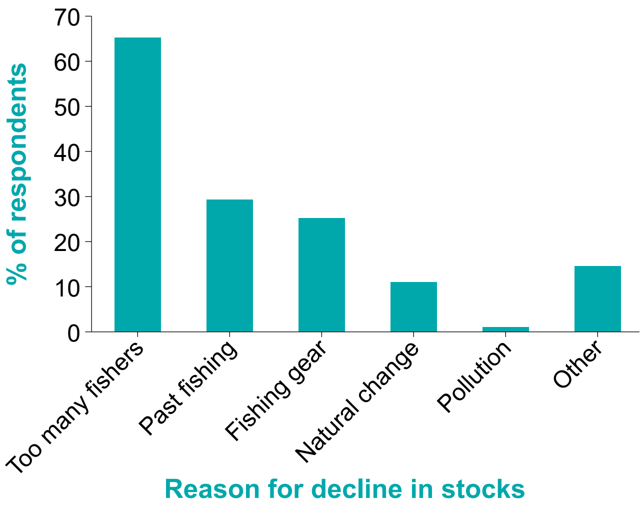

Figure 3. Bar graph of overall percentage of fishers in Fiji who perceived different reasons for declines in stock. Only fishers who responded that they thought stocks were declining were included.

Perceptions about past catches

CPUE in the past was generally perceived to be greater than it is at present across all years of experience of fishers, since 78% of fishers responded that they caught more sea cucumbers in the past when they had first started fishing (Fig. 4). There was much variation in the reported proportional difference between past and present catch rates. For many of the cases where fishers caught less in the past, the fishers often explained that they were previously targeting and catching small numbers of high-value species whereas nowadays they need to catch high quantities of low-value species. So this usual shift in fishing strategy would bias our estimates of proportional difference between past and present-day catches downwards. This makes it even more striking that catch rates have fallen significantly across the spectrum of fishing experience (Fig. 4).

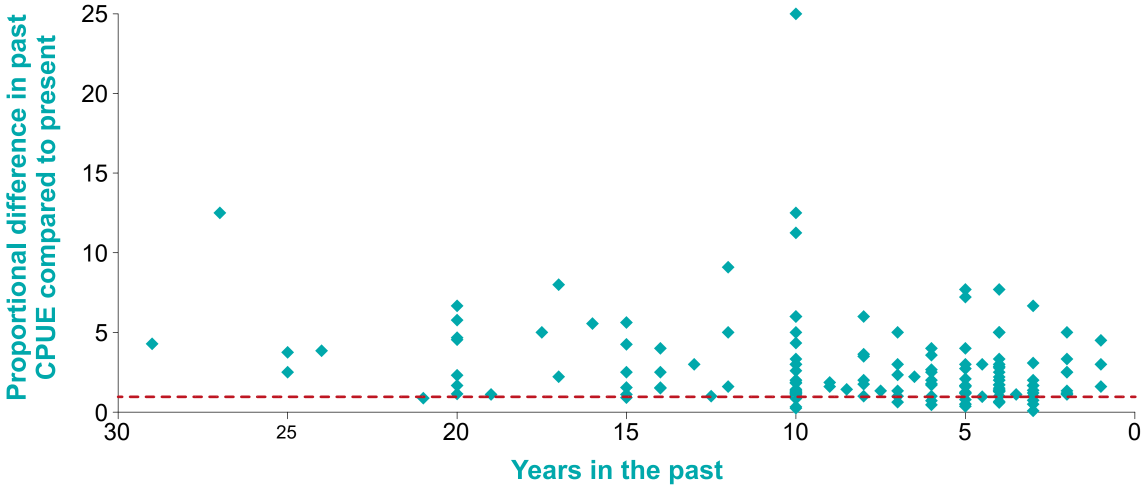

Figure 4. Scatter plot of the proportional difference between past and present catch-per-unit-effort (CPUE) of sea cucumber fishers in Fiji. For example, a difference of 5 means the catch rate for an average day fishing in the past was 5 times the catch rate for an average day nowadays. Each data point is one interviewed fisher. For each fisher, years in the past is their number of years of experience fishing sea cucumbers. Adapted from Purcell et al. (2016).

Our data suggest that a lot of fishers have entered the fishery the last 10 years, since a majority had less than 10 years of experience (Fig. 4). Of the fishers for whom we recorded data on fishing experience, 45% had ≥10 years' experience fishing sea cucumbers. Large variation in catch rates among fishers can be attributed to some fishers collecting a small number of high-value species (e.g. the SCUBA divers) while others collect higher volumes of lower-value species. Present catch rates for fishers with at least 10 years of experience (32 [± 40] sea cucumbers day^{-1}) was the same as those with less experience (32 [± 32] sea cucumbers day-1). Experienced fishers reported catching on average 79 (± 102) sea cucumbers per day 10 or more years ago, whereas fishers who began fishing in the past decade reported catching on average 61 (± 67) sea cucumbers per day when they first started fishing.

Average catches for each time period do not match up paired measurements for each fisher. By calculating the proportional difference in catch for each fisher and then taking averages, we get a clearer picture of declines over time. This approach finds that experienced fishers caught on average 3.5 times as many sea cucumbers on an average day 10 or more years ago than nowadays. Less experienced fishers reported catching 2.3 times more sea cucumbers per day when they started fishing in the past decade.

Discussion

Underwater visual censuses (UVCs) of sea cucumbers in Fiji from 2002–2009 (Friedman et al. 2010) and more recent UVCs (Pakoa et al. 2013, Lalavanua et al. 2017) indicate that stocks at most sites were low or very low. One potential limitation of UVC-based assessments is that researchers might not census animals in the same places where fishers collect them. Hence, integrating socioeconomic data from fisher surveys will improve an understanding of fishery dynamics (Daw et al. 2011). In this context, our results from the perspective of fishers reinforce the general conclusions about stock health from UVCs. Sea cucumber fishers in Fiji are in the water several days each week and have on average 11 years of experience in searching for sea cucumbers (Purcell et al. 2016). Past and recent UVCs and our present study on fisher perceptions together paint a congruent picture that sea cucumber stocks are in an over-harvested state across most locations in Fiji.

Fisher knowledge from the present study in Fiji suggests that catch rates 10 or more years in the past were about triple the current catch rates, and that catch rates have declined by about half in the past decade. In certain fisheries, fisher knowledge might exaggerate stock declines compared to landing data, but the reasons can be complex (Daw et al. 2011, O' Donnell et al. 2012). Nonetheless, the size of the declines is quite large and knowledge from experienced fishers provides a historical comparison that would be otherwise unobtainable because UVC surveys prior to 2002 are lacking.

We note that, where catch per day is still high, fishers told that this mostly consists of low-value species. This was the case on the island of Taveuni, where many of the fishers now target large quantities of *Stichopus monotuberculatus/horrens*, which is small and low value. Therefore, a limitation in comparing past and present CPUE is that it does not differentiate between the species of sea cucumbers that are caught, and declines in stocks can be masked by shifts in fishing strategies over time.

One-quarter of fishers believed the problem of declining stocks was due to fishing gears, namely SCUBA. The use of SCUBA gears adds greater cost to fishing and might draw fishers into a situation of debt or dependency on buyers who supply the gears (Purcell 2010) while increasing their risk of injuries (Tabunakawai-Vakalalabure et al. 2017). Prohibition on the use of SCUBA in the fishery might lessen overall rates of exploitation, especially for animals in deep water. However, SCUBA divers generally targeted a small subset of species and in different areas to gleaners and breath-hold divers. So, the recent ban on underwater breathing apparatus (UBA) in Fiji unlikely to bring about sustainability in the fishery without other more stringent regulations such as limited-entry rules or short fishing seasons. Likewise, minimum legal size limits specific to species or species groups (see Purcell 2010), and a short list of allowable species that can be harvested (see Purcell et al. 2014), would be very useful in this fishery but those two regulations would probably not bring about sustainability in the fishery without limitations on fishing capacity.

A high participation rate (i.e. too many fishers) in the fishery was perceived by a majority of fishers as the reason for declining stocks. One management solution is limited-entry rules (see Purcell 2010) in which fishing rights are given to a small number of fishers through a limited number of licences issued in the fishery. Some key exporters told us that there are at least 7000–9000 sea cucumber fishers in Fiji. Limited-entry rules could, for example, mean issuing licences to only 1000 fishers in the country. One obstacle is that limiting the numbers of fishers to participate in Fiji's sea cucumber fishery would conflict with traditional rights of communities to be able to fish.

Ultimately, the problem in the fishery is that too many sea cucumbers are harvested annually. An alternative to limited-access rules would be to impose short fishing seasons, e.g. two months per year (Purcell et al. 2014, Purcell and Pomeroy 2015). The result would be to reduce the overall amount of sea cucumbers extracted per year. Fishers might accept this regulation more readily than limited-entry rules.

Recommendations

- Use socioeconomic surveys to diagnose changes in sea cucumber stocks.
- Enforce the recent ban on UBA gears for the fishery.
- Consider limited-entry rules by issuing a relatively small number of fishing licences to fishers (e.g. no more than 1000 for the whole of Fiji).

Acknowledgements

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3 Value-chain analysis of the wild-caught sea cucumber fishery

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Abstract

A value-chain analysis of Fiji's wild caught sea cucumber fishery was conducted in early 2015 to document the relationships and linkages between buyers, processors, sellers, and other service providers, and to identify opportunities and constraints to industry growth and competitiveness through the value-chain lens. Four main types of actors participated in the fishery — fishers, processors, local traders and exporters. The majority of sea cucumbers is exported to mainland China and Hong Kong, with smaller volumes exported to New Zealand, Taiwan, Australia and the United States of America. Most fishers sold sea cucumbers in raw form (76.5%) and only a small percentage completed the early stages of processing (16.5%) because they had not received training on the correct processing methods. Local traders generally purchased raw sea cucumbers for resale to exporters or other traders in a raw form or as a semi- or fully-processed product (i.e. dried). There was very high variation in the prices received for different species, likely reflecting both the bargaining power of fishers and quality of product in Fiji. The establishment of product grades and accepted standards in Fiji is critical to guide transactions along the value chain, and to ensure that fishers and processors receive a fair price for their product. This will remove the variable standards being set solely by the exporters and ensure greater transparency for the fishery.

Introduction

Sea cucumbers are an important source of income for local fishers, including women, and their export is considered one of the oldest trades in Fiji (Ram et al. 2016). Fiji has traded sea cucumbers since 1813 with 600 tonnes exported from 1827 to 1835 (Pakoa et al. 2013). There were booms in sea cucumber exports in 1986–1987 and in 1996–1997, but since 1998 export volume declined and averaged around 243 tonnes per year for a decade (Fig. 10 in Pakoa et al. 2013, Fig. 2 in Ram et al. 2016). While many other Pacific Island countries have declared moratoria on their crashed stocks, Fiji has continued trading sea cucumbers (Purcell et al. 2012).

The severe decline in sea cucumber populations throughout Fiji is of high concern. Despite Fiji's efforts to control the trade of sea cucumbers using a 7.6 cm size limit and an export ban in 1988 on the highly depleted *Holothuria scabra* (sandfish), population densities are some of the lowest recorded in the Pacific Island region (Pakoa et al. 2013), including in more remote provinces such as Lau (Jupiter et al. 2013). Exports for half of commercial species have declined (Pakoa et al. 2013), and densities for all species in Fiji are lower than the average Pacific “regional densities” and those recommended for healthy stocks (SPC 2014).

Despite efforts to undertake in-water resource assessments, there has been little effort to map out and understand the supply chain in Fiji. Mapping out the markets is valuable for understanding factors that might constrain the function or performance of a fishery, the value-chain players, the enabling environment (e.g. policies, institutions, infrastructure) that surround a fishery, and the service providers that support the value-chain operations.

In 2015, the Wildlife Conservation Society (WCS) and Ministry of Fisheries conducted a value-chain analysis (VCA) of the wild caught sea cucumber industry on the islands of Viti Levu and Vanua Levu in Fiji. The objective of the study was to understand the relationships and linkages between buyers, processors, sellers, and other service providers, and to identify opportunities and constraints to industry growth and competitiveness in Fiji through the value-chain lens. Value-chain analysis was selected as a tool to examine the industry in detail, across all the market players and assesses their investments along the wild-caught sea cucumber supply chain. This work was timely, given that the Ministry of Fisheries has drafted a national management plan for sea cucumbers and regional efforts by the Pacific Community (SPC) to address the overexploitation of this fishery. This chapter is a summary of some of the key findings of the VCA for the wild caught sea cucumber fishery. A more detailed report with recommendations can be found in Mangubhai et al. (2016).

Methods

A value chain analysis (VCA) is “*a detailed description of a full range of activities and services required to bring a raw product from its initial state to a marketable commodity for delivery to final customers*” (Kaplinsky and Morris 2000). A two-step VCA was conducted for the wild caught sea cucumber fishery in Fiji. Firstly, using expert knowledge within the Ministry of Fisheries, WCS and James Cook University (JCU) the wild-caught sea cucumber supply chain was qualitatively mapped out for Fiji and a list compiled of known exporters, middlemen, agents and villages active in the fishery.

Secondly, a VCA survey was implemented on Vanua Levu and Viti Levu using questionnaires between 19 February and 9 April 2015 (see Appendix 1 in Mangubhai et al. 2016). The questionnaire for fishers focused on questions relating to harvesting strategies, fishing efforts, costs of equipment and perishable goods (e.g. fuel), catch species and volumes, market access, livelihood dependency and income satisfaction. Those fishers, middlemen and agents that processed sea cucumbers were asked about processing techniques, purchasing and selling prices (broken down by grades and sizes where applicable), staffing, and input costs (e.g. equipment, perishable goods). The questionnaire for exporters focused on species and volumes of sea cucumbers bought and sold (broken down by grades and sizes), purchasing and selling prices, export countries, number and size of shipments, operations costs, and quality issues.

A total of 335 people were interviewed consisting of 155 fishers who only sell raw products, 79 fishers who process sea cucumbers, 74 middlemen and agents and processors, 8 community boat drivers, 7 market sellers, 66 restaurant staff or owners, and 7 exporters. Of the fishers interviewed, 87 were women (37%) and 147 were men (63%), residing in 25 villages across 12 districts and 7 provinces (Fig. 1).

Two teams were established for the VCA study. One team focused on interviewing fishers, buyers/middlemen and boat drivers based in villages, while the second team focused on interviewing middlemen and exporters based in towns, including the capital city of Suva. The two teams were in telephone contact and kept each informed of any emerging players in the value chain. For example, if fishers in villages provided the names of the middlemen, agents or exporters they sold to in towns, these were shared with the second team who would then try to find and interview these people or representatives of their companies.

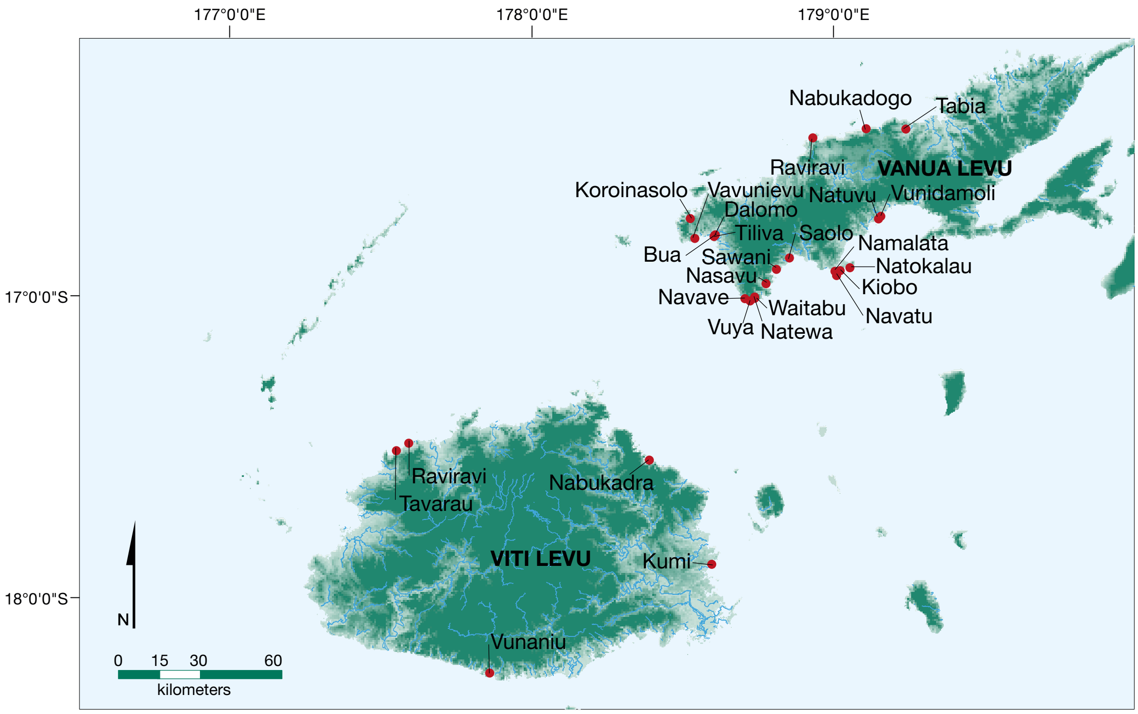

Figure 1. Location of villages in Fiji where sea cucumber fishers were interviewed.

Results and Discussion

Sea cucumbers are predominantly a commercial commodity that is exported from Fiji as fully-processed product. The flow of product and activities involved from the source to the final markets is shown in Figure 2. The VCA revealed there were four main players: (1) fishers, (2) processors (fishers, independent processors, agents for exporters), (3) middlemen (independent middlemen, agents for exporter), and (4) exporters. For fishers, these include those who originate from within the village being interviewed, as well as fishers from outside villages. Smaller players involved in the trade were community boat drivers who provided boating services to sea cucumber fishers, as well as local market sellers and restaurants.

From interviews with exporters, we found that Fiji exports largely to mainland China and Hong Kong, with smaller volumes exported to New Zealand, Taiwan, Australia and the United States of America (Fig. 3). This concurs with findings by Purcell (2014) for Fiji and Kiribati and Tonga. Of the 27 species known to be commercially exploited in Fiji, the VCA found 22 species of sea cucumbers are collected and exported from the islands of Viti Levu and Vanua Levu, including *H. scabra*, which is currently banned for export from Fiji.

Only a small number of species and a small proportion of the overall catch of sea cucumbers are consumed in villages or sold in local markets or restaurants in Fiji. Indigenous Fijians eat a few sea cucumber species (e.g., *H. scabra* and *H. fuscogilva*), with consumption higher on Vanua Levu with 29% of fishers there stating they sometimes or often consume sea cucumbers, compared to 7% of fishers on Viti Levu who only sometimes consume sea cucumbers. Harvested sea cucumbers are largely sold at local markets in Suva and Lautoka, largely to Chinese consumers and restaurants. *H. scabra* and *H. fuscogilva* (white teatfish) were the two main species sold at local markets throughout the year, with local sellers who were almost exclusively women who sold largely a raw (85.7%) product. Most fishers stated they preferred to sell to local traders or exporters because they receive a better price than if they sold it directly themselves at local markets.

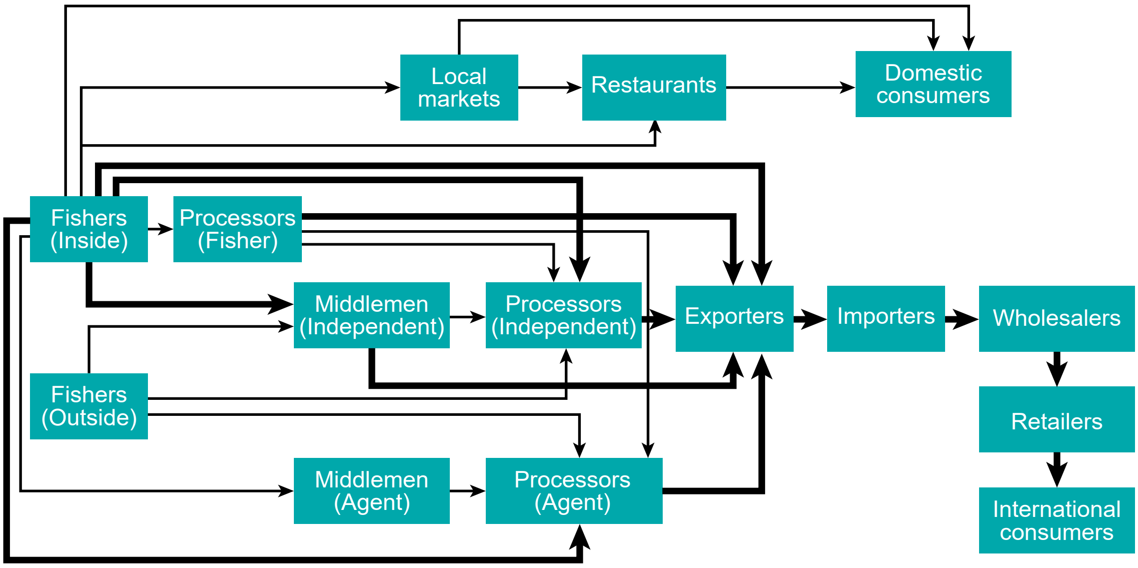

Figure 2. The value chain of wild caught sea cucumbers as they pass through different players in either raw form or transformed from raw form to a fully-processed product. In the case of fishers, these can also be processors. Thick lines indicate that more sea cucumbers are traded along that pathway.

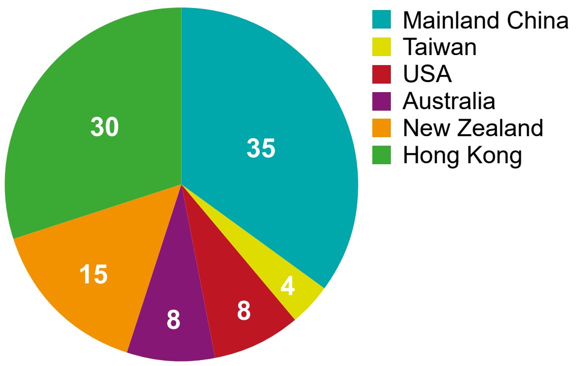

Figure 3. Target countries for sea cucumbers exported from Fiji. Numbers represent relative percentages.

The majority of fishers (77%) sold sea cucumbers in raw form and a small percentage (17%) completed salting and/or first cook because they had not received training on the correct processing methods. This result concurs with Purcell and Lalavanua (2017) who found that a high proportion of fishers in some regions in Fiji were selling sea cucumbers raw. Sea cucumbers are processed straight away to avoid spoilage, and very few fishers (2%) stored animals in a freezer for sale later to local traders. Men and women generally process their own sea cucumbers (67%) or with the help of their spouse (29%). Men generally worked with a wider number of fishers to collect sea cucumbers for processing, whereas women preferred to largely collect on their own (61%) or source them from immediate family members (27%).

In contrast, processors, middlemen and agents, generally purchased raw sea cucumbers for resale to exporters or other traders in a raw form or as a semi- or fully-processed product. At a local scale, processors, middlemen and agents commonly grade sea cucumbers before sale. As expected, the quality of the final product is highly dependent on the knowledge and experience of individual players and what training they received on processing steps required for the different species. While processors, middlemen and agents are able to complete a number of the processing steps, exporters will often still do some level of reprocessing to improve the quality prior to export (Mangubhai et al. 2016). This suggests there is still room for adding value to products being produced by these traders in Fiji.

Sea cucumbers collected by exporters directly from community fishing grounds or purchased through fishers or local traders are sorted by species, size and stage of processing at exporters' place of business. Exporters purchase raw/semi-processed sea cucumber directly from local fishers (43%), from local traders (29%), local processors (21%) or others (7%). All exporters stated they preferred to process sea cucumbers themselves, especially high- and medium-value species, to ensure the correct processing technique is applied to each species to control the quality of the product for the export market and prevent wastage or value loss. They also provide some training to processors to help improve processing and product quality. However, Purcell et al. (2016) showed that less than one-tenth of fishers in Fiji had been trained in processing by exporters.

Prices received for different species varied greatly, likely reflecting the bargaining power of fishers and quality of product as it passes between the different players (Table 1). The prices fetched for sea cucumbers vary greatly depending on the care taken during collecting and processing. Poor handling methods during collecting can result in the body of the animals having abrasions or disintegrating before death. However, there are no consistent differences in prices between semi-processed products in Fiji (Table 1), likely reflecting a wide range in quality in partially-processed products and lack of a grading standard in Fiji. This particularly impacts fishers who also partly process their product prior to sale. The establishment of grades and standards for Fiji would ensure greater transparency for the fishery and support more value-adding prior to export.

Recommendations

- The establishment of grades and standards by the Ministry of Fisheries in consultation with industry is critical to guide transactions along the value chain, and to ensure processors receive a fair price for their product.
- Improve the quality of the processing of sea cucumbers, especially at the community level through training on processing techniques.

Acknowledgements

We thank all the communities, middlemen, transporters, exporters, market sellers and restaurant employees for participating in this study. We are grateful for staff from the Ministry of Fisheries, Wildlife Conservation Society, and World Wide Fund for Nature, as well as volunteers for assisting with the surveys. Steve Purcell, Hampus Eriksson, Rhona Barr and Stacy Jupiter provided invaluable advice on the survey design. This work was funded by the David and Lucile Packard Foundation (#2015-41007) and John D. and Catherine T. MacArthur Foundation (13-104090-000-INP).

Table 1. Sea cucumber species and the range in prices (and average price in parentheses) received per kg by different players when they sell their product in different forms. Grades A to C represent a semi/fully processed product. All values are in Fijian dollars and are ordered from the highest to lowest prices fetched by exporters.

Common name	Exporter	Local traders (middlemen, agents)			Fishers	
	Fully processed	Grade A	Grade B	Grade C	Raw	Dried
White teatfish	170–469 (376)	35–250 (105)	25–150 (81)	15–150 (59)	20–200 (63)	100 (100)
Black teatfish	149–383 (304)	20–180 (50)	25–80 (61)*	15–70 (48)	5–80 (28)	15–30 (26)
Dragonfish	64–320 (256)	5–60 (30)	3–40 (20)	10–25 (18)	3–20 (6)	3–40 (13)
Deepwater blackfish	128–341 (233)	25–120 (48)	15–20 (18)	12–15 (14)	3–70 (20)	10–13 (10)
Greenfish	117–313 (226)	12–150 (88)	20–100 (63)	1–80 (43)	1–80 (26)	1–100 (23)
Deepwater redfish	107–341 (213)	5–100 (27)	5–40 (24)	10–40 (30)*	2–36 (13)	10–40 (25)
Sandfish	107–213	2–120 (60)	15–80 (58)	10–60 (43)	2–50 (12)	3–20 (13)
Curryfish	117–298 (200)	1.5–100 (40)	1–80 (31)	3–60 (26)	4–80 (20)	4–65 (14)
Stonefish	106–341 (139)	10–140 (38)	6–40 (16)	5–20 (12)	4–60 (26)	6–60 (16)
Prickly redfish	53–341 (194)	7–140 (57)	20–60 (40)	30 (30)	2–60 (23)	30 (30)
Hairy blackfish	85–298 (198)	10–180 (59)	8–100 (33)	5–80 (28)	3–60 (23)	10–40 (17)
Surf redfish	75–256 (139)	10–150 (38)	8–15 (11)	5–8 (7)	3–40 (15)	2–6 (6)
Golden sandfish	213	–	–	–	3–7 (5)	–
Flowerfish	17–170 (94)	1–15 (6)	10 (10)	2–3 (3)	1–30 (9)	3–4 (3)
Amberfish	43–139 (92)	3–40 (12)	2–8 (5)	4	2–30 (8)	3–6 (6)
Leopardfish/ tigerfish	64–128 (92)	5–70 (15)	3–30 (12)	20*	3–40 (10)	6–16 (7)
Brown sandfish	60–107 (79)	5–50 (13)	5–25 (13)	7	2–60 (13)	2–45 (11)
Snakefish	64–86 (75)	5–45 (13)	–	–	2–70 (15)	7–18 (9)
Elephant trunkfish	15–170 (58)	3–164 (48)	64 (64)	40	2–10 (5)	–
Lollyfish	32–85 (38)	2–30 (6)	2–5 (3)	1–4 (3)	1–45 (8)	3–25 (10)
Chalkfish	21–53 (36)	2–25 (17)	6–25 (18)	5–25 (16)	1–50 (10)	7–35 (17.2)
Pinkfish	26–85 (26)	2–15 (6)	3	1	1–40 (9)	3–6 (4)

* Prices may be unreliable or reflect different sizes that are being sold within the grade.

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Fishers from Vanuabalavu with their catch. © Watisoni Lalavanua/WCS

4 Postharvest processing of sea cucumbers in Fiji

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Abstract

Proper postharvest processing methods will yield export-quality bêche-de-mer and, potentially, higher prices for fishers. We conducted interview-based surveys of sea cucumber fishers in multiple villages within eight locations in Fiji. From 0–71% of fishers practised postharvest processing of their catch, depending on location. Information sources about processing methods were largely absent. Poor handling methods in the boat were sometimes used, and some fishers used incorrect techniques for cutting and cooking sea cucumbers. Investment in time by fishers to process their catch also varied among locations. A new training manual, training video and village workshops have built capacity among fishers in postharvest processing methods. The new information tools give hope for higher sale prices and reduced wastage. Further support is needed in Fiji to train fishers in villages not involved in this project. Despite improved knowledge, many fishers experienced problems in accessing coarse salt for processing and getting fair prices by middlemen. To improve income to fishers in the industry, actions are needed to help fishers to access coarse salt and to develop and implement industry standards on the prices fishers should expect to receive for different grades of bêche-de-mer.

Introduction

Sea cucumbers are significant to coastal Pacific island communities as a high-value export (Kinch et al. 2008a; Purcell et al. 2016a). In 2014, the multi-species sea cucumber fishery in Fiji yielded more than FJ$13 million in reported export revenue (source: Ministry of Fisheries Fiji). The main issues facing sea cucumber fisheries in the Pacific Islands and other tropical countries are the poor quality of postharvest processing by fishers, inadequate or ineffective management frameworks, weak enforcement and governance (Purcell 2010, Purcell et al. 2014).

Postharvest processing involves handling and care of the animals, cutting and gutting, salt-curing, cooking, smoke-curing, and drying. These steps yield the non-perishable product called bêche-de-mer, which in Pacific Islands is exported predominantly to China (Purcell 2014a). Different processing methods are needed for different species groups (Purcell 2014b). The price paid to village fishers by middlemen and exporters depends on body size, species and the quality of postharvest processing (Kinch et al. 2008b; Brown et al. 2010; Ram et al. 2014a). Unfortunately, much potential income is lost in Fiji through poor processing methods (Ram et al. 2014a).

Until recent years, Pacific Island fishers had few accessible information sources on postharvest processing. Conand (1990) gave short descriptions of traditional processing steps for two groups of species. Small sections on postharvest processing are found in field identification cards (SPC 2004) and in an outdated species guidebook (SPC 1994). But neither document explains processing in great detail and fishers might not have access to those information tools.

A recent study found a high proportion of fishers in Fiji sold unprocessed sea cucumbers to large exporting companies (Purcell et al. 2016b). Processors and exporters tend to prefer this mode, as they then control the processing and can achieve a high product quality of bêche-de-mer (Mangubhai et al. 2016). However, this mode deprives fishers of the value adding opportunity, which could yield them more income from their catch.

Ram (2008) described processing practises in Fiji in 2006–2007, involving surveys of 86 fishers. He revealed that many fishers were using poor processing practises, resulting in damaged products and spoilage (Ram et al. 2014b). More recently (2014), further questionnaire-based surveys were made of 235 fishers in 34 villages in Fiji, and reinforced that many fishers were using poor processing practises (Purcell et al. 2016b).

This chapter summarises our recent results about processing methods used by fishers in Fiji (Purcell et al. 2016b) and some additional findings. We also give insights from the ongoing follow-up surveys of fishers. This synthesis highlights that training of fishers, and the provision of user-friendly information sources, can have positive outcomes for fishers. However, future support is needed to help fishers overcome several significant hurdles in processing and selling sea cucumbers in Fiji.

Methods

The study was conducted in 8 locations in Fiji as follows, with number of villages in brackets: Ra Province [3], Bua Province [3], Yasawa group [4], Kadavu [5], Cakaudrove [4], Taveuni [5], southern Lau Group [5] and Vanua Balavu [5] (Fig. 1). In consultation with the Ministry of Fisheries Fiji, villages with sea cucumber fishers were selected within each location. Within each location, we visited 3–5 villages where sea cucumber fishing was occurring.

Questionnaire-based interviews were held with fishers from February to September 2014. On average, 7 fishers (±2 SD) were interviewed per village; 235 fishers in total across the eight locations. After presenting the customary *sevusevu* to gain local approval in each village, we consulted village elders or the *turaga ni koro* (village headman) to find sea cucumber fishers and asked interviewees the whereabouts of other fishers to interview (‘snowball’ technique). We interviewed women fishers where possible. Otherwise, our sampling of fishers was irrespective of whether fishers were young or old, part-time or full-time, or how they collected sea cucumbers.

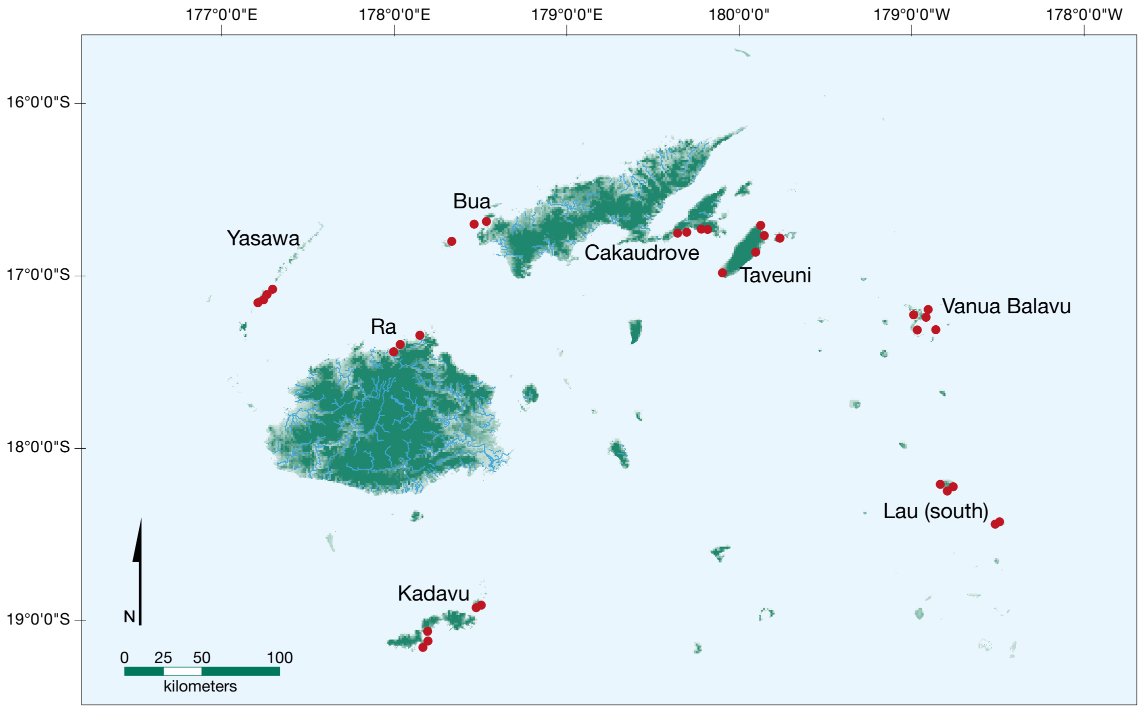

Figure 1. Map of Fiji Islands with the study locations (regions) for socioeconomic surveys annotated. The geographic locations of villages are indicated by red dots.

During interviews, we asked fishers questions from a structured questionnaire (see Purcell et al. 2016c, Supplementary material S1). Questions included whether fishers had received any training on postharvest processing, questions about processing methods used for different species, and time spent on average to process one day's catch. We also occasionally observed how sea cucumbers were stored on boats by fishers. We interviewed commercial processors with a separate questionnaire.

In 2014–2015, we produced a training manual on postharvest processing, a studio-produced training video (online and DVD), and gave 1½-day hands-on training workshops in 24 villages on the best-practice processing methods. Around one year after training the fishers, we revisited villages and interviewed fishers irrespective of whether they had received any training or not. Some of the same questions were asked to fishers as in 2014, and we asked some new questions about socioeconomic impacts of the training and problems faced by fishers in applying the best-practice methods. At the time of preparing this chapter that research was still ongoing so only preliminary findings are presented. For this study, we pooled data from fisher surveys among villages within locations.

Results

Postharvest handling and training

Careful handling of sea cucumbers before cooking is crucial for obtaining undamaged final products. This was one aspect we explained in the village-based workshops and training videos[2]. Many fishers either did not understand the importance of handling practices or disregarded them. On many occasions, fishers just stored sea cucumbers dry on the hull of their boats or would stack too many into bins with insufficient seawater (Fig. 2). In such cases, the outer body wall of certain species (e.g. *Stichopus* spp., *Bohadschia* spp.) would be damaged, so fishers had already lost some value of the end product even before they have started processing the animals.

Of the fishers who were processing sea cucumbers, 59% had not received any training on what methods to use. Very few fishers had ever received information sources on processing of sea cucumbers (Purcell et al. 2016b).

Figure 2. Examples of poor postharvest handling in Fiji. Left: sea cucumbers transported dry in the bottom of a boat at Lautoka wharf. Middle: sea cucumbers transported with little water in the hull of a boat in southern Lau group. Right: sea cucumbers stacked with insufficient water in a tub in Bua district.
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Processing methods used by fishers – overview

The proportion of fishers processing sea cucumbers varied greatly among locations (Fig. 3). In Bua and Taveuni, a majority of fishers were processing their catch. In contrast, few or none of the fishers in Yasawa group and Ra province were processing their catch (Fig. 3). Fishers not processing their catch were selling the animals fresh (raw) to middlemen or commercial processors who were then doing the postharvest processing.

2 Processing sea cucumbers into bêche-de-mer: a 'how to' training video. Southern Cross University, 2014. Online English version: www.youtube.com/watch?v=KH6u0oZoclk Online Fijian version: https://www.youtube.com/watch?v=9Wd18O1Rdgo Downloadable files: http://scu.edu.au/environment-science-engineering

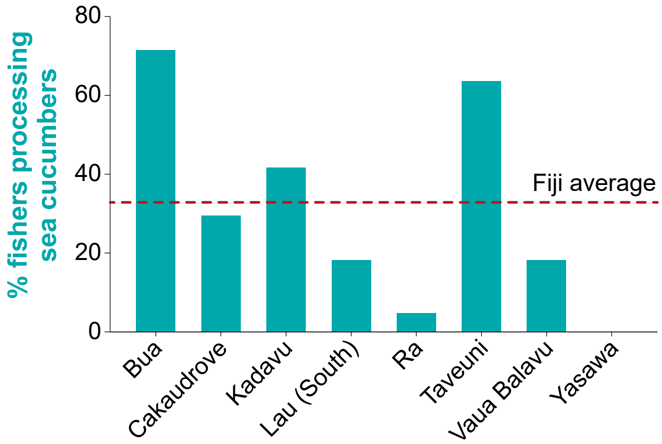

Figure 3. Percentage of fishers in each location that were processing the sea cucumbers they catch. Dashed line is the country-wide average.

Cutting

Many fishers were cutting the sea cucumbers in the correct place with a cut of an appropriate length, but many others were using incorrect methods (Purcell et al. 2016b). For example, one third of fishers were not cutting white teatfish (*sucuwalu*) and black teatfish (*loaloa*) in the correct place (dorsally). Generally, fishers were cutting most species in the genera *Actinopyga*, *Bohadschia*, and other species in *Holothuria*, at the correct place.

Salt-curing

Although all of the commercial processors and exporters in Fiji use a salt-curing step, just 58% of Fijian fishers who process sea cucumbers practised salt curing. Recent follow-up surveys revealed that most fishers cannot buy coarse salt in their district. The number of days that different species were left in salt varied somewhat among commercial processors, and fishers tended to leave animals in the salt for slightly fewer days than would the commercial processors (Purcell et al. 2016b).

Cooking methods

All Fijian fishers used wood as the fuel to heat water for cooking sea cucumbers. A common flaw for fishers was that they would often put the sea cucumbers into boiling water for the first cook (c.f. Purcell 2014b). Average cooking times used by fishers were similar to commercial processors but variable. Undercooking can lead to spoilage due to poor drying and rotting (Fig. 4). An unexpected result from our recent follow-up surveys is that some fishers said they are saving time since our manual and workshops because they now know they do not need to cook the animals for so long.

Figure 4. Processed sea cucumbers in a village in Kadavu, which had not been cooked well, were foul-smelling and were not dried fully.

Smoking and drying methods

The majority of fishers use some sort of smoking stage try help dry out sea cucumbers (Purcell et al. 2016b). The smoke-curing also preserves the flesh from rotting. Most fishers do not have access to a drying oven and instead dry the products in the sun.

Time investment in processing

In Fiji, spouses of fishers, and even children and other family members are involved in processing sea cucumbers (Purcell et al. 2016b). This shows that a diversity of people is involved in the fishery. The amount of time spent by fishers in processing one day's catch varied greatly among locations (Fig. 5). An average of 3 h to process one day's catch of sea cucumbers by fishers in Vanua Balavu contrasted greatest with fishers in Ra province who spent on average less than 40 min to process their catch.

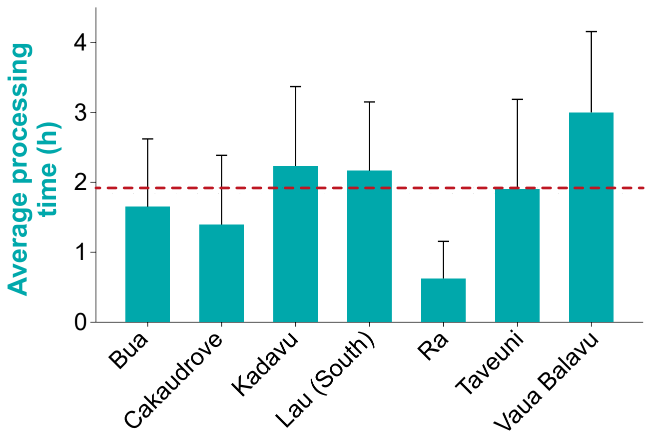

Figure 5. Average processing time (± standard deviation) for one day's catch of sea cucumbers per fisher among locations. The Yasawa group is not shown because fishers were not processing sea cucumbers there. Dashed line is the country-wide average.

New training and information tools

A studio-produced training DVD and a 44-page manual (Purcell 2014b) were developed. The manual and DVD provide simple best-practice methods, with versions in the i-Taukei (indigenous Fijian) language, and more than 2500 Fijian versions have been distributed to fishers in Fiji. Through Partners in Community Development Fiji and Southern Cross University, postharvest processing workshops were conducted with 353 fishers in 24 villages in the eight locations (Fig. 1). Workshop satisfaction forms showed that 99% of fishers found the manual relevant and of high quality, and the workshop "provided new knowledge" to 99.7% of participants.

Problems and opportunities for improvement

Fishers still face challenges in improving their income from bêche-de-mer, despite better understanding of best-practice processing methods. Fishers far from major towns cannot easily buy coarse salt because it is rarely sold in village shops. So, they either had to skip that processing step, or decided not to process their sea cucumbers because they lacked coarse salt and so sold fresh sea cucumbers to commercial processors.

In recent interviews, many fishers complained about economic exploitation by middlemen, who they believe offer them unfair prices. Many fishers had few options for selling products and had to accept prices by middlemen. Middlemen might offer lower prices to fishers for poorly processed product (e.g. not 100% dry, under-cooked, poorly cut), and problems arose because of subjectivity in judging whether a product was fully dried or not, or well processed or not.

Sometimes, buyers encouraged fishers to sell the sea cucumber raw so that they can process it. Some fishers told that buyers had tampered with balances used to weigh sea cucumbers. On a bright note, many fishers told that they were receiving higher prices for their bêche-de-mer since using the methods shown in the manual and workshops.

Discussion

Fiji's sea cucumber fishery started in 1813 (Ward 1972) and ramped up production in the 1880s (Pakoa et al. 2013). Until recently, local communities have lacked knowledge on best-practice methods for processing sea cucumbers into high-quality bêche-de-mer that attract higher prices (Ram et al. 2014b). A training manual for processing sea cucumber into quality bêche-de-mer (Purcell 2014b) has now been adopted in Fiji.

Salt not only aids in dehydrating sea cucumbers and preserving the flesh, it also adds weight to the product, meaning that one earns more income per piece by practising salt-curing. Limited access to coarse salt for fishers is a problem that deprives fishers of potential income from the fishery. We believe the best opportunity for fishers to access to salt in remote areas would be for the Ministry of Fisheries to buy 20-kg bags of salt and sell them at cost price to fishers through their regional fisheries stations. This strategy is currently used for selling ice to fishers.

The problem of some middlemen exploiting fishers by offering unfair prices could be partly addressed through information tools and controls on prices. Many fishers informed us that their product is now of high quality, and should fetch higher prices per kilogram. To minimise the opportunity for subjectivity about product quality, an "industry standard guide" could be developed to illustrate different grades of bêche-de-mer and fair prices. Fishers would then know what prices to expect for different grades for each species. We note that this conclusion and recommendation was also reached through a value-chain analysis in Fiji (Mangubhai et al. 2017).

Recommendations

- Support further training of fishers in postharvest processing using village-based workshops and training manuals should be given across all fishing villages in Fiji in order to improve.
- Take action to make coarse salt available for fishers to buy in remote locations.
- Develop and implement throughout Fiji an "industry standard guide" showing grades and industry-approved prices of bêche-de-mer (e.g. by stocking and selling bags of coarse salt at regional fisheries stations).

Acknowledgements

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5 Pre-export sizes of bêche-de-mer in Fiji

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Abstract

Understanding the population size structure of bêche-de-mer through monitoring of export consignments is critical to the management of the fishery. Here, we present length frequency information for 15 species of bêche-de-mer exported by a single Fiji-based commercial exporter in September 2014. Of the 7497 animals that were measured, 31% were below the 7.6 cm minimum length restriction for exporting bêche-de-mer. Six species were predominantly undersized: *Bohadschia vitiensis* brown sandfish (60%), *Actinopyga miliaris* hairy blackfish (54%), *Holothuria scabra* sandfish (68%), *A. lecanora* stonefish (53%), *B. marmorata* chalkfish (95%) and *Stichopus chloronotus* greenfish (53%). Fiji's current size limit, however, is unlikely to be effective for a multi-species sea cucumber fishery where different species reach reproductive maturity at different sizes. We recommend that minimum size limits be set according to a size larger than which each species becomes fully mature to ensure adequate recruitment and population replenishment. Specifically we recommend the proposed management plan should apply three legal dry size limits of 10, 15 and 20 cm.

Introduction

The Fiji sea cucumber fishery started in the early 1800s with early records showing exports of approximately 600 tonnes between 1827 and 1835 (Pakoa et al. 2013). Of the 27 species of sea cucumber reported in Fiji, at least 22 are important in the sea cucumber fishery (Mangubhai et al. 2017). Historically, this trade was based on high-value species including *A. miliaris* (hairy blackfish), *Holothuria fuscogilva* (white teatfish), *H. whitmaei* (black teatfish), *H. scabra* (sandfish) and *H. lessoni* (golden sandfish). However, this has changed with medium and lower-value species, including *H. edulis* (pinkfish), *Pearsonothuria graeffei* (flowerfish) and *H. atra* (lollyfish) dominating recent exports (Pakoa et al. 2013), and new previously unexploited species such as *Bohadschia ocellata*, *A. spinea* and *Stichopus monotuberculatus* entering the markets (Purcell et al. 2016).

Harvesting and processing of sea cucumbers was restricted to Fiji nationals and outlined in the sea cucumber exploitation guidelines set by the Government of Fiji in 1984 (Adams 1992). By 1988, sandfish *H. scabra* was banned for export and a minimum export size limit of greater than 7.6 cm (3 inches) on all bêche-de-mer was introduced (Adams 1992). Two years after the introduction of the minimum export size limit, undersized bêche-de-mer was reported in exports (Adams 1992) and documented again more recently (Ram 2010).

Overexploitation of the sea cucumber fishery in Fiji combined with a lack of enforcement and poor management prompted the Ministry of Fisheries to develop the Fiji National Sea Cucumber Management Plan in 2013, which aimed to provide policy guidance and direction on the management of the Fiji sea cucumber fishery. Whilst the current single minimum size limit allows for relatively easy monitoring and enforcement, biologically this restriction could contribute to recruitment overfishing as it may be below the size at maturity for many species. Therefore, the Ministry of Fisheries in partnership with the Pacific Community (SPC) conducted a review of the size limit for bêche-de-mer species in Fiji in 2014. Understanding the size structure of bêche-de-mer through monitoring of export consignments will assist in decisions on the management of the fishery. This chapter summarises the size structure of bêche-de-mer in exports from the Vanua Levu (i.e. Northern Fisheries Division). The chapter also gives management advice on proposed size limits the government could legalize through the management plan, and the Ministry of Fisheries and Customs Authority could enforce during monitoring, control and surveillance of bêche-de-mer exports from Fiji.

Methods

From 2–5 September, 2014, staff from the Ministry of Fisheries collected size data from a commercial exporter in Labasa, on Vanua Levu, prior to their processed sea cucumbers (i.e. bêche-de-mer) being packed for export. The exporter gave permission for the data to be collected. Bêche-de-mer species were identified from knowledge of dried forms and identification guides, and verified by the exporter. Each specimen was then measured with a measuring board to the nearest millimetre. Only straight bêche-de-mer were measured, and deformed and bent forms were avoided. A total of 7497 dried animals were measured from 15 species (average of 500 animals/species) over a 4 hour period for four consecutive days.

Results

Of the 7497 bêche-de-mer measured, 31% were below the 7.6 cm minimum length restriction for harvesting and exporting in Fiji (Fig. 1). Six species were predominantly undersized: *B. vitiensis* brown sandfish (60%), *A. miliaris* (54%), *H. scabra* (68%), *A. lecanora* (53%), *B. marmorata* chalkfish (95%) and *Stichopus chloronotus* greenfish (53%) (Fig. 2).

Six species had less than half of the export product undersized: *H. fuscogilva*, *A. mauritiana* (surf redfish), *B. argus* (leopardfish), *H. atra* (lollyfish), *Thelenota ananas* (prickly redfish) and *S. herrmanni* (curryfish) (Fig. 3). Two different size structures were observed in the length frequency for *H. atra* (Fig. 3). This may be attributed to the two types of *H. atra* that are present in Fiji; reef lolly and lagoon lolly, which can be distinguished by differences in size and morphology. Only three species were found to be consistently above the minimum legal size for export: *T. anax* (amberfish), *H. fuscopunctata* (elephant trunkfish) and *H. coluber* (snakefish) (Fig. 4).

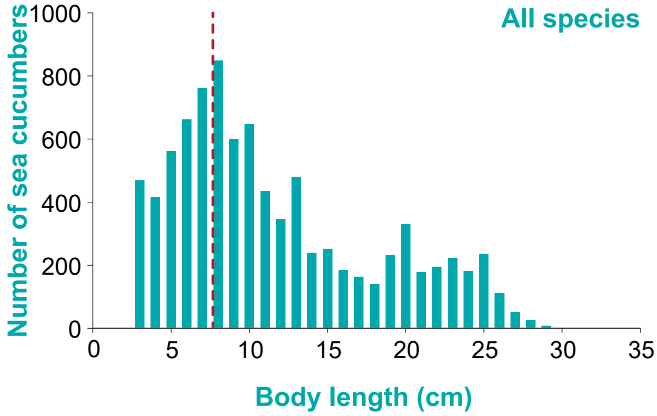

Figure 1. Length frequency for 15 bêche-de-mer species sampled from an exporter's warehouse in Labasa. Red dashed line indicates the current 7.6 cm legal dry size for exporting bêche-de-mer under the Fisheries Act (1942).

Drying and storage of sea cucumbers at a commercial processor's station. © Watisoni Lalavanua/WCS (top, bottom right), Ravinesh Ram (bottom left)

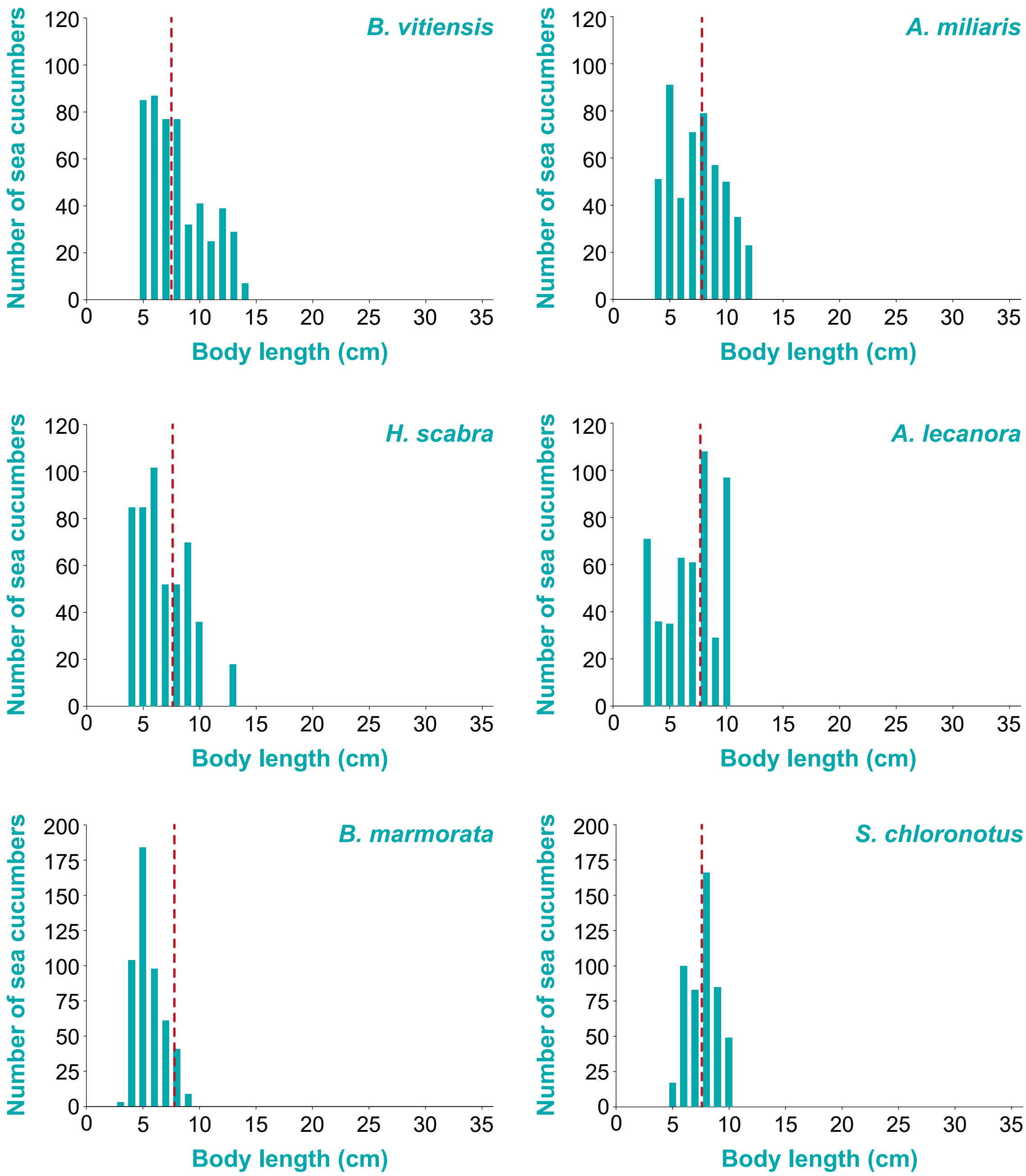

Figure 2. Length frequency for bêche-de-mer species, where 51–100% of individuals measured were below the current legal size limit. Red dashed lines indicate the current 7.6 cm legal dry size for exporting bêche-de-mer.

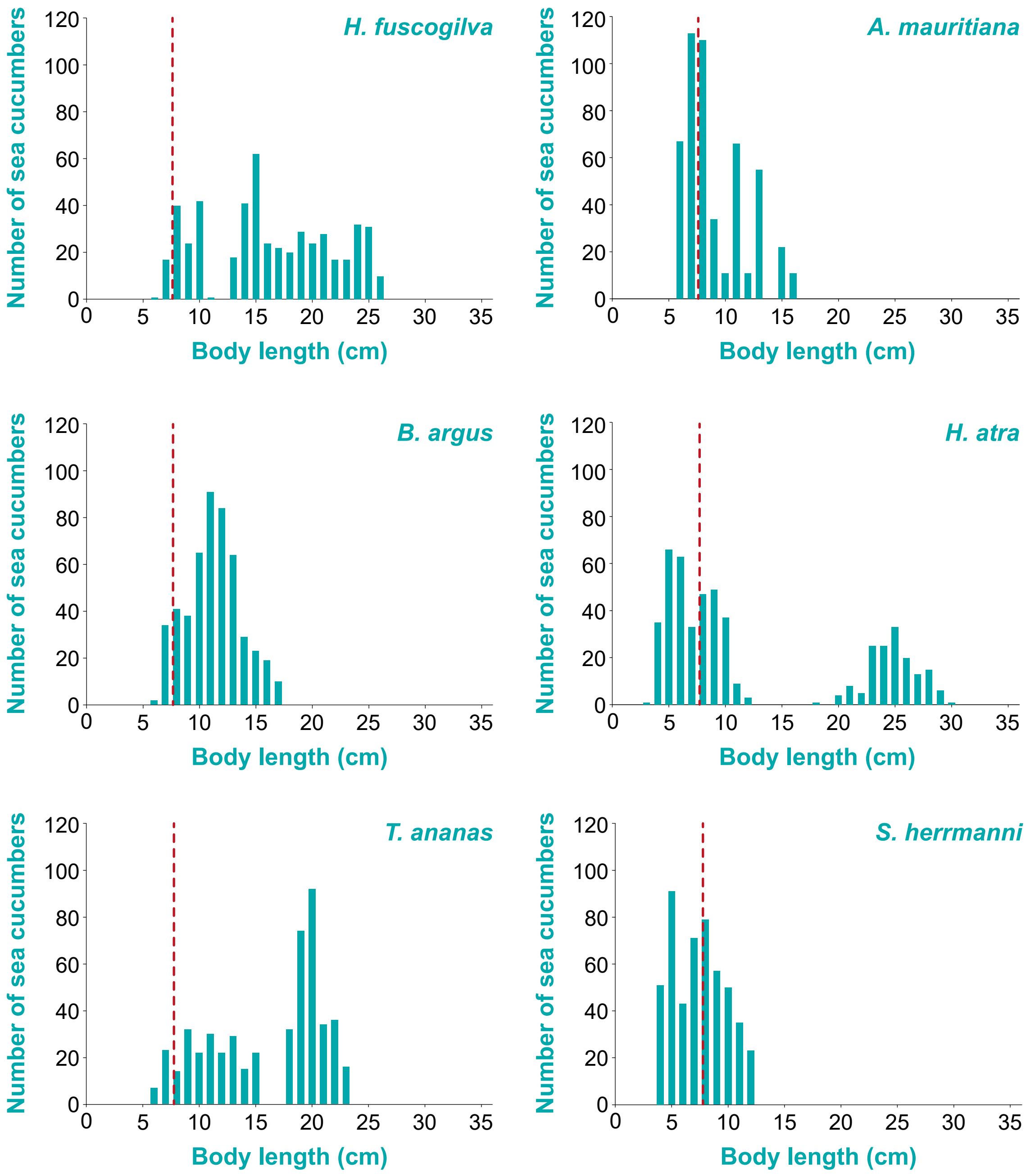

Figure 3. Size structure for bêche-de-mer species where 50% or less of individuals measured were below the current legal size. Red dashed lines indicate the current 7.6 cm legal dry size for exporting bêche-de-mer.

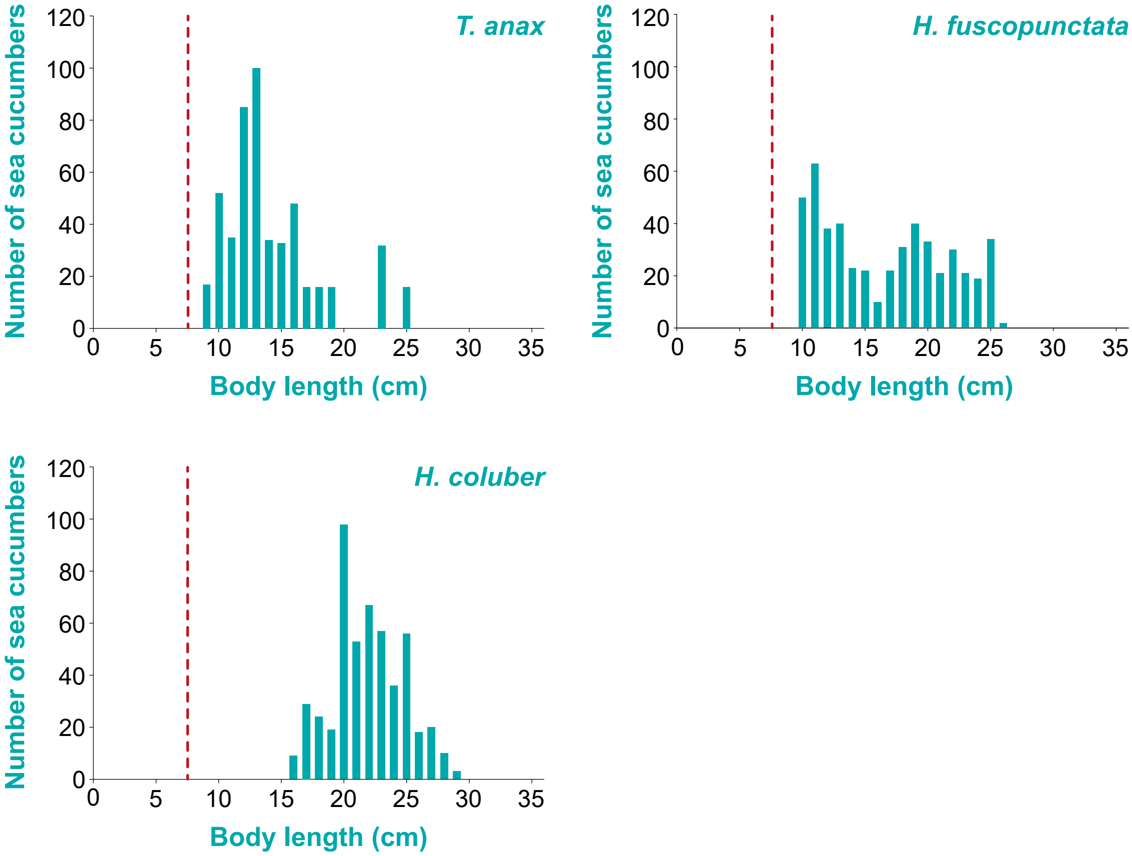

Figure 4. Size structure for bêche-de-mer species where none of the individuals measured were below the current legal size. Red dashed lines indicate the current 7.6 cm legal dry size for exporting bêche-de-mer.

Discussion

A healthy sea cucumber population should be comprised of many large individuals, across a wide range of size classes. The data from this current study confirms the sale and exporting of bêche-de-mer from Fiji that represent juvenile and sub-adult sea cucumbers that are below the current dry legal size limit. This is of great concern given how depleted stocks are in Fiji (Pakoa et al. 2013, Lalavanua et al. 2017) and the impact to local livelihoods (Purcell et al. 2017).

The current legislation provides for a minimum size limit of 7.6 cm (3 inches) for all species. This is inadequate for a multi-species bêche-de-mer fishery where different species reach reproductive maturity at different sizes. For example, *H. scabra* matures at 16 cm wet length (6.2 cm dry length) and *H. fuscogilva* matures at 35 cm wet length (15 cm dry length) (Conand 1990). Therefore, minimum size limits should be set above the size at which sea cucumbers become fully mature to ensure adequate recruitment. Using size-at-maturity data from other countries in the region such as Papua New Guinea, Solomon Islands, New Caledonia and Australia, three sizes limit groups (i.e. 10, 15 and 20 cm total dried length) are recommended to replace of the current single legal size limit in Fiji (Table 1).

The current draft sea cucumber management plan provides a list of species permitted for export, with the list to be reviewed every two years. The management plan proposes the banning of *H. scabra* and *B. marmorata* based on the rationale that these species are important locally for consumption. Given this study found that the majority of *B. marmorata* individuals being exported was mostly below the legal size limit, a ban on exports should stop further declines in natural populations, provided it is strongly enforced.

Monitoring of export consignments prior to export is a cost-effective way of assessing the state of the fishery over time, compared to in-water surveys which are generally expensive and time consuming, and are only indicative of the state of the fishery at a single point in time and at one place. Data on export consignments could be complemented by a compulsory catch logbook scheme if there was a need to get more detailed data on the source of harvest and bêche-de-mer production at provincial, divisional or customary fishing ground (*qoliqoli*) levels. More effective enforcement is critical to reversing the decline in sea cucumbers populations in Fiji.

Recommendations

- Inspections and monitoring of fully processed bêche-de-mer to the species level prior to export.
- Fully enforce the current ban on the export of *H. scabra* and under sized bêche-de-mer from Fiji, through more regular inspections at exporter warehouses.
- Introduce a compulsory catch logbook scheme, where processors or exporters are required to record and report on such information as the source of their bêche-de-mer product, number and weights of sea cucumbers separated by each species, fisher name purchased from, form of product, and location fished.
- Revision to the size limits for fresh (unprocessed) sea cucumbers and bêche-de-mer for Fiji as detailed in Table 1.
- Conduct size-at-maturity studies of bêche-de-mer species in Fiji, and determine if size limits are adequate to protect the successful reproduction of all species harvested and exported.

Acknowledgements

Foremost we would like to thank one of the exporters for providing access to export their warehouse and the Ministry of Fisheries for funding this work. We are grateful to Chloe Vandervord and Steve Purcell for providing edits on this chapter.

Table 1. Proposed size limits based on scientific literature on size at maturity for the species of sea cucumbers.

Trade Name	Local Name	Minimum Size (cm)	
		Live	Dried
Amberfish	Basi	40	15
Black teatfish	Loloa	30	15
Brown curryfish	Laulevu	25	10
Brown sandfish	Vula	35	15
Chalkfish	Mudra	25	10
Curryfish	Laulevu, Kari, Lokoloko ni qio	35	15
Deepwater blackfish	Dri ni cakau	30	15
Deepwater redfish	Tarasea	25	10
Elephant trunkfish	Tinani dairo, Dairo ni toba	35	15
Flowerfish	Senikau	30	15
Golden sandfish	Dairo kula	25	10
Greenfish	Barasi, Greenfish	20	10
Hairy blackfish	Dri, Driloa	25	10
Loli's mother	Tina ni loli	40	20
Lollyfish	Loliloli	30	10
Peanutfish, Dragonfish	Katapila	20	10
Pinkfish	Lolipiqi	30	15
Prickly redfish	Sucudrau	45	20
Sandfish	Dairo	20	10
Snakefish	Yarable,	40	20
Spiky deepwater redfish	Tarasea	25	10
Stonefish	Dritabua, Drivatu	20	10
Surf redfish	Tarasea	25	10
Tigerfish	Vulanicakau, Vulawadrawadra	30	15
White teatfish	Sucuwalu	35	15

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Sea cucumbers drying outdoors. © Ravinesh Ram

6 UBA: What is the social and economic cost to society?

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Abstract

The use of Underwater Breathing Apparatus (UBA) has been banned in a number of countries in the Pacific to reduce overexploitation of marine resources and prevent injuries and deaths caused by decompression sickness. Until very recently, this has not been the case in Fiji where exemptions were granted for a number of fisheries, including for the harvesting of sea cucumbers. In Fiji, a total of 50 injured divers were admitted to the hyperbaric unit in Suva for treatment for decompression sickness from 2012–2014. Of these, 37 were sea cucumbers fishers. The majority of sea cucumber-related UBA injuries (70%) occurred in the Northern and Western Divisions. Analysis of financial data from 2012–2014 showed the annual cost of hospitalisation for UBA-related accidents was FJ$515,000. The cost to society is estimated to be much higher at FJ$5.8 million over this same period. This study demonstrates that the use of UBA in the sea cucumber fishery in Fiji had a large socioeconomic to rural communities, and financial cost to the government and wider society.

Introduction

Over-exploitation, poor fisheries management and high demand from traders have driven declines in stocks in sea cucumbers in Fiji and the wider Pacific (Kinch et al. 2008). As fishers deplete sea cucumber stocks in shallow habitats, many have moved away from free diving and are using Underwater Breathing Apparatus (UBA) to access depths greater than 35 m (Pakoa et al. 2013). UBA gear enables fishers to stay underwater longer and access deeper water species such as *Holothuria fuscogilva* (white teatfish), *Holothuria whitmaei* (black teatfish) and *Thelenota anax* (amberfish) (Purcell 2010). At least 11.9% of sea cucumber fishers use UBA to collect sea cucumbers from their traditional fishing grounds, and are exclusively male who purchase or rent gear themselves or are provided the gear by middlemen or agents (Mangubhai et al. 2016). UBA has been banned for the purposes of collection of sea cucumber in a number of countries in the Pacific (e.g. Federated States of Micronesia, New Caledonia, French Polynesia, Guam, Palau, Tonga), to both protect marine resources from overexploitation and prevent injuries and deaths caused by decompression sickness. In late 2016, Fiji ceased the issuance of exemptions for using UBA to harvest sea cucumbers and so the use of any UBA gear in the sea cucumber fishery is now totally prohibited in Fiji.

With growing concern about the increase in the number of reported cases of decompression illnesses associated with the sea cucumber fishery, the Ministry of Fisheries and the Pacific Community (SPC) conducted a study in 2014–2015 to look at the socioeconomic impacts of UBA-related injuries and the larger financial cost to the government and the wider society in Fiji.

Methods

Between January 2014 and June 2015, officers from the Ministry of Fisheries collected data and conducted interviews with key informants at identified health centres such as the Nausori Health Centre and the Hyperbaric Chamber at the Colonial War Memorial Hospital (CWMH) on the number of UBA relating injuries from each of the four Divisions (Northern, Western, Central and Eastern) in Fiji. Information was gathered on the name, ethnicity and age of the fishers who suffered from UBA-related injuries including decompression sickness. Data from the hyperbaric chamber were only available from 2012–2014.

This study also evaluated both the direct financial and the social costs of accidents caused by the use of UBA to harvest sea cucumbers across the Pacific region. Direct financial costs of hospitalisations and transportation were estimated from the best available data[3]. We used established techniques to evaluate the impact of injuries as a result of reported UBA accidents. The benefits to the fishers and society from using UBA under exemptions were approximated by estimating the value of sea cucumber harvested under exemptions using average per day harvest rates. Combining the social[4] and financial costs and benefits we assessed the net impact on society of the use of UBA to harvest sea cucumbers, using two indicators: (i) the benefit cost ratio (BCR); and (ii) net present value (NPV). A benefit cost ratio of more than 1 means that the benefits outweigh the costs. A positive NPV means that society benefits from an activity, conversely a negative NPV means that society suffers from an activity.

Results

UBA-related injuries

From 2010–2014, there were steady increases in applications for UBA exemptions to harvest sea cucumbers stocks in deeper waters (Fig. 1). In 2010, 25 UBA exemptions were issued and this rose to 65 in 2014. In practise, a single UBA exemption holder was allowed to have up to 24 working divers and up to 95 SCUBA tanks. The Western Division had the greatest number of approved sea cucumber harvesting UBA exemptions in 2010–2011 followed by a significant decrease (Fig. 1). The Northern Division had the highest number of exemptions, with 116 issued in over the period 2010–2014.

A total of 50 injured divers were admitted to the CWMH's Hyperbaric Unit for treatment from 2012 to 2014, 37 of which were sea cucumbers fishers. Between 2012 and 2014 over 79% of cases per year were a result of fishers using UBA for collecting sea cucumbers (Fig. 2a). The majority of sea cucumber-related UBA injuries (70%) occurred in Northern and Western

[3] Where data from Fiji were unavailable, costs were estimated from external sources (e.g. World Bank).

[4] Due to uncertainties, the ecological impact of harvesting sea-cucumber is excluded.

Divisions (Fig. 2b). That only two exemptions were granted during this period to fishers in the Western Division but 14 cases were recorded suggests there were a high number of illegal UBA fishers operating in this Division in those years. Of the reported sea cucumber-related UBA accidents, 97% were within the productive working-force age (18–58 years) and all were men (Fig. 3). These numbers should be seen as under-estimates of the scale of the problem, because many incidences were not reported and the number of deaths annually from UBA related activities is not known for Fiji.

The proportions differed slightly when comparing certified versus untrained/uncertified divers who were admitted for hyperbaric treatment between 2012 and 2014. Forty-two percent of UBA accidents treated were for uncertified divers and 58% for certified divers (Fig. 4). Interviews with sea cucumber fishers that used UBA suggested that the majority of injuries were caused by uncontrolled ascent rates. The divers explained they used UBA because of the quick cash and high monetary returns they received from sea cucumber agents. Most fishers dived more than once per day to depths greater than 30 m. Some divers admitted they did 4–5 dives per day at depths exceeding 30 m. These practices are dangerous and greatly increase the risk of decompression sickness or death.

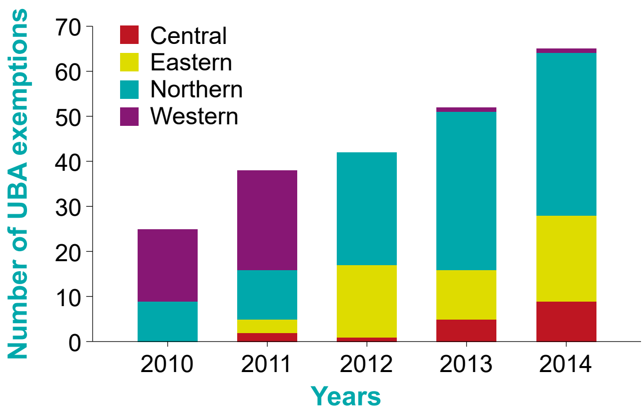

Figure 1. Number of Underwater Breathing Apparatus (UBA) exemptions issued for each division from 2010–2014. Source: Fiji Ministry of Fisheries licensing records

At least 64% of injured divers did not receive any form of 'initial treatment'; i.e. they had no access to any first aid or medical assistance from the time they were first injured (i.e. either at sea or at home village) until they reached the CWMH Hyperbaric Chamber Unit in Suva. Medical officers at CWMH stated that the seriousness of UBA dive-related complications were significantly reduced for patients who received immediate medical attention such as oxygen supply at the accident site. Additional information provided on dive survey forms indicated that 22% of UBA divers who were treated for at least 3–6 months for decompression sickness were re-admitted and treated again in the hyperbaric chamber. Many of the UBA divers who suffered decompression sickness will encounter lifelong problems such as paralysis, body joint pains, chronic back pain and hearing disabilities.

An independent study by a SeaWeb Asia Pacific in 2014 found that for the period 2004–2014, 174 people in Fiji were admitted at the hyperbaric unit for UBA related decompression treatment (SeaWeb, unpublished data). Of the 174 patients treated there was a 15% re-admission rate because these divers would go back to the village and again dive for sea cucumber after their first treatment. Many of the affected local divers would wait until their decompression illness got really bad before going to the hospital. The delay in seeking treatment is likely to lead to more severe and longer term injuries than if they had been treated immediately.

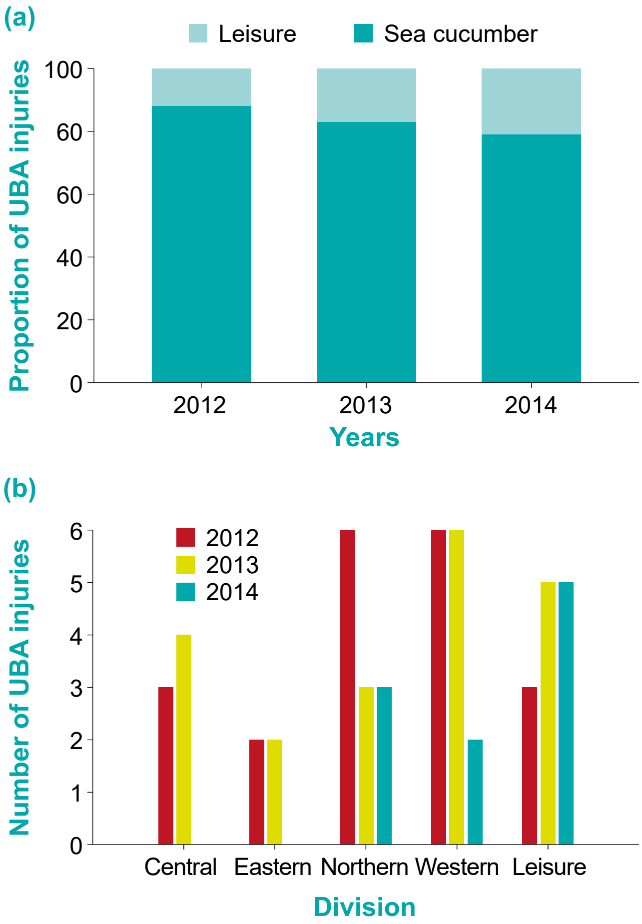

Figure 2. (a) The relative proportion of injuries between sea cucumber fishing by division and leisure diving (i.e. tourist or recreational diving). (b) Officially reported and treated Underwater Breathing Apparatus (UBA) related accidents in Fiji. Source: Colonial War Memorial Hospital Hyperbaric Chamber Unit, Ministry of Health.

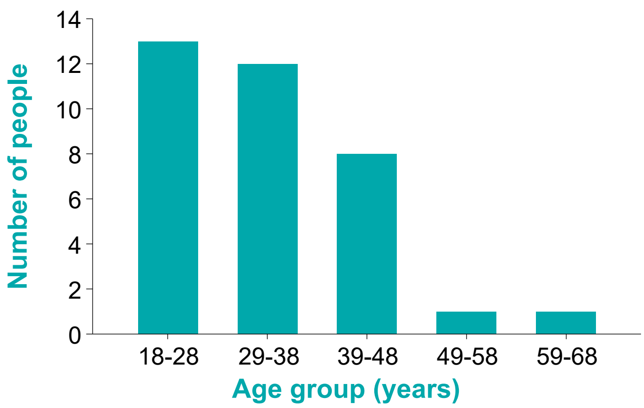

Figure 3. Age distribution of sea cucumber fishers who were treated for decompression sickness. Source: Ministry of Health.

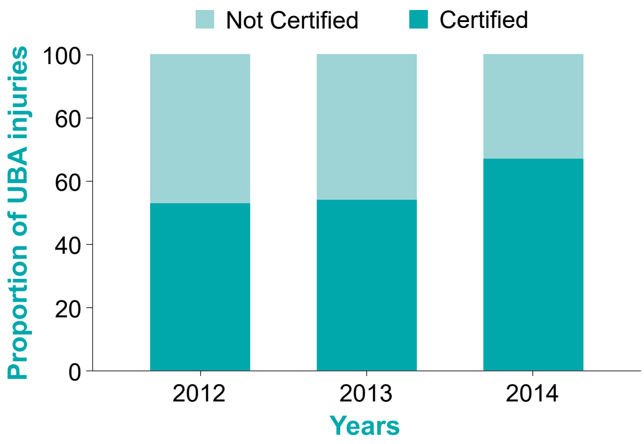

Figure 4. Distribution of Underwater Breathing Apparatus (UBA) accidents related to diver certification between 2012 to 2014. Source: Colonial War Memorial Hospital Hyperbaric Chamber Unit of the Ministry of Health.

Valuing the impact

An analysis of data over the period of 2012–2014 on hospitalisations showed the estimated direct financial cost of UBA-related accidents involving local fishers using UBA averaged FJ$515,000 per year. As discussed above, these accidents have significant impacts on individuals' health and to society more widely. This analysis only reviews sea cucumber harvested under exemptions and not the wider value of sea cucumbers to the Fijian economy. The cost to society is not represented in the financial cost. This analysis shows a NPV of allowing the UBA exemptions for sea cucumber harvesting of negative FJ$5,750,000 from 2012–2014. This means that allowing UBA exemptions has a cost to society of an estimated FJ$5.8m over three years, representing a benefit cost ratio of 0.66. This means it costs society $1 for every $0.66 of benefits extracted.

The analysis does not value some impacts due to the lack of data (e.g fuel costs of harvesting sea cucumber by boat) and uses conservative assumptions (e.g. value of life, length of injuries, treatment time). Therefore the above estimated cost to society is likely to be the minimum cost of harvesting sea cucumber with UBA. Data limitations meant that we could only value the impact on those who attended hospital and not unreported injuries and impacts. Including costs from unreported injuries would increase the cost to society above the estimated $5.8m NPV.

The ongoing injuries were only valued as a cost to the individual. On-going injuries are likely to impact family members of the affected individual. The wider impacts on the family may include greater burden of household tasks, lower food security, lower incomes and less diverse diet among many others. These impacts were excluded from this analysis. Our assumptions state that injuries do not last longer than 3 months and, due to data reliability, deaths are excluded from the analysis. We estimate that including deaths in the analysis would reduce the BCR from 0.66 to below 0.5.

Data limitations required the analysis to focus on the period of 2012–2014 and did not project future injury or harvest rates. Sensitivity testing of the assumptions corroborated the conclusion that using UBA to harvest sea-cucumber has a negative impact on society, and the conclusion is robust to changes in the modelling assumptions.

Discussion

UBA is widely discouraged in the Melanesian countries (Carleton et al. 2013) due to its human and environment disaster (Eriksson 2012, Eriksson et al. 2010). This study documented both the direct financial costs incurred as a result of UBA accidents, such as hospital visits, and the social impact costs such as the impact of the accident on an individual's quality of life. Financial analysis of the available data over the period of 2012 to 2014 shows that the direct cost of hospitalisation resulting from the 37 UBA accidents involving local fishers is an average of FJ$515,000 per year. The analysis showed that the benefits from harvesting sea cucumbers are lower than the financial cost and social cost of injuries associated with the use of UBA.

While there are no national figures on the number of deaths resulting from the use of UBA by sea cucumber fishers, a recent study in 2015 by the Wildlife Conservation Society and Ministry of Fisheries recorded between one and five deaths in a number of villages in Bua Province (Mangubhai et al. 2016). In addition, the ecological impacts of harvesting sea cucumbers are now well documented (Purcell et al. 2016, Lee et al. 2017). These data are excluded from the social cost of the use of UBA above.

The findings from this study were used to submit a Cabinet paper to revoke and prohibit the issuance UBA exemptions, and call for a total ban on the use of UBA across all fisheries.

Recommendations

- Education and awareness materials should be developed for local communities to help them understand the impact of the socioeconomic impacts of the use of UBA for fishing.
- The recent total ban on the use of UBA in Fiji's sea cucumber fishery is supported by this study's findings of substantial costs to the health system and social disruption in communities.
- The issuing of exemptions for the use of UBA to harvest other marine food resources (fishes and invertebrates) should be prohibited.

Acknowledgements

We would like to thank the staff from health centres and the CWMH for sharing their data, and for the Ministry of Fisheries staff who assisted with the survey. We are grateful to Steve Purcell for providing feedback and edits on this chapter. This work was funded by the Fiji Government and the Pacific Community.

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Fishing sea cucumbers using SCUBA tanks. © Watisoni Lalavanua/WCS

7 Effect of sea cucumber density on the health of reef-flat sediments

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Abstract

Sea cucumbers are thought to play an important role in the recycling and remineralization of organic matter in reef sands through feeding and bioturbation. However, growing demand and high prices from Asian markets are driving the overexploitation of sea cucumbers globally, with little understanding of the consequences of local-scale removal from inshore coral reef ecosystems. Densities of *Holothuria scabra* were manipulated in enclosures *in situ* on a reef flat adjacent to Natuvu village, on the island of Vanua Levu, Fiji, between August 2015 and February 2016 to simulate an unfished and an overfished stock density. Two treatments were used: (i) high sea cucumber stocking density (350 g m^{-2}); and (ii) exclusion of sea cucumbers (0 g m^{-2}). Two controls accounted for cage effects: (i) cage controls (no cage walls); and (ii) natural density (60 g m^{-2}). Sedimentary oxygen consumption (SOC), grain size distribution, sediment porosity, and O_2 penetration depth were recorded. SOC rates were consistently lower in high-density enclosures than when sea cucumbers were exclude, indicative of 'healthy' sediments. O_2 penetration depth decreased significantly when sea cucumber removal coincided with elevated sea surface temperatures which are indicative of sediment health decline. Thus the removal of sea cucumbers reduces the efficiency of reef sediment to function as a filter system to buffer organic matter pulses, and negatively affects the function and productivity of inshore reef ecosystems.

Introduction

Sediments in tropical coastal habitats are capable of trapping a substantial amount of organic matter (OM) (Wild et al. 2004). Water flows are able to transport OM into and within the sediment, and small organisms living within sediments are able to efficiently degrade OM (Rush et al. 2006). Because the seafloor and the overlying water are closely linked through such transport processes, changing the function of sediments can have direct negative consequences on the quality of the overlying water (Wild et al. 2004). Porous sediments are thus considered as a kind of biocatalytical filter system (Rusch et al. 2006).

Several factors can affect the efficiency of this filter, including temperature, water currents, the amount of organic matter entering the system, and the burrowing or burying activity of organisms digging up and turning over the sediment, referred to as bioturbation (Kristensen 2000). Of these factors, bioturbation has the greatest effect on the efficiency of the biocatalytical filter, as it can increase the surface area of the sediment and mix the sediment (Kristensen 2000). The efficient function of this filter system is critical as it provides the marine environment with capacity to buffer pulses of OM. The ability to buffer negative effects of OM pulses becomes increasingly important as coastal ecosystems face threats from increasing nutrient and OM inputs from agriculture and sewage discharge (Barnes 1973, Mosley and Aalbersberg 2003).

Several species of sea cucumbers inhabit soft bottom habitats (Purcell et al. 2012), interacting directly with and influencing the quality of sediments through feeding and bioturbation (Uthicke 1999, 2001, Purcell et al. 2016). The present study focused on the deposit-feeding sandfish *Holothuria scabra*, historically found in high densities on reef flats throughout the Pacific (Ward 1972, Shelly 1981). *H. scabra* ingests a large amount of sediment and can bury itself in soft sediments (Fig. 1) during part of the day (Mercier et al. 1999; Purcell 2004), therefore playing a key role in bioturbation. This species is also of high value in the sea cucumber trade (Pakoa et al. 2013, Purcell 2014). Our study investigated the effect of *H. scabra* on the function of the biocatalytical filter system by assessing effects on sediment composition, the depth to which oxygen (O_2) penetrated into the sediment, and sedimentary oxygen consumption (SOC), which are indicators of the decomposition of organic matter. The combination of SOC and O_2 penetration depth indicate how efficiently the sediment is functioning as a biocatalytical filter system.

Figure 1. Bioturbation from *H. scabra* burying cycle exposes anoxic sediment (black/grey) and breaks up algal mats.

Methods

Fieldwork was conducted on an extensive reef flat in front of Natuvu village, Wailevu District East, Vanua Levu, Fiji (16°44.940'S, 179°9.280'E), between August 2015 and February 2016. The site was selected as it had been identified by the Wildlife Conservation Society as having a relatively high *H. scabra* density for the region as a result of restocking of community fish grounds in 2009 (Hair 2012). Densities of *H. scabra* at the study site were similar to unfished densities found in Papua New Guinea (Shelley 1981), and therefore were assumed similar to natural population densities.

Sixteen square enclosures (3 m x 3 m) were constructed at the study site and stocked with two densities of *H. scabra*. Two treatments (*n*=4 per treatment) were used: (i) high sea cucumber density cages (ca. 350 g m^{-2}); and (ii) cages without sea cucumbers or 'exclusion cages' (0 g m^{-2}). Two controls (*n*=4 per control) were established to account for cage effects; natural (ca. 60 g m^{-2}) and cage controls which had no walls/mesh. Natural density (ca. 60 g m^{-2}) was determined in a pilot study at the study site. High density (350 g m^{-2}) was based on high stocking biomass for *H. scabra* used in previous studies in natural ranching sites (Battaglene 1999, Lavitra et al. 2010).

To determine grain size distribution, sediment cores were collected to a depth of 3 cm (*n*=3 per enclosure) and dried in an oven at 70°C for ca. 24 hours. Dry sediment samples were weighed then transferred to a column of sieves (≥2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, <125 µm). The sieve column was shaken for seven minutes, and sediment remaining in each sieve weighed to the nearest 0.02 g. Grain size analysis, textural classifications and distribution of sediments were based on methods by Folk and Ward (1957).

Sediment porosity was determined by comparing the wet weight to dry weight of sediment cores following methods by Olson (2014). The depth to which oxygen reached (penetrated) into the sediment was measured by collecting sediment cores to a depth of 3 cm using a clear corer. The oxygen penetration depth was determined using methods adapted from Kemp et al. (2015); measured as the distance from the sediment surface to the depth at which sediment was consistently darker[5] (Fig. 2).

Figure 2. Sediment corer used to quantify oxygen penetration depth. Consistently darker sediment indicates anoxic sediment, as indicated by a white arrow.

[5] Consistently dark sediment indicates low oxygen conditions.

Lastly, *in situ* sedimentary oxygen consumption (SOC) was measured using methods by Ford et al. (unpubl data). Sediment cores ca. 10 cm^3 were collected to a depth of 1 cm from enclosures and transferred immediately to glass incubation chambers (160 ml). Chambers were then filled with undisturbed water from the same location (*n*=4 treatments per enclosure, *n*=3 controls per enclosure). Controls only contained undisturbed water from our site; this allowed us to account for microbial activity in the overlying water column. Samples were placed into opaque bags and placed in an icebox filled with water from the site to maintain temperature consistency. Approximately 30 ml of water was removed from the chamber to prevent water overflowing from the chamber during measurement. Oxygen (O_2) concentration, salinity and temperature was measured using a WTW Multi 3320™ O_2 sensor and salinity probe. Oxygen saturation was consistently at 70–120% at initial measurements. Water removed (ca. 30 ml) was replaced, and additional water (3–5 ml) collected from the site was used to top-up the incubation chamber to ensure the chamber was sealed airtight with no air bubbles. Chambers were incubated in the corresponding opaque bags, in an icebox filled with water from the site for ca. 1 h. Chambers were collected and O_2 concentration, salinity and temperature were re-measured. The exact durations (min) of all incubations were recorded.

Results from cage controls and natural controls, for each parameter, were compared in post-hoc tests and, if there were no significant differences between natural and cage controls, high density and exclusion treatments were compared. Data from enclosures were analysed using repeated-measures ANOVA.

Results

Cages without sea cucumbers showed no significant difference in grain size composition from September to December. However for the same time period enclosures with high sea cucumber densities exhibited a shift towards finer grains, with an increase in particular in 125 µm grain sediments (*U test, p*=0.03) and a significant reduction in the proportion of 1000 µm grain sediment (*U test, p*=0.03). Due to storm surge affecting our site five days prior to January measurements, we do not consider January results to be caused by the manipulated densities of *H. scabra* in enclosures (treatment).

Sediment porosity showed a marginally significant change over time from the onset of the experiment (*ANOVA, p*=0.05), however there were no significant differences among treatments (*U test, p*>0.05). O_2 penetration depths were similar between high density and sea cucumber exclusion treatments in November (*U test, p*=0.73). Although O_2 penetration increased significantly in December within cages with high sea cucumber densities (*U test, p*=0.03) (Fig. 3), there was no significant difference between high sea cucumber density cages and cages without sea cucumbers (*U test, p*=0.32). February, however, shows a distinctly different pattern. Whilst the high-density treatments had values identical to those in November (*U test, p*=1), oxygen penetration depth in the cages without sea cucumbers decreased significantly (*U test, p*<0.01) by 63% from 32 mm (±3 SE) to 12 mm (±2 SE). Neither controls showed any significant differences in oxygen penetration depth over time throughout the study (*U test, p*>0.05).

At the beginning of the study all cages had similar SOC rates (September *U test, p*=0.55). Four weeks later the SOC rates increased significantly in cages with no sea cucumbers (U-test, September–October, *p*<0.01) by almost two-fold from 43.0 mmol O_2 m^{-2} day^{-1} (±4.6 SE) to 75.96 (±4.7 SE) mmol O_2 m^{-2} day^{-1}. No changes occurred within the high sea cucumber density cages during the same time period (U-test, September–October, *p*=0.74).

Heavy rains and flooding occurred ten days prior to November sampling (Fig. 4). Following the flooding, SOC rates increased significantly without high-density cages (U-test, October–November, p=0.03). In November there were no longer significant differences among treatment cages (U-test; November; p=0.25). Following further heavy rains prior to sampling in January, both treatments showed similar patterns as before (i.e. SOC rates decreased within the cages with no sea cucumbers and increased within cages with high densities of sea cucumbers), and were not significantly different from each other in January (*U test,* p=0.99) and February (*U test,* p=0.07).

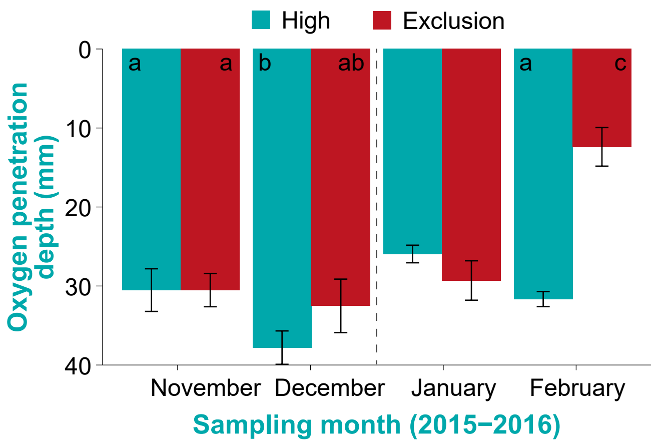

Figure 3. Oxygen penetration depth (mm) of high density and exclusion treatments. Mean values with standard error. Vertical break indicates flooding and storm surge five days prior to January sampling. Different letters (a, b, c) indicate significant differences (p<0.05), same letters indicate no significant differences (p>0.05). January results were not considered in the analysis.

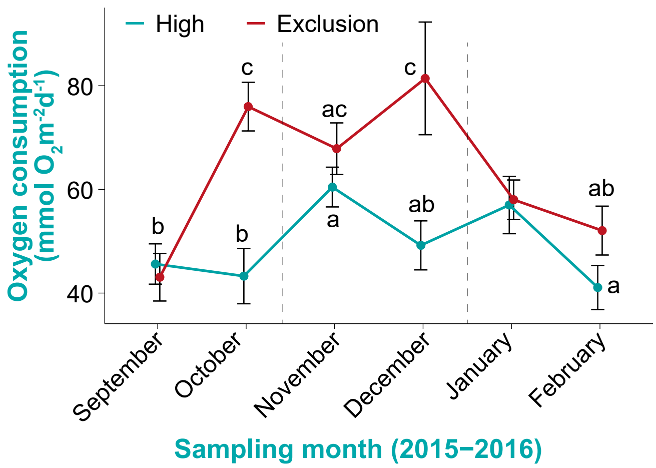

Figure 4. Sedimentary oxygen consumption (mmol O_2 m^{-2} day^{-1}) of high sea cucumber density (High) and areas void of sea cucumbers (Exclusion). Mean values with standard errors. Vertical break between October and November indicates flooding 10 days prior to November sampling. Vertical break between December and January indicates flooding and storm surge 5 days prior to January sampling. Different letters (a, b, c) denote significant differences (p<0.05), same letters (a, a/ b, b/ c, c) denote non-significant differences (p>0.05). January results were not considered in the analysis.

Discussion

Changes to grain size composition in the presence of sea cucumbers, and the lack of any significant changes in their absence suggest that when sea cucumbers are present on inshore reef flats they play a key role in the physical reworking and change of sediment structure in marine ecosystems. Several species of sea cucumber are able to change sediment grain size through dissolution via acidity in their gut (Hammond 1981), and potentially abrasion while sediment passes through their gut.

Generally in the presence of high densities of sea cucumbers, SOC rates exhibited a buffered response, recovering to near background levels following flooding at the study site. A similar 'buffered' response was observed in O_2 penetration depth, where the absence of sea cucumbers caused erratic changes in O_2 penetration depth.

The abrupt decrease in O_2 penetration depth from December to February coincided with increased water temperatures (26°C in December to 31°C in February) and calm weather, however O_2 penetration depth remained unaffected in areas with high densities of sea cucumbers. Warmer seawater temperatures likely caused small organisms and microbes within the sediment to consume more oxygen (Nydahl et al. 2013). Relatively calm conditions for the same time period meant limited mixing of the sediment and overlying water column by wave action, normally this mixing helps to deliver oxygen into sediment and the overlying water. The buffered response of O_2 penetration depth recorded in areas with high densities of sea cucumbers suggests that during such weather conditions (warm seawater temperatures, calm seas), bioturbation by sea cucumbers may provide essential mixing, helping to deliver oxygen into the sediment.

Sea cucumbers actively feed on organic matter (OM), reducing its concentration in sediment (Uthicke and Karez 1999, Michio et al. 2003). Therefore, it is likely that there was a reduced concentration of OM in sediment where high densities of sea cucumbers were present compared to areas where sea cucumbers were excluded. The resulting high concentrations of OM in the absence of sea cucumbers likely caused an increase in the activity and abundance of small organisms (including microbes) within the sediment (MacTavish et al. 2012), as they would feed on the abundant OM. Respiration of these small organisms, and their waste products, are likely to have resulted in the increased SOC rates (Kristensen 2000).

The buffered responses of SOC and O_2 penetration depth in sediments where high densities of sea cucumbers were present are likely to have been caused by the considerable bioturbation impact *H. scabra* has on sediments (Purcell, 2004; Lee 2016). Bioturbation increases the surface area of the sediment and helps to drive water flow into and within sediment, delivering O_2 and degradable materials. High densities of sea cucumbers likely promoted aerobic decomposition[6] of OM, which is ca. 10 times faster than anaerobic[7] (Kristensen et al. 1995).

Trends seen in SOC and O_2 penetration depth indicate that some functions of sediments, i.e. as a biocatalytical filter system, are compromised as a result of sea cucumber removal. The resistance and resilience of coastal ecosystems to local (e.g. increased nutrient or OM content) and global (e.g. increased sea surface temperatures) stressors are likely being compromised by the extensive reduction in sea cucumber stocks of inshore areas. Consequently the ecosystem

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6 Aerobic decomposition – the breakdown of biodegradable material in the presence of oxygen

7 Anaerobic decomposition – the breakdown of material in the absence of oxygen

functions that Pacific Island communities rely heavily on for their food and livelihoods are being undermined by the removal of sea cucumbers, leaving coastal ecosystems and the communities that rely upon them increasingly vulnerable.

Recommendations

- Moderate to high densities of sea cucumbers should be maintained on reefs through effective regulatory controls on fishing. This will allow sea cucumbers to play their role in maintaining sediment function.
- Given the current low abundances of sea cucumbers in Fiji, the proposed national sea cucumber management plan should consider a moratorium on collection and sales until stocks are able to sufficiently recover and ecosystem function is restored.

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8 Genetic connectivity among populations of lollyfish (*Holothuria atra*)

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Abstract

Preserving genetic connectivity across populations is crucial to maintain genetic diversity and is therefore a conservation management priority. We assessed the degree of genetic connectivity of *Holothuria atra* (lollyfish), which is fished commercially in Fiji. We compared the mitochondrial DNA cytochrome oxidase I (COI) gene of specimens from reefs of four Fijian islands. The populations show overall genetic connectivity, with net gene flow moving from east to west along the Bligh Waters, a major oceanic current in Fiji. There was unexpectedly high differentiation, inferring low connectivity, between the two populations (Taveuni and Vanua Levu) that were spatially nearest to each other. The Vanua Balavu population had the lowest genetic diversity while Malevu in the Yasawa group had the highest. This study on *H. atra* indicates that sea cucumber populations in eastern Fiji should be carefully managed because they might act as sources for population replenishment and gene flow for stocks in western Fiji. Management plans should consider the fishery as a network of reefs, and regulations need to maintain viable breeding populations on each island in order to safeguard genetic biodiversity of sea cucumber stocks within the fishery.

Introduction

Genetic connectivity is a measure of great importance when considering the status of a fishery. It is a proxy for dispersal and mating between members of different populations within a species, and therefore a high level of measured genetic connectivity among populations indicates a high degree of physical movement across geographic regions over multiple generations. Low genetic connectivity indicates that populations are structured, and that individuals from those populations disperse between sites less frequently (Lowe and Allendorf 2010).

Behaviour, locomotion, life history, and habitat all effect how organisms interact with their physical environment, and thus influence connectivity. Despite the capabilities of some larvae, oceanic currents can limit genetic connectivity between populations if individuals are unable to traverse those currents, as this reduces gene flow (Barber et al. 2002, Treml et al. 2008). Conversely, ocean currents can promote connectivity if they transport larvae from upstream to downstream sites, thus generating asymmetrical gene flow (Vuilleumier and Possingham 2006).

Genetic connectivity data can inform decisions about the harvest and/or protection of fishery-targeted species. One tool commonly used to mitigate global reef and fisheries degradation is the creation of marine reserve networks – i.e. spatially explicit areas of ocean where human activities are regulated or prohibited. The optimal orientation for reserve networks requires information concerning the degree of demographic or larval exchange occurring between populations, which can be estimated with genetic connectivity (Roberts et al. 2003, Almany et al. 2009). Reserve networks that explicitly incorporate connectivity in their design are more resilient to threats like overfishing, disease, and climate change because neighbouring reserves can help reseed reefs in the event of disturbances, thereby boosting the stability of the system as a whole (McLeod et al. 2008, Almany et al. 2009, Green et al. 2014).

Previous work on genetic connectivity among reefs in Fiji revealed asymmetrical gene flow along an east-west gradient for three of five coral reef fish species studied, potentially indicating that the Bligh Waters – a fast-moving current that bisects Fiji's main islands – could be facilitating larval transport for multiple taxa within Fiji (Drew and Barber 2012). However, that study was based on a suite of fish species that were not fisheries targets. A more relevant framework for conservation planning might instead be crafted based on the connectivity dynamics of economically significant species. Here, we expand upon previous work and investigate the role of the Bligh Waters in shaping the connectivity patterns of a holothuroid species commonly targeted by inshore fisheries across the Fijian archipelago: the lollyfish *Holothuria atra* (Family: Holothuriidae).

Methods

Study species

Holothuria atra, widely known as lollyfish, is a significant species harvested throughout the Indo-Pacific (Bruckner et al. 2003, Purcell et al. 2013). *H. atra* can reproduce both sexually via broadcast spawning, and asexually by fission (i.e. splitting), producing anterior and posterior parts that each can regenerate a full body (Chao et al. 1993, Conand 1996). The larval duration of *H. atra* is approximately 18–25 days (Laxminarayana 2005, Skillings et al. 2011), and its range extends from the Western Indian Ocean to the Eastern Pacific Ocean. It tends to be relatively sedentary as an adult, and congeners (members of the same genus) have been recorded as traveling <20 m per day (Navarro et al. 2013).

Sample collection

We sampled lollyfish at four locations across Fiji (Fig. 1), with study sites chosen to maximize regional coverage within the country. All individuals were collected under the auspices of a Columbia University Animal Care Protocol (AC-AAAF6300) and followed the laws of the Republic of Fiji and with permission of the traditional marine resource owners. Forty *H. atra* individuals were collected by hand. A small sample of the outer body wall was taken from each individual, and was stored in ethanol or frozen in liquid nitrogen to preserve DNA. Individuals were then placed back onto the reef.

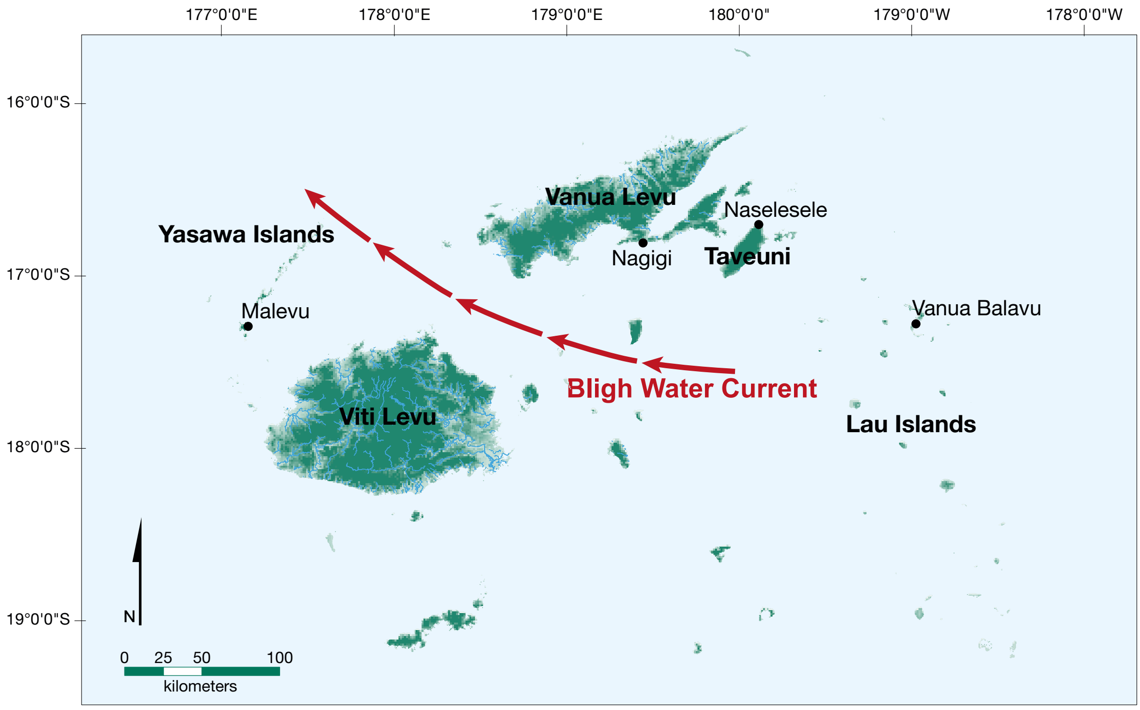

Figure 1. Sampling locations within Fiji, with island names in bold and village names adjacent to points.

Genetic analysis

Genomic DNA was extracted from dermal samples using a DNeasy Tissue Kit (Qiagen, Hilden, Germany). We amplified part of the cytochrome c oxidase 1 (COI) gene using primers designed by Skillings et al. (2011). Polymerase chain reaction (PCR) parameters are reported by Eastwood et al. (2016). Sequences were generated at the American Museum of Natural History on an ABI 3730 sequencer (Applied Biosystems, Inc., Foster City, CA, USA) and sequence quality was checked and sequences were aligned using Geneious 8.0 (Kearse et al. 2012). Sequences were deposited in GENBANK with accession numbers KT378456-KT378495.

Data analysis

To investigate the amount of genetic differentiation occurring between sampled populations, pairwise ΦST measures (a modified *F*-statistic specific to mitochondrial DNA) were calculated for each species in ARLEQUIN 3.5 (Excoffier and Lischer 2010), using 1000 replicates to estimate significance.

To test whether regional-level genetic structuring was present, analyses of molecular variance (AMOVAs) were also performed in ARLEQUIN. Data from Daliconi and Narocivo, two villages 13 km apart on the island of Vanua Balavu, were pooled into island-level assemblages because low sample sizes would have made individual locality results unreliable (n=3 and n=4, respectively).

We calculated magnitude and direction of gene flow using MIGRATE-n (Beerli and Palczewski 2010). Two runs of 1,000,000 generations were conducted with an initial 25% burn-in. Because of this program's underlying assumptions that population size and migration rates have not changed over time, Tajima's *D* statistics were determined in ARLEQUIN, to assess the likelihood of recent demographic expansion or contraction for each species.

Finally, to test whether any observed genetic differences could be due to geographic distance versus phylogeographic barriers, a Mantel test was also performed for each species using Isolation-By-Distance 3.23 (Jensen et al. 2005).

Results

We sequenced 376 base pairs of the COI gene from 40 individuals of *H. atra*, which displayed low haplotype diversity. *H. atra* exhibited complex patterns of connectivity among the four populations sampled, with a wide range of pairwise ΦST values (Table 1). There was little to no genetic differentiation between Taveuni and Vanua Balavu but a high degree of partitioning between Taveuni and Vanua Levu despite these two locations' geographic proximity.

Table 1. Population fixation indices (Φst) for the four sampled populations. * indicates $p<0.05$.

	Vanua Levu	Taveuni	Yasawa	Vanua Balavu
Vanua Levu	—			
Taveuni	0.3287	—		
Yasawa	0.0865	0	—	
Vanua Balavu	0.5042*	0	0.1395	—

Further, the majority of *H. atra* samples (*n*=35) fit into one of three haplotypes (Fig. 2). The most highly represented haplotype (*n*=23), accounting for 58% of samples, was found in all four sampled locations, suggesting an overall trend of connectivity across the region despite observed differences in the degree of connectivity in each pair of sites.

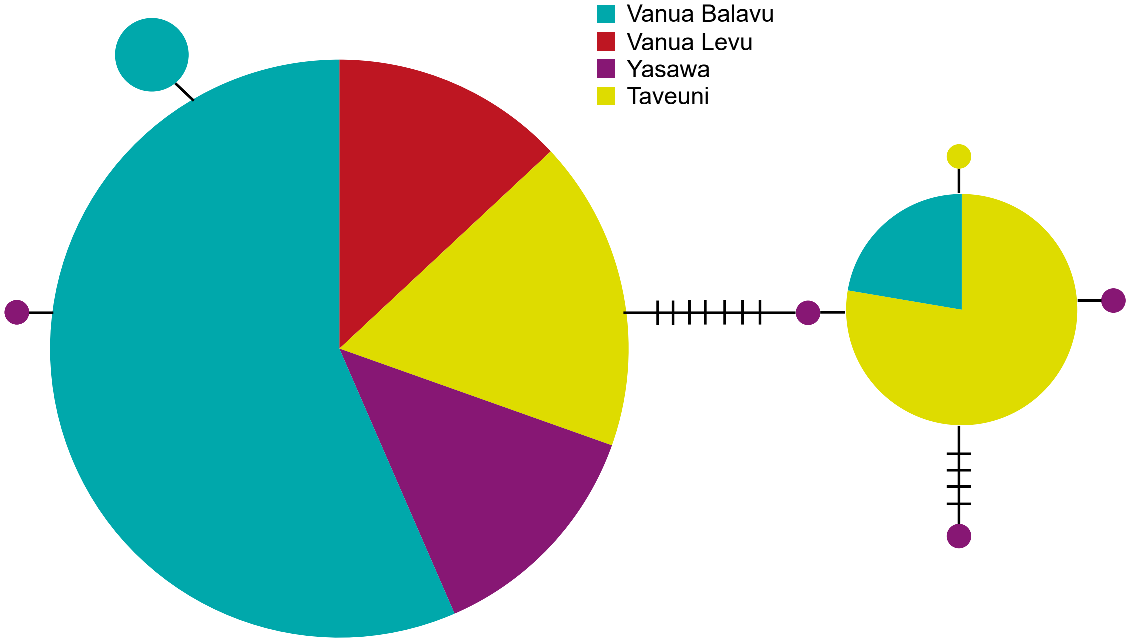

Figure 2. Haplotype network for *Holothuria atra*. Each circle represents a haplotype. Size of the circle is scaled to the number of individuals that share that haplotype, Hash marks on connecting lines indicate the number of base pair differences between haplotypes.

MIGRATE analyses resolved high levels of migration but with a predominately east-to-west pattern. The highest estimated median number of migrants per generation was from Vanua Balavu to Taveuni (672), while the lowest estimated number of migrants per generation was from Malevu to Vanua Balavu (388). There were more westward moving migrants than eastward moving migrants for four of the six pairs of sites. (Table 2). This concurs with previous studies showing unidirectional patterns of east-to-west gene flow for several Fijian taxa (Drew and Barber 2012). The east to west pattern of gene flow for *H. atra* is also supported by the haplotype diversities of each location, as the western population of Malevu, in the Yasawa islands, has the highest genetic diversity while Vanua Balavu, which lies farthest to the east in the Lau group, has the lowest (Fig. 2).

Table 2. Median number of recruits per generation as generated by MIGRATE, with migration occurring from row to column.

	Vanua Levu	Taveuni	Yasawa	Vanua Balavu
Vanua Levu	—	522	480	555
Taveuni	455	—	514	412
Yasawa	438	487	—	388
Vanua Balavu	533	672	582	—

Finally, the Mantel test revealed little correlation between pairwise measures of genetic differentiation and geographic distance in *H. atra* (R^2 = 0.010), indicating that this species' patterns of genetic differentiation cannot be explained simply by geographic distance between populations.

Discussion

The Yasawa population, which lies farthest downstream the Bligh Waters, has the highest intra-population genetic diversity while Vanua Balavu, which lies farthest upstream, has the lowest. This suggests that larvae spawned in Vanua Levu, Taveuni, Vanua Balavu and other unsampled populations may potentially recruit more often to reefs in the western Yasawa Islands, promoting high genetic diversity there. The results from MIGRATE also support the hypothesis of east-to-west larval transport via the Bligh Waters, as those results show that Vanua Balavu exports the most larval migrants out to the more westerly islands, and Naviti exports the fewest larval recruits east to Vanua Balavu.

The populations in the Vanua Balavu and Taveuni were genetically divergent from those in Vanua Levu, despite their relative proximity. This may be due to oceanographic characteristics of the Somosomo Strait, the narrow channel that passes between the islands of Taveuni and Vanua Levu. More oceanographic investigation is necessary to understand if larvae spawned at Taveuni are brought out to sea by a current that bypasses the reefs on the southern edge of Vanua Levu. Skillings et al. (2011) found *H. atra* to be genetically differentiated across distances comparable to that between Vanua Levu and Taveuni (75 km), suggesting that there are many other factors besides this species' larval potential to drift great distances that determine larval dispersal and consequent connectivity.

The boom-bust demographic cycle of *H. atra* (Uthicke et al. 2009) may explain how all populations came to share the dominant haplotype, but still display levels of differentiation between populations. This shared haplotype may be the vestige of a time when there were large population sizes and high rates of migration, while the varying levels of genetic differentiation may be the result of subsequent population contraction and lesser gene flow across the archipelago. This is supported by *H. atra*'s positive, though non-significant, Tajima's-*D* (0.71194, p=0.712), which indicates that the sea cucumber populations studied may have undergone recent demographic contraction (Tajima 1983).

It is important to recognize that this study represents the genetic connectivity of a single species, and that these results may not be generalizable to other sea cucumber species. However, this study does corroborate previous findings that the Bligh Waters contribute to larval flow in Fiji, and that reefs across Fiji are interconnected. Management plans that consider connectivity across reefs may provide the best outcomes for maintain Fiji's rich biodiversity.

These results were originally published in Eastwood et al. (2016). For complete background, results and discussion, as well as connectivity data for two Fijian reef fish species, see Eastwood et al. (2016).

Recommendations

- This study on *H. atra* indicates that sea cucumber populations in eastern Fiji may act as sources for population replenishment and gene flow for stocks in western Fiji, and should therefore be prioritised in management plans.
- Regulations and enforcement should be especially robust for the eastern islands of Fiji in order to safeguard genetic biodiversity of sea cucumber stocks within the fishery.

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Recommendations

Below is a consolidated summary of the key recommendations from each of the papers presented in this report.

1. National Management Plan

- A major shift in management strategy is needed to safeguard the sea cucumber fishery for the future. The new management plan should impose a shortlist of permissible species (which are the only ones that can be collected and exported), which excludes species at low current abundance and those recognized as being threatened. In order to keep the fishery active, the Ministry of Fisheries should consider reducing fishing effort by quickly bringing in more restrictive regulations such as very short fishing seasons (e.g. 2 months per year until stock abundance recovers), or greatly reduce the number of fishers permitted to collect sea cucumbers by imposing 'limited-entry rules' that reduce the number of fishers to no more than one thousand in the whole country. If the Ministry cannot impose such regulations rapidly (i.e. within the coming year), then it may wish to consider imposing a 10-year moratorium on all collection and exporting, and plan to only open fishing after this period and for species that have been shown by underwater censuses to be well above regional reference densities and their size at maturity.
- The management plan should include more robust regulations, including more appropriate size limits, shortlists of permissible species, a complete ban on the use of UBA, and a licensing system that will reduce the number of exporters and fishers in the fishery.
- Prohibition on the collecting of sea cucumbers species from areas where populations are below regional reference densities.
- Revision of the minimum legal size limit for fresh (unprocessed) sea cucumbers and bêche-de-mer for Fiji as detailed in Table 1 in Tabunakawai-Vakalalabure et al. (2017a).
- Regulations and enforcement should be especially robust for the eastern islands of Fiji in order to safeguard genetic biodiversity of sea cucumber stocks within the fishery.

2. Value adding and post-harvesting standards

- Development and implementation throughout Fiji of an “industry standard guide” showing grades and industry-approved prices of beche-de-mer.
- Village-based workshops and training manuals should be given across all fishing villages in Fiji in order to improve the quality of the processing of sea cucumbers, especially at the community level.
- Action by the Ministry of Fisheries to make coarse salt available for fishers to buy in remote locations (e.g. by stocking and selling bags of coarse salt at regional fisheries stations).

3. Monitoring and research

- Use socioeconomic surveys to diagnose changes in sea cucumber stocks.
- Introduce a compulsory catch logbook scheme, where processors or exporters are required to record and report on such information as the source of their bêche-de-mer product, number and weights of sea cucumbers separated by each species, fisher name purchased from, form of product, and location fished.
- Conduct size-at-maturity studies of bêche-de-mer species in Fiji, determine if size limits are adequate to protect the successful reproduction of all species harvested and exported. This could be undertaken as part of a postgraduate student project.

4. Enforcement

- Enforcement of the ban on the export of *H. scabra*, with strong penalties (e.g. fines, cancelling of licences) for non-compliance.
- Enforcement of the ban on the use of UBA for harvesting sea cucumbers. Education and awareness materials should be developed for local communities to help them understand the impact of the socioeconomic impacts of the use of UBA for fishing.
- Stronger enforcement and controls over what species, sizes and volumes leave Fiji, would have a quick 'trickledown effect' throughout the value chain.

Sea cucumber species recorded in community fishing grounds in Fiji. Clockwise: flowerfish, curryfish, greenfish leopardfish, amberfish, pinkfish. © Sangeeta Mangubhai, Watisoni Lalavanua/WCS