Economic and other benefits of enforcing size limits in Melanesian sea cucumber fisheries

Steven Lee[1], Hugh Govan[2], Matthias Wolff[3], Steven Purcell[4]

Abstract

Melanesian countries have made recent progress in developing sea cucumber fishery management systems including tools such as species-specific minimum legal size limits. Despite a consensus among the scientific community that size limits are a vital management tool, decision-makers, fishers and traders might not fully appreciate the benefits of minimum size limits. Consequently, compliance and enforcement is often weak. It is relatively clear that any increase in the length of time sea cucumbers are allowed to grow increases the chances of reproductive success and prolongs their beneficial impacts on the ecosystem; however, the economic benefits of doing so are not so straightforward. This study modelled the economic benefits of imposing and strictly enforcing science-based minimum size limits in sea cucumber fisheries. Four high-value species *Thelenota ananas, Holothuria scabra, H. fuscogilva, H. whitmaei* were investigated, using size limits that have been recently agreed upon by the Melanesian Spearhead Group (MSG), and size distribution samples from recent export data from Fiji and Vanuatu. Our analysis found that if minimum legal size limits were enforced, the entire long-term harvest of some species could increase by up to 97% and generate up to 144% more revenue. In other words, fishers and governments lose significant revenue by not strictly enforcing size limits. This economic loss reinforces the importance of enforcing strict science-based size limits in sea cucumber fisheries.

Introduction

Many coastal and island communities of Pacific Island countries and territories (PICTs) have generated considerable income from sea cucumber fisheries over the last two centuries (Turbet 1942; Russell 1970; Ward 1972). The sea cucumber fisheries of Melanesian Spearhead Group (MSG) countries (Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia and Fiji) have traditionally supplied the majority of exports from the Pacific Islands region (Govan 2018). Furthermore, Melanesia's sea cucumber fishery is reputedly the second-most valuable export fishery in that region, after tuna (Pakoa et al. 2013; Léopold 2016; Govan et al. 2018). The animals are almost exclusively exported in the processed form known as beche-de-mer (BdM).

Growing demand from Asian markets, particularly China, has fuelled a rapid expansion of sea cucumber fisheries throughout the region in recent decades (Purcell et al. 2013; Eriksson et al. 2015). However, development and adaptation of management systems of these fisheries have been outpaced by the rate of exploitation. Consequently, most, if not all, sea cucumber stocks of PICTs have been overexploited (Carleton et al. 2013; Purcell et al. 2014). In response to population collapses caused by overfishing, many PICTs have imposed moratoria to allow stocks to recover that are alternated with short fishing seasons. Although some form of periodic exploitation cycle has characterised the fishery since it began in the early 1800s (Kinch et al. 2008), recently, the loss of production caused by over-exploitation has been equated with substantial economic loss to fishers and national export tariffs (Carleton et al. 2013).

Over the last five years, Melanesian countries have made progress on developing sea cucumber fishery management systems (Govan 2018). Their management plans – along with the improvements in staffing and/or technical capacity, which are evident in fisheries agencies – provide the basis for improving the sustainability of the fisheries and increasing revenue for fishers and national coffers.

As part of these management systems, three Melanesian countries (Papua New Guinea, Solomon Islands and Vanuatu) recently introduced national sea cucumber fishery management plans (Govan 2018). However, the enforcement of the two main management tools, i.e. catch quotas and minimum legal size limits, has been extremely poor (Govan 2018). When exports have been sampled, a considerable proportion of the animals were found to be under the minimum legal size. For example, in Vanuatu, Léopold (2016) found that 83% of BdM exports in 2015–2016 were under the national legal size limit. In Fiji, 31% of exports were found to be below the current minimum legal dry size limit (Tabunakawai-Vakalalabure et al. 2017). If the best

---

[1] Corresponding author. Email: steven.d.a.lee@gmail.com. P.O. Box 4332, Nadi, Fiji.

[2] Consultant, SPC-World Bank PROP / Adjunct Senior Fellow, University of the South Pacific (USP), School of Government, Development & International, Affairs (SGDIA). Email: hgovan@gmail.com

[3] Leibniz Center for Tropical Marine Research. Email: matthias.wolff@leibniz-zmt.de

[4] Associate professor, Southern Cross University. Email: Steven.Purcell@scu.edu.au

available size-at-maturity data from countries in the region (Papua New Guinea, Solomon Islands, New Caledonia and Australia) calculated by Tabunakawai-Vakalalabure et al. (2017) are used then 67% of Fiji's exports would be immature specimens.

Minimum size limits (MSLs) provide a powerful and relatively easy tool for managing sea cucumber fisheries (Friedman et al. 2008; Purcell 2010). MSLs set that are well above the estimated size-at-maturity can ensure that animals are able to reproduce before entering the fishery – improving the fishery's sustainability, and possibly increasing revenue as well (Pakoa et al. 2013; Léopold 2016; Purcell et al. 2018). Furthermore, sea cucumbers fulfil important ecosystem functions (Purcell et al. 2016a; Lee et al. 2017). Allowing these animals to reach MSL means they perform their ecosystem roles for a longer period of time. MSG countries recently agreed that common MSLs should be implemented in future management plans (Govan et al. 2018) based on those proposed by Tabunakawai-Vakalalabure et al. (2017).

Although MSG countries have made some progress towards managing their sea cucumber fisheries, gaining political and public support for fishery management interventions remains a challenge. If enforcing science-based MSLs could increase revenue from the fishery it should provide a strong impetus for the political will to enforce these measures and improve the likelihood of public compliance. It could also provide the opportunity to recover enforcement costs. The purpose of this study was to estimate the potential changes in stock biomass and revenue for four species of harvested sea cucumber (*Thelenota ananas; Holothuria scabra; Holothuria fuscogilva; Holothuria whitmaei*) if MSLs were enforced, and compare the resulting revenue and biomass to actual exports.

Modelling methods

Full details of the modelling methods are provided in Annex 1. Biological parameters to estimate growth of the animals to a given size were based on the best conservative estimates from published studies.

Essentially the model did three things:

1. Calculated the time it takes for a sea cucumber to grow to MSL
2. Calculated the number of animals that would survive during the time taken to grow to MSL
3. Calculated the biomass and value (yield) of the surviving animals (survivors) that have reached MSL

The yield of survivors, and the yield of the animals already >MSL were added together to determine the yield of the entire harvest if MSLs were enforced. This was then compared with the estimated yield of the current situation in which MSLs are inadequately enforced – i.e. the length-frequency of BdM reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016).

The authors note that the modelling method used in this paper has been simplified and restricted to only four species, which is due to the scarcity of available data. As new and reliable data become available, this work should be built upon and refined. Similar research is encouraged, since investigating economic returns brought about by fisheries management tools/schemes can provide tangible results that are useful for policy makers.

Results

Table 1 summarises the undersized portion of samples reported by Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016) for Fiji and Vanuatu, respectively, using the MSG-agreed MSLs. Figure 1 illustrates the differences in biomass and revenue of the entire harvest between the current situation in which MSLs are inadequately enforced and if MSLs were adequately enforced.

If MSLs were enforced, the biomass from the entire harvest of the four species would have been between 8–69% greater for Fiji, and 1–97% greater for Vanuatu. Likewise, revenue from the entire harvest of the four species would have been between 12–111% greater for Fiji, and 2–144% greater for Vanuatu.

Table 1. Portion of the sample reported by Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016) – Fiji and Vanuatu, respectively – that were undersized compared to agreed MSG minimum size limits (Govan et al. 2018).

Species	Dry size limit	Percentage of sample undersized	
		Fiji	Vanuatu
Thelenota ananas (prickly redfish)	15 cm	39 %	72 %
Holothuria scabra (sandfish)	10 cm	93 %	25 %
H. fuscogilva (white teatfish)	15 cm	45 %	30 %
H. whitmaei (black teatfish)	15 cm	n.a.	94 %
		Mean: 57 %	

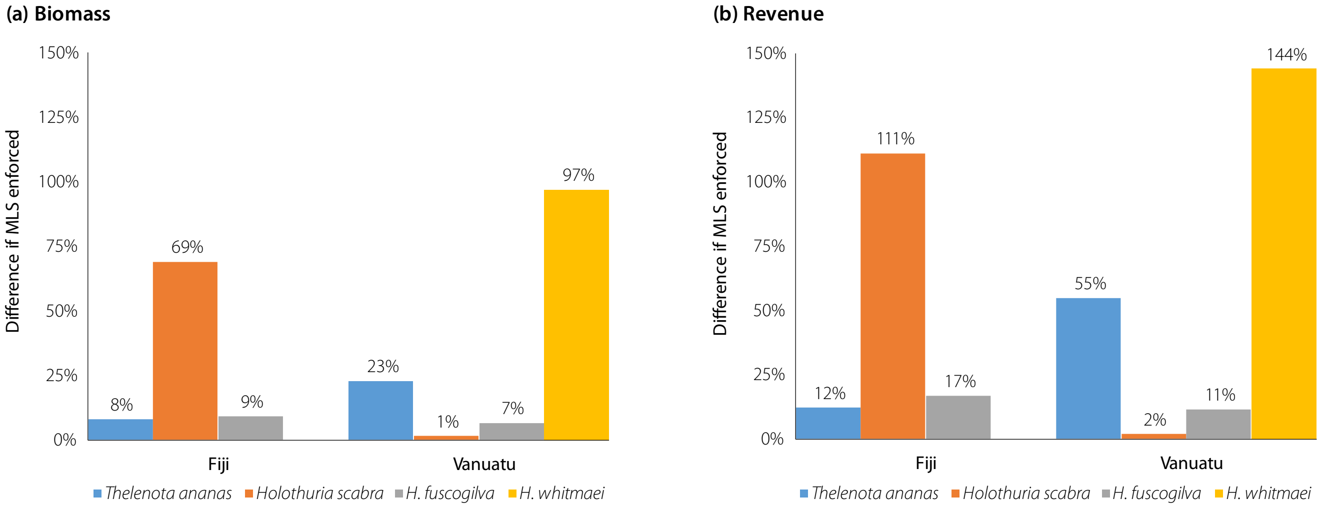

Figure 1. Difference in biomass (a) and revenue (b) of the entire BdM harvest if MSG MSLs were applied and enforced compared to the current practice. Expressed as a percentage of the biomass and revenue from the entire sample reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016).

Discussion

If all four species had been harvested at their respective MSLs, immediate landings of small sea cucumbers would have stopped, which represents approximately 57% of the entire harvest (Table 1). However, if these undersized animals had been left in the sea longer to grow to MSL before being harvested, some would have been lost to natural mortality, but the surviving cohort would have gained up to 91% more biomass and consequently become worth up to 144% more (Figure 1). For all species tested, the results represent a greater yield in terms of biomass and value from the entire harvest than the returns of the current practice.

The improved yield is the product of two factors: 1) increased biomass due to growth outweighing the biomass loss through natural mortality had the animals been left longer in the sea, and 2) the general trend of larger sea cucumbers commanding higher prices (Purcell 2014; Purcell et al. 2018).

While this study looked at size limits as one management measure, decision-makers should also be aware that fisheries will need other regulations and better enforcement in order to become sustainable. Several fishery researchers have concluded that sea cucumber fisheries should also be regulated by short fishing seasons and/or limiting the number of fisher licences, shortlists of permissible species (rather than bans on certain species), and bans on the use of underwater breathing apparatus (UBA). In the case of size limits, better enforcement should entail more frequent inspections of sea cucumbers at processing and export stations, and strict penalties.

For the four species investigated, countries could expect more sustained export volumes of higher-value specimens, and higher economic returns from their respective sea cucumber fisheries if science-based MLSs are adopted and enforced. Currently, all of the MSG sea cucumber fisheries have followed a process of opening the fishery then closing by moratorium. For fisheries currently under a moratorium, there are unlikely to be any shortfalls in landings from imposing the recommended minimum size limits if the fisheries re-open with the new size limits in place. This will require a public awareness campaign to ensure that fishers are aware of new size limits and the incentives of leaving undersized sea cucumbers to grow to a legal market size, as well as restricting legal market outlets for undersized sea cucumber products.

The price per kilo of these undersized beches-de-mer would have more than doubled if they had been left long enough in the sea to reach their size-at-maturity (image: Ian Bertram).

These findings support the MSG's recent adoption of more stringent MSLs, and suggest that the enforcement of these MSLs are not only beneficial but costs could be recovered if a proportion of the increased value can be captured (e.g. through taxes). Furthermore, these economic benefits do not take into account the increased reproductive capacity afforded by only harvesting adults of the population that have had an opportunity to spawn or the ecological benefits of leaving animals to perform their ecosystem function for an increased period of time (Purcell et al. 2016a; Lee et al. 2017).

Acknowledgements

The authors would like to thank Dr Sebastian Ferse of the Leibniz Center for Tropical Marine Research (ZMT) for his initial comments and feedback regarding the model, and Dr Sven Uthicke of the Australian Institute of Marine Science for his advice regarding life-history parameters. Funding was provided for Hugh Govan through the coastal component of the World Bank-funded Pacific Regional Oceanscape Programme coordinated by the Forum Fisheries Agency and implemented by the Pacific Community.

References

Carleton C., Hambrey J., Govan H. and Medley P. 2013. Effective management of sea cucumber fisheries and the bêche-de-mer trade in Melanesia: bringing the industry under rational control. Nautilus Consultants, Secretariat of the Pacific Community. 56 p.

Eriksson H., Österblom H., Crona B., Troell M., Neil A., Wilen J. and Folke C. 2015. Contagious exploitation of marine resources, Frontiers in Ecology and the Environment 13:435–440. doi: 10.1890/140312

Govan H. 2018. A review of sea cucumber fisheries and management in Melanesia. SPC Fisheries Newsletter 154:31–42.

Govan H., Hopa D., Wapot S. and Masu R. 2018. Melanesian Spearhead Group of countries addresses sea cucumber fisheries management. SPC Fisheries Newsletter 154:19–21.

Kinch J., Purcell S., Uthicke S. and Friedman K. 2008. Population status, fisheries and trade of sea cucumbers in the Western Central Pacific. pp. 7–55. In: V. Toral-Granda, A. Lovatelli, and M. Vasconcellos. Sea cucumbers. A global review of fisheries and trade. FAO Fisheries and Aquaculture Technical Paper. No. 516. Rome: FAO.

Lee S., Ferse S., Ford A., Wild C. and Mangubhai S. 2017. Effects of sea cucumber density of the health of reef-flat sediments. pp. 54–61. In: Manghbhai S, Lalavanua W, Purcell S.W. (eds). Fiji's Sea Cucumber Fishery: Advances in Science for Improved Management. Wildlife Conservation Society. Report No. 01/17. Suva: Fiji.

Léopold M. 2016. Evaluating the harvest and management strategies for the sea cucumber fisheries in Vanuatu. Projects No 4860A1 (BICH2MER) and No CS14-3007-101 (BICHLAMAR). Nouméa: IRD. 64 p.

Pakoa K., Saladrau W., Lalavanua W., Valotu D., Tuinasavusavu I., Sharp M. and Bertram I. 2013. The status of sea cucumber resources and fisheries management in Fiji. Noumea, New Caledonia: Secretariat of the Pacific Community. 49 p.

Purcell S.W. 2010. Managing sea cucumber fisheries with an ecosystem approach. FAO Fisheries and Aquaculture Technical Paper No. 520. Rome: FAO.

Purcell S.W. 2014. Value, market preferences and trade of beche-de-mer from Pacific Island sea cucumbers. PloS ONE 9(4): e95075. doi: 10.1371/journal.pone.0095075

Purcell S.W., Mercier A., Conand C., Hamel J., Toral-Granda M.V., Lovatelli A. and Uthicke S. 2013. Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. Fish and Fisheries 14:34–59. doi: 10.1111/j.1467-2979.2011.00443.x

Purcell S.W., Lovatelli A. and Pakoa K. 2014. Constraints and solutions for managing Pacific Island sea cucumber fisheries with an ecosystem approach. Marine Policy 45:240–250. doi: 10.1016/j.marpol.2013.11.005

Purcell S.W., Conand C., Uthicke S. and Byrne M. 2016a. Ecological roles of exploited sea cucumbers. Oceanography and Marine Biology: An Annual Review 54:367–386.

Purcell S.W., Piddocke T.P., Dalton S.J. and Wang Y. 2016b. Movement and growth of the coral reef holothuroids *Bohadschia argus* and *Thelenota ananas*. Marine Ecology Progress Series 551:201–214. doi: 10.3354/meps11720

Purcell S.W., Ngaluafe P. and Williamson D.H. 2018. Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture. Marine Policy 91:58–65. doi: 10.1016/j.marpol.2018.02.005

Russell P. 1970. The Papuan beche-de-mer trade to 1900. MA Thesis, University of Papua New Guinea, Port Moresby, Territory of Papua and New Guinea.

Tabunakawai-Vakalalabure M., Kuridrani N., Lalavanua W., Mangubhai S. and Bertram I. 2017. Pre-export sizes of bêche-de-mer in Fiji. pp. 38–46. In: S. Mangubhai, W. Lalavanua and S.W. Purcell (eds). Fiji's Sea Cucumber Fishery: Advances in Science for Improved Management. Wildlife Conservation Society. Report No. 01/17. Suva, Fiji.

Turbet C.R. 1942. Beche-de-mer Trepang. Transactions and Proceedings of the Fiji Society 2:147–154.

Uthicke S. and Benzie J.A.H. 2002. A genetic fingerprint recapture technique for measuring growth in 'unmarkable' invertebrates: negative growth in commercially fished holothurians (*Holothuria nobilis*). Marine Ecology Progress Series 241:221–226.

Uthicke S., Welch D. and Benzie J.A.H. 2004. Slow growth and lack of recovery in overfished holothurians on the Great Barrier Reef: Evidence from DNA fingerprints and repeated large-scale surveys. Conservation Biology 18(5):1395–1404. doi: 10.1111/j.1523-1739.2004.00309.x

Ward R.G. 1972. The Pacific bêche-de-mer trade with special reference to Fiji. pp. 91–121. In: Ward R.G. (ed) Man in the Pacific Islands. Oxford: Clarendon Press.

Annex 1. The model

Four species were studied: *Thelenota ananas*, *Holothuria scabra*, *Holothuria fuscogilva*, and *Holothuria whitmaei*. These were selected as they are commercially harvested for the beche-de-mer (BdM) trade and have sufficient life-history data available for modelling.

Total sea cucumber biomass change is dependent on growth (K) and natural mortality (M). The model presented does not consider migration as studies have shown that sea cucumbers are mobile within a limited range (e.g. Purcell et al. 2016). Under the enforced MSL situation, fishing mortality (F) for animals below minimum legal size (MSL) is zero ($F = 0$) as is their exploitation rate ($E = 0$)[1] and for animals >MSL all mortality is due to fishing and $E = 1$; i.e. all animals <MSL are not fished or exploited and all animals >MSL are captured as it is probable that fishers would hardly ever leave any accessible specimens >MSL unharvested.

Two sets of values for K and M are used:

- *Deep water*: $K = 0.09$ and $M = 0.125$
- *Shallow water*: $K = 0.18$ and $M = 0.25$

Deep water values were based on recent studies (e.g. Uthicke et al. 2002, 2004; and Purcell et al. 2016) and discussions (S. Uthicke and S. Purcell *pers. comm.*). *Shallow water* values were calculated by doubling the *deep water* values. *Deep water* values result in slow growth and low natural mortality; *shallow water* values result in a faster growth rate but higher natural mortality.

Recent research suggests that many species of sea cucumbers are slower growing, longer lived, and have lower rates of natural mortality than previous research has indicated (Purcell et al. 2015). As such this study assumed a slower growth and lower natural mortality for all species compared with previous work (e.g. Plagányi et al. 2015). This is particularly true for species that inhabit deeper sections of reefs such as slopes and channels. *Deep water* values are applied to *T. ananas*, *H. fuscogilva*, and *H. whitmaei* as they inhabit such environments. *Shallow water* values are applied to *H. scabra* as this species predominantly inhabits shallow waters and is known to be relatively fast growing (Hamel et al. 2001).

While the parameter values used in this study are based on the best available information they are likely to vary spatially, temporally, and for different species. This issue could be addressed by using a range of values for each species as a sensitivity analysis. As preliminary results of this sensitivity analysis showed no large changes, we have omitted it in this version for simplicity.

The instantaneous rate of change (b) is calculated for every species. This was done by inserting length-at-maturity and age-at-maturity data into the equation and changing the value of b until the equation agreed with length-at maturity and age-at-maturity data. Length-at-maturity and age-at-maturity data were chosen as the MSLs used were based on length-at-maturity (Tabunakawai-Vakalalabure et al. 2017, Govan et al. 2018). The values of K, M, and b, and other information used in the model are provided in Table A1.

Spreadsheet procedure (see Table A2)

1. Dry length is taken as the mid-point of the respective size class

2. Dry length is converted into live length by dividing [1] by the length retention rate (Table A1)

3. Live length is converted to live weight using the respective length-weight relationship (Table A1)

4. Number of animals of each dry length/live length inserted here.

5. Growth required to reach MSL is calculated by subtracting the live length [2] from MSL

6. As growth rate is often rapid in the early life stages of an animal and gradually reduces as that animal ages a negative exponential relationship was used to determine the time (years) taken for an animal to grow to MSL. The equation below reduces K at a rate of b for the duration it takes to reach a length of [5]. Once the specimen reaches MSL it is presumably taken by fishers therefore growth is no longer a consideration – i.e. fishing mortality (F) of a specimen >MSL = 100%. Time (years) taken to reach MSL is given as:

   $$[5]/(K^{-b})$$

   Similarly, natural mortality (M) is reduced as an animal grows, and the equation below reduces M for a duration of [6]. This mortality rate is subtracted from one (1) to determine the survival rate. The overall effect is an increase in the survival rate as an animal ages. As it is assumed that F of specimens >MSL is 100%, M is only applied for the duration that the animal is <MSL. Survival rate is calculated as:

   $$1 - M^{\frac{1}{[6]}}$$

---

[1] Exploitation rate (E) = Fishing mortality (F) / Total mortality (Z)

7. Survival rate is applied to size-frequency data from sampling:

$$[7]\times[4]$$

8. Weight of all animals at each size is determined:

$$[8]\times[3]$$

9. The weight of survivors at MSL is calculated by multiplying the number of survivors by the weight of an animal at MSL (Table A1):

$$[8]\times \mathit{Weight\ at\ MLS}$$

10. Value[8] of the sample is calculated by applying the length-value relationship (Table A1) to the respective length [2] then multiplying this value by the weight of the sample [9], providing the total value of animals of that particular length. If the animal's length is below the data range provided by Purcell (2014), the minimum price point is used; if the animal's length was greater than the data range, the maximum price point is used (Table A1).

11. The value of survivors at MSL is calculated by multiplying the weight of the undersized portion of the surviving sample [10] by the value of an animal at MSL (Table A1). This is added to the value of animals from sampling that were >MSL [11]. Such that:

$$([10]\times \mathit{Value\ at\ MLS})+[11]_{>MLS}$$

Table A1. Summary of parameters and additional inputs used in the model. MSLs are the minimum size limits agreed upon by MSG countries (Govan et al. 2018). Minimum and maximum price points are based on the minimum and maximum range of length data used by Purcell (2014) to produce the respective length-weight relationships.

Parameters	*T. ananas*	*H. scabra*	*H. fuscogilva*	*H. whitmaei*
K (growth constant) (y^{-1})	0.09	0.18	0.09	0.09
M (natural mortality)(y^{-1})	0.125	0.25	0.125	0.125
b (instantaneous rate of change)	0.837	1.175	0.837	0.777
Size-at-maturity (cm)[2]	30	15	32	26
Age-at-maturity (y)[2]	4	2	4	4
Length retention rate[7]	0.375	0.400	0.429	0.500
Length-weight relationship	[4]Log *W* = -6.67+2.36*Log(L*10)	[5]*W* = 0.1878 L ^ 2.5807	[4]*W* = 0.0011*L^2.407	[6]*W* = 0.9345*L^1.927
Length-value relationship[7]	*V* = 143.0175 + (-10685648.95*exp(-L))	*V* = 63.0807 / (1 + (-0.0771*L))	*V* = *L*/(0.48375 + (-0.052125*L) - (-0.0017185*L^2))	*V* = -195.06 + 95.6813*L^.5
MSL (live, cm)	40	25	35	30
MSL (dry, cm)	15	10	15	15
Value at MSL (dry, USD kg^{-1})	140.65	275.46	169.42	175.51
Weight at MSL (live, kg)	1.932	0.491	3.768	0.992
Min. price point (USD kg^{-1})	35.67	102.65	45.27	39.00
Max. price point (USD kg^{-1})	143.92	556.51	107.81	227.18

---

[2] Taken from Table S1. Plagányi et al. (2015)

[3] Calculated by dividing the MSG agreed dry MSL by the live MSL

[4] Conand (1989)

[5] Lee et al. (in press)

[6] Prescott et al. (2015)

[7] Purcell (2014)

[8] It is acknowledged that the length-value relationships used in this study (Table A1) apply to BdM therefore steps [11] and [12] should first convert weight into dry weight; however, as we are only interested in percentage changes and not the actual monetary value, converting back into dry (BdM) weight is unnecessary.

Table A2. *H. fuscogilva*, Fiji export sample. MSL = 15 cm (dry)/35 cm (live). Life-history parameters used: *K* = 0.09, *M* = 0.125, *b* = 0.837

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Dry length (cm)	Live length (cm)	Live weight (kg)	Number observed	Growth needed to reach MSL (cm)	Time taken to reach MSL (y)	% of sample that will reach MSL	Number of animals that will reach MSL (survivors)	Total weight of sample (live, kg)	Total weight of survivors at MSL (live, kg)	Value of sample exported (USD)
4.5	8.8	0.315	0	24.5	3.26	47%	0	0.00	0.00	0.00
5.5	10.8	0.511	0	22.1	2.95	51%	0	0.00	0.00	0.00
6.5	12.7	0.763	14	19.8	2.64	55%	8	10.69	43.60	483.83
7.5	14.7	1.077	32	17.5	2.33	59%	19	34.47	107.95	1560.63
8.5	16.7	1.456	32	15.2	2.02	64%	21	46.59	117.56	2402.49
9.5	18.6	1.903	30	12.8	1.71	70%	21	57.09	120.66	3775.43
10.5	20.6	2.421	17	10.5	1.40	77%	13	41.16	75.19	3433.02
11.5	22.5	3.014	0	8.2	1.09	85%	0	0.00	0.00	0.00
12.5	24.5	3.684	15	5.8	0.78	93%	14	55.26	79.82	6859.44
13.5	26.5	4.434	36	3.5	0.47	99%	36	159.62	203.32	23106.08
14.5	28.4	5.266	49	1.2	0.16	100%	49	258.03	279.97	41920.48
15.5	30.4	6.183	43	-1.2	0.00	100%	43	265.87	245.69	46468.69
16.5	32.4	7.187	22	-3.5	0.00	100%	22	158.12	125.70	28497.34
17.5	34.3	8.281	20	-5.8	0.00	100%	20	165.61	114.27	29617.88
18.5	36.3	9.466	27	-8.2	0.00	100%	27	255.57	154.27	43943.77
19.5	38.2	10.744	26	-10.5	0.00	100%	26	279.35	148.56	45104.78
20.5	40.2	12.119	30	-12.8	0.00	100%	30	363.56	171.41	54248.61
21.5	42.2	13.591	9	-15.2	0.00	100%	9	122.32	51.42	16703.81
22.5	44.1	15.163	22	-17.5	0.00	100%	22	333.58	125.70	41483.03
23.5	46.1	16.836	24	-19.8	0.00	100%	24	404.05	137.13	45682.39
24.5	48.0	18.612	32	-22.1	0.00	100%	32	595.58	182.84	64209.57
25.5	50.0	20.493	20	-24.5	0.00	100%	20	409.86	114.27	44187.48
26.5	52.0	22.481	0	-20.5	0.00	100%	0	0.00	0.00	0.00

[12]	Total weight of sample in current situation[9] (kg)	4016	
	Total weight if MSL enforced (kg)	4382	9% increase
	Total value of sample in current situation (USD)	543689	
	Total value if MSL enforced (USD)	634322	17% increase

---

[9] MSLs are inadequately enforced i.e. the length-frequency of BdM reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016)

References

Conand C. 1989. The fishery resources of Pacific island countries. Part 2 Holothurians. FAO Fisheries Technical Paper, No. 272.2. Rome: FAO. 143 p.

Conand C. 1998. Les holothuries aspidochirotes du lagon de Nouvelle-Caledonie: Biologie, écologie et exploitation. Institut Francais de Recherche Scientifique pour le Dévelopment en Cooperation. 133–240.

Govan H., Hopa D., Wapot S. and Masu R. 2018. Melanesian Spearhead Group of countries addresses sea cucumber fisheries management. SPC Fisheries Newsletter 154:19–21.

Hamel J.F., Conand C, Pawson D.L. and Mercier A. 2001. The sea cucumber *Holothuria scabra* (Holothuroidea: Echinodermata): Its biology and exploitation as beche-de-mer. Advances in Marine Biology 41:129–223. doi: 10.1016/S0065-2881(01)41003-0

Lee S., Ford A., Mangubhai S., Wild C. and Ferse S. 2018. Length-weight relationship, movement rates, and in-situ spawning observations of *Holothuria scabra* (sandfish) in Fiji. SPC Beche-de-mer Information Bulletin 38:11–14.

Léopold M. 2016. Evaluating the harvest and management strategies for the sea cucumber fisheries in Vanuatu. Projects No 4860A1 (BICH2MER) and No CS14-3007-101 (BICHLAMAR). Noumea, new Caledonia: IRD. 64 p.

Plagányi E.E., Skewes T, Murphy N., Pascual R. and Fischer M. 2015. Crop rotations in the sea: Increasing returns and reducing risk of collapse in sea cucumber fisheries (SI), PNAS. doi: 10.1073/pnas.1406689112

Prescott J., Zhou S. and Prasetyo A.P. 2015. Soft bodies make estimation hard: correlations among body dimensions and weights of multiple species of sea cucumbers. Marine and Freshwater Research 66:857–865. doi: 10.1071/MF14146

Purcell S.W. 2014. Value, market preferences and trade of beche-de-mer from Pacific island sea cucumbers. PloS ONE 9(4): e95075. doi: 10.1371/journal.pone.0095075

Purcell S.W., Uthicke S., Byrne M. and Eriksson H. 2015. Rotational harvesting is a risky strategy for vulnerable marine animals. PNAS letter, 112(46). doi: 10.1073/pnas.1515074112

Purcell S.W., Piddocke T.P., Dalton S.J. and Wang Y.G., 2016. Movement and growth of the coral reef holothuroids *Bohadschia argus* and *Thelenota ananas*. Marine Ecology Progress Series 551:201–214. doi:10.3354/meps11720

Tabunakawai-Vakalalabure M., Kuridrani N., Lalavanua W., Mangubhai S. and Bertram I. 2017. Pre-export sizes of bêche-de-mer in Fiji. pp. 38–46. In: S. Mangubhai, W. Lalavanua and S.W. Purcell (eds). Fiji's Sea Cucumber Fishery: Advances in Science for Improved Management. Wildlife Conservation Society. Report No. 01/17. Suva, Fiji.

Uthicke S. and Benzie J.A.H. 2002. A genetic fingerprint recapture technique for measuring growth in 'unmarkable' invertebrates: negative growth in commercially fished holothurians (*Holothuria nobilis*). Marine Ecology Progress Series 241:221–226.

Uthicke S., Welch D. and Benzie J.A.H. 2004. Slow growth and lack of recovery in overfished holothurians on the Great Barrier Reef: Evidence from DNA fingerprints and repeated large-scale surveys. Conservation Biology 18(5):1395–1404. doi: 10. 1111/j.1523-1739.2004.00309.x

Once processed and dried, these juvenile sea cucumbers will weigh a few grams, and be worth almost nothing on Asian markets that favour large specimens (image: Antoine Teitelbaum).