Marine Policy 91 (2018) 58–65

Contents lists available at ScienceDirect

Marine Policy

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

Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture

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ARTICLE INFO

Keywords:
International markets
Luxury seafood
Invertebrate
Sea cucumber
Fishery management
Aquaculture

ABSTRACT

Market prices of seafood underpin harvest and management strategies for fisheries and aquaculture. Beche-de-mer (processed, dried sea cucumbers) are highly valued in Asian markets. Market prices of Pacific Island beche-de-mer were previously reported from data collected in 2011. Recent economic slowdown in China and government austerity policy have dampened demand for certain luxury seafood products. This study presents updated data on prices, and relationships with product size, of beche-de-mer from 24 species of Indo-Pacific sea cucumbers sold in Hong Kong and Guangzhou, China. Average retail prices were highest in Hong Kong. Prices per individual increased exponentially with increasing beche-de-mer length for three high-value species, *Holothuria fuscogilva* (white teatfish), *H. lessoni* (golden sandfish) and *H. scabra* (sandfish). However, for seven other species, price per unit weight did not relate significantly to product length. Across 20 species, average prices increased by an average of 16.6% from 2011 to 2016, equating to an increase of 2.4% p.a., slightly exceeding China's average CPI increase over the same period (2.1% p.a.). Products that were traditionally lower value appear more accepted in the marketplace. The analysed relationships offer rationale for large minimum legal size limits to improve the economic performance of fisheries for the high-value species *H. fuscogilva, H. lessoni* and *H. scabra*. The disproportionately high prices for larger specimens of these species also challenge a rethink of optimal harvest strategies for aquaculture operations. Lastly, the findings provide evidence of increasing demand and retail prices for these luxury seafood products in an ambiguous market climate.

1. Introduction

Market prices and preferences for seafood are critical factors that underpin regulatory measures to improve the economic performance of wild fisheries and harvest strategies for mariculture operations. Changes in market prices over time can indicate species that are likely to be increasingly exploited, and thus might need stricter regulatory measures, and relationships between product size and price could inform decision making about minimum size limits. Over 70 species of sea cucumbers are exploited globally from wild fisheries — most of which are sourced from tropical countries [1,2]. More than 30 species are harvested from multispecies fisheries in the tropical Indo-Pacific [1,3]. Like many other luxury seafood products, the vast majority of harvested sea cucumbers are exported to Asian seafood markets, primarily as a dried product called beche-de-mer. Most beche-de-mer exported from Pacific Islands is first imported at the primary global market of Hong Kong, before much of the products are redistributed to markets in mainland China [4–7]. Sea cucumbers are a delicacy in Chinese cuisine and they hold significant cultural importance [8,9]. These products serve as a useful case to illustrate trends likely for other seafoods traded to Asia in view of their wide geographic distribution and predominance of trade to China [2,7].

Hong Kong and Guangzhou are the two major Chinese trade hubs for tropical sea cucumbers [7]. Market prices for 20 species of dried sea cucumber from Pacific Islands were determined at both marketplaces in 2011 and subsequently reported [4]. Prices ranged greatly from high-value to low-value species, and product size affected market price for some species, although the relationships were variable. The study also found a 93% chance that physical damage to the outer body wall of beche-de-mer resulted in reduced market prices. Such market data underpin value-chain analyses [10–12], conservation priorities [13–15], fisheries management [16,17] and aquaculture valuations [18–20]. Indo-Pacific fishery managers have voiced a specific need for updated market prices in order to devise economic controls over trade in sea cucumber fisheries [21–23].

International market prices for sea cucumbers are believed to have

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https://doi.org/10.1016/j.marpol.2018.02.005
Received 19 November 2017; Received in revised form 4 February 2018; Accepted 4 February 2018
Available online 16 February 2018

risen sharply in recent years, spurring increased fishing pressure in many poorly managed fisheries [11,24] as well as the establishment of new sea cucumber fisheries [2,25]. Over-exploitation of sea cucumbers has resulted in declining export volumes from the Pacific region [26]. In the past decade, fisheries were forced into moratoria in Papua New Guinea, Solomon Islands and Vanuatu [27,28]. Most recently, sea cucumber fisheries in Madagascar, Kiribati, Tonga and Fiji have followed the same path, owing to fears of irrecoverable overfishing under continued fishing. Fishery institutions responsible for many of these fisheries are now reforming their management strategies, implementing additional regulations and, in some cases, introducing minimum wholesale pricing for sea cucumber products.

Minimum legal size limits are one regulatory measure that generally has widespread support in sea cucumber fisheries [22,23], but such limits are sometimes poorly devised and often weakly enforced [28,29]. From a biological standpoint, data on size at sexual maturity and size-specific fecundity should form the basis for setting minimum size limits in order to safeguard egg production and reduce the chances of recruitment overfishing [30]. Minimum size limits should also seek to maximise the economic performance of the fishery (cf [31,32].), especially if larger individuals attract substantially higher market prices.

In addition to the global expansion of sea cucumber fisheries, aquaculture production has expanded rapidly in recent years and is increasingly viewed as a sustainable means to meet market demand [33]. Presently, the high-value sandfish *Holothuria scabra* is the most extensively cultured tropical species, but other species including *H. fuscogilva* and *H. lessoni* have been cultured in hatcheries for restocking, sea ranching or sea farming [34]. Profitability for commercial mariculture is predicated on harvesting the animals at a size that optimizes economic yield relative to grow-out costs [19,34,35]. Relationships between animal size and market price are therefore integral to optimal production strategies.

Rapid economic development and increasing wealth in China has driven rising demand (and prices) for a broad range of luxury seafood, including beche-de-mer [9]. On the other hand, there has been a slowdown in the Chinese economy since 2011 [7]. In addition, the Chinese government implemented a campaign in 2012 to discourage “conspicuous consumption” of luxury seafood at government-funded banquets, which has reportedly dampened sales of many products, including sea cucumbers [7,36]. Conflicting pressures on Chinese demand for luxury seafood therefore lead to uncertainty about how market prices of tropical beche-de-mer may have changed in recent years.

This study examined recent changes in retail prices of beche-de-mer in both Hong Kong and mainland China markets and assessed the relationships between product size and price across multiple species harvested and exported from the tropical Indo-Pacific region. The focus was on species harvested from Pacific Islands but many of these are also targeted in sea cucumber fisheries operating throughout southeast Asia and the Indian Ocean. The findings provide an economic rationale for implementing regulations of relatively large minimum size limits for wild fisheries and an empirical basis for cost-benefit analyses of optimal size-at-harvest for aquaculture operations. Annualised change in prices of beche-de-mer over the 2011–2016 period compared to the average annual consumer price index in China offers a way to infer recent trends in demand for these luxury seafood products in an ambiguous market climate.

2. Material and methods

2.1. Sampling beche-de-mer in Chinese markets

Assessments of size and retail price of beche-de-mer were conducted during mid-November 2016 at 26 stores in the Sheung Wan district in Hong Kong and 33 stores in the Yide Lu markets in Guangzhou (Canton). Access to products in the stores was facilitated by a Chinese-national interpreter. Nearly all of the stores in both marketplaces that specialise in selling beche-de-mer and were exhaustively visited, and entry or permission to measure products was declined by more than half of the store owners. Prices of beche-de-mer per unit weight were listed on labels or told by the show workers via our interpreter. Stores in Guangzhou sold in both wholesale and retail volumes, whereas stores in Hong Kong sold predominantly in retail volumes. Store owners in Guangzhou reported retail prices, and noted that prices would be lower for products purchased at wholesale volumes. Hong Kong stores sold a narrower range of higher-value beche-de-mer species than Guangzhou stores. Despite the restricted access to many stores, the sample of beche-de-mer products is the most comprehensive to date for Chinese retail markets. The sampled beche-de-mer are considered representative of the species and product sizes available and the prices attained across both the Hong Kong and Guangzhou retail markets.

Beche-de-mer species were identified from observer knowledge of dried forms, from experience at commercial processors in the Pacific Islands, and from an identification guidebook [1]. Data were collected for 24 species of sea cucumber that are fished and exported from the Pacific Islands region. Beche-de-mer were sold in open bags, bins or jars (herewith called ‘lots’), with prices per unit weight (per *jīn* [市斤 or *shìjīn*], equivalent to 500 g, at Guangzhou; per catty [斤 or *kati*], equivalent to 604.79 g, at Hong Kong). Where possible, 2 or 3 lots of beche-de-mer of different grades for each available species were sampled haphazardly in each store. In most cases, four random specimens were selected from each lot as subsamples. Prices were recorded, then later converted using international rates applicable during the sampling period: 1 CNY = 0.15665 US$; 1 HKD = 0.129 US$. Specimen lengths were measured to the nearest 0.5 cm along the ventral surface with a ruler and their weights were measured to ± 1 g using an electronic balance. Photographs were taken of some specimens for reference and to document maximum prices of some particularly high-value products that were not permitted to be handled. Data on 2011 market prices of the various species are presented in Purcell [4] and were collected in October 2011 using the same methods outlined above. In the present study, temporal changes in market prices were examined for 20 species that were sampled in both 2011 and 2016.

2.2. Data analyses

Average product (body) lengths and weights were calculated from the four specimens sampled from each lot. Length versus price regression analyses were conducted using average length and price values for each lot. Despite best efforts to maximise sample sizes in 2016, restrictions imposed by store owners and a limited number of lots for some species in the markets meant that there was an acceptable minimum replication for regression analyses ($n > 5$) for only 10 of 24 sampled species. The largest numbers of samples were attained for *Holothuria fuscogilva* and *Holothuria scabra* which were found in many stores.

Potential linear and non-linear relationships between average product length and price were assessed independently for species with at least six replicates using the Datafit statistical software package (Oakdale Engineering, USA). Three-parameter models tended to overfit the data and result in spurious relationships, so for each species, the best-fit 2-parameter model based on the *r*-squared regression value was chosen. Model fits were only plotted for species for which statistically significant regression relationships were found. Plotting of relationships and confidence intervals was conducted using SigmaPlot v13 software (Systat Sofware, USA).

Relationships between *H. scabra* product length vs price per individual and length vs price per kg appeared comparable for sample sets from both Hong Kong and Guangzhou stores and thus data from both market locations were pooled. However, for *H. fuscogilva*, length vs price per individual and length vs price-per-kg relationships appeared incongruent between the two marketplaces, and were thus modelled separately for Hong Kong and Guangzhou data sets.

Table 1
Market value and size descriptors of beche-de-mer species in Chinese stores (Hong Kong & Guangzhou) in 2016 and 2011. Only species fished in the Pacific islands are presented. *n* = number of lots (container of 4 individuals) sampled. Standard deviations (shown as superscripted text) are based on average prices of replicate lots, except for species for which only 1 lot was sampled, for which individual measurements were used. For species with only 1 sampled lot, the maximum price was considered equal to the average price. Arrows adjoining 2016 price values indicate either an increase (↑) or decrease (↓) in prices relative to 2011 prices.

Market location			2016				2011	
Species	Common Name	*n*	Av. Price (US$ kg^{-1})	Max. Price (US$ kg^{-1})	Av. Len. (cm)	Av. Wt. (g)	Av. Price (US$ kg^{-1})	Max. Price (US$ kg^{-1})
Hong Kong								
A. lecanora	Stonefish	1	166	166	8 [1]	33 [5]	-	-
A. palauensis	Panning's blackfish	1	145	145	15 [1]	158 [16]	-	-
B. vitiensis	Brown sandfish	1	209	209	13 [2]	74 [23]	-	-
H. fuscogilva	White teatfish	47	219 [53] ↑	401 ↑	17 [4]	240 [129]	192 [36]	274
H. lessoni	Golden sandfish	15	389 [147] ↑	849* ↑	11 [2]	70 [41]	385 [27]	787
H. scabra	Sandfish	67	369 [230] ↑	1898* ↑	9 [2]	48 [38]	303 [159]	1668
H. whitmaei	Black teatfish	5	208 [73] ↑	294 ↑	13 [3]	127 [70]	180 [32]	230
S. herrmanni	Curryfish	2	350 [12] ↑	358 ↑	15 [2]	107 [33]	197 [47]	214
S. monotuberculatus	Dragonfish	1	188	188	9 [2]	27 [3]	-	-
S. naso	Dragonfish	1	145	145	8 [1]	15 [3]	-	-
S. vastus	Brown curryfish	1	230	230	10 [1]	47 [9]	-	-
Guangzhou								
A. echinites	Deepwater redfish	1	69 ↑	69 ↑	8 [1]	33 [6]	63	63
A. lecanora	Stonefish	6	76 [24] ↓	107 ↓	7 [2]	28 [14]	94 [14]	108
A. mauritiana	Surf redfish	1	72 ↓	72 ↓	9 [1]	69 [13]	75 [10]	79
A. palauensis	Panning's blackfish	10	77 [33] ↓	131 ↑	13 [2]	108 [46]	106 [15]	116
A. spinea	Burying blackfish	1	110 ↑	110 ↑	11 [1]	81 [27]	79 [22]	95
B. argus	Leopardfish	4	63 [6] ↑	70 ↑	15 [1]	115 [11]	58 [7]	63
B. vitiensis	Brown sandfish	3	55 [25] ↑	81 ↑	11 [1]	69 [14]	48	48
H. atra	Lollyfish	1	31	31	11 [3]	38 [14]	-	-
H. coluber	Snakefish	1	37 ↓	37 ↓	15 [2]	30 [2]	38	38
H. fuscogilva	White teatfish	27	154 [39] ↑	219 ↑	19 [4]	306 [116]	120 [37]	165
H. fuscopunctata	Elephant trunkfish	14	22 [17] ↑	78 ↑	18 [3]	193 [83]	15 [3]	19
H. scabra	Sandfish	13	153 [50] ↑	251 ↑	7 [1]	19 [12]	137 [31]	200
H. whitmaei	Black teatfish	10	161 [32] ↑	194 ↑	14 [3]	210 [98]	68 [43]	116
S. chloronotus	Greenfish	4	100 [23] ↑	125 ↑	10 [1]	22 [5]	79 [22]	95
S. herrmanni	Curryfish	14	145 [58] ↑	219 ↑	12 [2]	78 [40]	121 [29]	159
S. horrens	Dragonfish	1	119 ↑	119 ↑	7 [2]	10 [1]	69 [19]	83
S. monotuberculatus	Dragonfish	7	127 [34] ↑	204 ↑	8 [1]	18 [10]	118 [13]	133
S. naso	Dragonfish	2	91 [4]	94	7 [1]	10 [2]	-	-
S. ocellatus	Eye-spot curryfish	1	78 ↓	78 ↓	15 [2]	112 [61]	111	111
S. pseudohorrens	-	1	119	119	12 [1]	58 [1]	-	-
T. ananas	Prickly redfish	22	107 [45] ↓	219 ↓	17 [4]	156 [68]	130 [40]	231
T. anax	Amberfish	3	31 [16] ↑	47 ↑	21 [1]	280 [47]	22 [7]	32

* Maximum price verified from a photograph, but not possible to record length of highest priced individuals.

The relationship between product length and weight of species for which at least 10 individuals were measured was assessed using the standard morphometric 'growth' equation, $y = ax^b$, using DataFit software. In this case, length and weight data from individual specimens were used. The exponent, *b*, reflects the degree of allometry in the relationship with changes in product length, and a value of 3 represents isometric growth, i.e. a similar relative body thickness with increase in length [37].

3. Results

3.1. Market prices

In 2016, average retail prices of beche-de-mer species were 1.3–3.8-fold higher in Hong Kong stores than in Guangzhou stores (Table 1). The tropical species with the highest maximum recorded price was sandfish *Holothuria scabra,* for which extra-large, premium quality product were retailing at over US$1800 per kg at one Hong Kong store. These highest priced individuals were exceptionally large specimens that would probably have weighed 1.5–2 kg as live animals. Prices of most sampled sandfish however, were comparable to those of golden

Fig. 1. Dried Japanese sea cucumber, *Apostichopus japonicus*, on sale in a Hong Kong store in November 2016. The retail price of HK$16,800 per catty equates to US$3583 per kg.

sandfish *H. lessoni*, which was found selling for as much as US$849 per kg. Other high-value tropical Indo-Pacific species included white teatfish *H. fuscogilva* (max. US$401 per kg) and several other species that were sometimes retailing at over US$200 per kg (Table 1). Nonetheless, prices for these high-value tropical species do not reach those attained for the highest-quality Japanese sea cucumber *Apostichopus japonicus*, a temperate-water species not present in the tropical Indo-Pacific, which was found retailing for up to US$3583 per kg (Fig. 1).

Of the 20 species sampled in both 2011 and 2016, the average prices of 14 species (70%) and the maximum prices of 15 species (75%) increased between the two sampling periods (Table 1). Average prices across the 20 species re-sampled in 2016 had increased by an average of 16.6% (± 7.6% s.e.) over the five-year sampling period (Table 1). This translates to an annual increase of 2.4% (± 1.4% s.e.), exceeding China's average CPI increase over the same period of 2.1% (± 0.2% s.e.) (www.inflation.eu). Furthermore, maximum prices of two relatively low-value species, *Bodaschia vitiensis* and *Holothuria fuscopuntata*, increased three-fold between 2011 and 2016 (Table 1). Prices for curryfish *S. herrmanni* had also increased dramatically in Hong Kong since 2011, and it could be considered a high-value species in that marketplace. Across all sampled species, the maximum recorded prices increased by 51.3% (± 21.7% s.e.) over the 5-year period, translating to an annual increase of 6.3% (± 2.4% s.e.). Thus, for a range of species, maximum retail prices of large, premium quality product increased to a far greater degree than average retail prices across the range of all sizes and quality of products.

3.2. Effect of body size on price

Significant relationships were found between product length and price for *H. fuscogilva*, *H. lessoni* and *H. scabra* in 2016 (Fig. 2). For *H. fuscogilva*, the price per individual increased exponentially with product length in both Hong Kong and Guangzhou stores ($p < 0.001$ in both cases, Fig. 2a). A significant relationship between *H. fuscogilva* price per kg and length was detected for Hong Kong stores ($p < 0.001$), however this relationship was non-significant for Guangzhou stores in 2016 (Fig. 2d). Owing to its large body size, and dried weight (often above 300 g per individual), *H. fuscogilva* readily attains prices of $US50–$US100 per individual in both Hong Kong and Guangzhou markets, and prices above $US100 per individual in Hong Kong stores for large products above 21 cm in length. Conversely, moderately sized *H. fuscogilva* (~ 15–18 cm TL) were attaining the higher prices in 2011 (Fig. 2d).

For both *H. lessoni* and *H. scabra*, both price per individual and price per kg increased exponentially with product length in 2016 ($p < 0.001$ in each case) (Fig. 2b,c,e,f). A similar pattern was observed for *H. scabra* price per kg in 2011 (Fig. 2f). In 2016, the average price for *H. scabra* of less than 10 cm product length was approximately US$213 per kg (± US$4 se.) and US$5.5 per individual (± US$0.9 se.). Conversely, for *H. scabra* greater than 10 cm length the average price per kg was US $570 per kg (± US$9 se.) and US$54 per individual (± US$3 se.). These figures translate to a 2.7-fold increase in price per kg, and a 9.8-fold increase in price per individual for *H. scabra* greater than 10 cm product length compared to sub-10 cm individuals.

The best-fitting non-linear relationships were non-significant for all other species for which at least six lots were sampled in 2016 (Fig. 3, Table 1). This is in contrast with significant relationships found for some of these same species in 2011 (Fig. 3). Corroborating the values in Table 1, increases in price from 2011 to 2016 were evident for similar sized individuals of *H. fuscopunctata*, *H. whitmaei* and *Stichopus herrmanni* sold in Hong Kong (Fig. 3). On the other hand, average prices for *Thelenota ananas,* particularly large individuals, decreased from 2011 to 2016 (Fig. 3, Table 1).

3.3. Morphometric relationships

Length-weight relationships for most sampled species displayed negative allometry (i.e., $b < 3$), whereby the beche-de-mer were progressively relatively thinner compared to their respective lengths with increasing product length (Table 2). This relationship was most pronounced for *A. lecanora*, *A. palauensis*, *B. argus*, *B. vitiensis*, *H. whitmaei*, *S. chloronotus*, and *T. ananas*. In contrast, the morphometric relationship for *H. scabra* was close to isometric.

4. Discussion

Seafood products such as shark fin, tropical reef fishes, abalone, king crab, fish maw (dried fish swim bladder) and beche-de-mer have long been premium, high value commodities in Chinese markets [8]. Rapid economic development and increasing wealth in China over the past few decades has resulted in rising demand and consumption of luxury seafood products [5,9], many of which are sourced from fully- or over-exploited wild stocks [14,23,27,28,36]. For many coastal communities throughout Southeast Asia and the Indo-Pacific, China's seemingly insatiable demand for luxury seafood products has driven increasing exploitation of wild stocks and sustained livelihoods for decades [5,33]. Despite recent government initiatives to limit "conspicuous consumption" of luxury seafoods in China [7,36], demand, and hence prices of most beche-de-mer species appear to have steadily increased since 2011.

The findings reveal that across 20 beche-de-mer species, average retail prices in Hong Kong and Guangzhou rose on average by more than 16% between 2011 and 2016 (2.4% per year), slightly outpacing China's CPI increase over the corresponding period (www.inflation.eu). Furthermore, maximum retail prices for grade-A beche-de-mer products increased by over 50% (6.3% per year) between 2011 and 2016. This rapid price increase may well be a symptom of the combined effects of increasing demand for premium-grade products and the increasingly limited supply of such products from source countries. This has clear implications for drivers of overexploitation of wild sea cucumber stocks (see [15]) and the fishing communities in source countries. Since sea cucumbers offer a lens through which to understand exploitation and trade of other luxury seafood for Asian markets [2,7], the findings suggest that consumer demand for foreign seafood continues to grow in China and trumps national policies in the absence of tangible trade

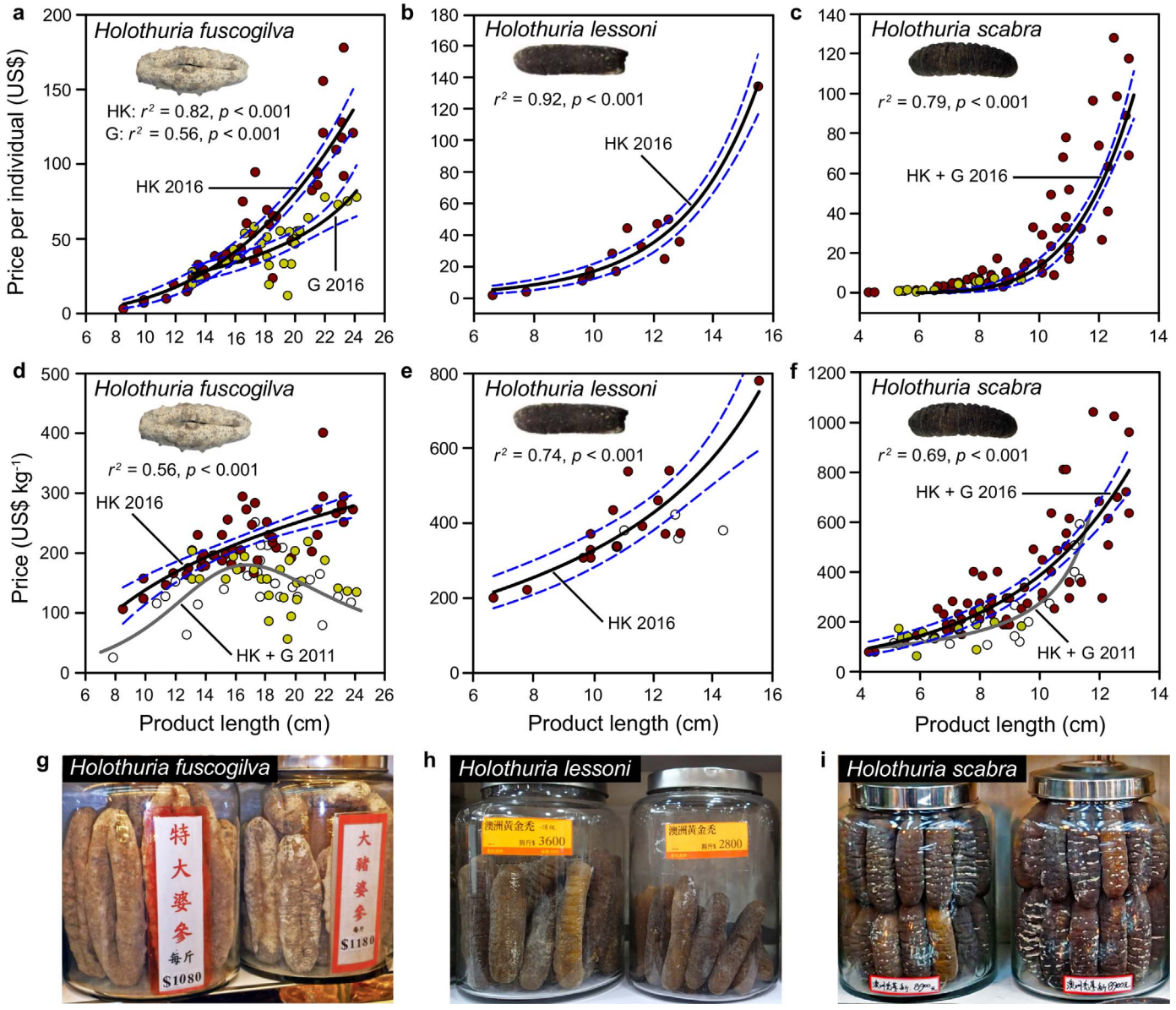

Fig. 2. Length vs price relationships for three high-value beche-de-mer species, *Holothuria fuscogilva, Holothuria lessoni* and *Holothuria scabra* in retail stores in Hong Kong (HK) and Guangzhou (G) in 2016 and in 2011 (*H. fuscogilva* and *H. scabra* only). Plots are length vs price per individual (2016 data only), and length vs price per kg (2016 and 2011 data) for *H. fuscogilva* (a and d), H. *lessoni* (b and e) and *H. scabra* (c and f). All data are average lengths and prices of four individual specimens from each sampled lot. Dark red markers are 2016 data from Hong Kong stores; yellow markers are 2016 data from Guangzhou stores; white markers are 2011 data from Hong Kong and Guangzhou stores pooled (price per kg only). Model curves are the best fit by AIC selection. Black model curves with dashed blue 95% CI bands relate to 2016 data, while grey model curves relate to 2011 data (price per kg only). Regression analyses results (r^2 and p values) relate to the 2016 model curves only. Photographs illustrate *H. fuscogilva* (g), *H. lessoni* (h), *H. scabra* (i) beche-de-mer for sale in Chinese stores in 2016. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

measures.

As Fabinyi, Barclay and Eriksson [7] claim, consumer demand for healthy and safe foods in China has expanded the markets for mid- and low-value beche-de-mer consumed in everyday meals. Indeed, the present study found that the largest proportional increases in prices were for previously low- and medium-value species such as *Stichopus herrmanni*, *Bodaschia vitiensis* and *Holothuria fuscopuntata* (Table 1). Additionally, for some other species, small individuals did not attract such disproportionately low prices in 2016 as they did in 2011 (see Figs. 2 and 3d,g). The data therefore lend support to the assertion of a recent shift in consumer preferences, whereby previously lower value products are now more accepted.

Although expanding aquaculture production should contribute to meeting increased demand, wild stocks that remain productive will continue to be exploited for the foreseeable future [36]. The absence of rigorous and effective fishery management, combined with unsustainable fishing practices and widespread misreporting of catches, has unfortunately resulted in a recurring pattern of stock depletion, fishery collapse and in some cases, local-scale extinctions of highly-targeted species [3,15,26,38,39]. Food safety and product quality are considered far more important than environmental resource condition by both Chinese consumers [40] and traders [7]. As one trader put it, “I just sell these products. It’s the responsibility of governments to regulate their fisheries properly” [7]. Therefore, sustaining the production of beche-de-mer from a diverse suite of harvested tropical marine species will require the implementation of major fisheries reforms within producing countries. Several previous studies have identified the critical changes needed to regulatory measures and enforcement [27,39], governance [2,41] and political will [24,42].

Regulatory measures likely to bring about sustainability of sea

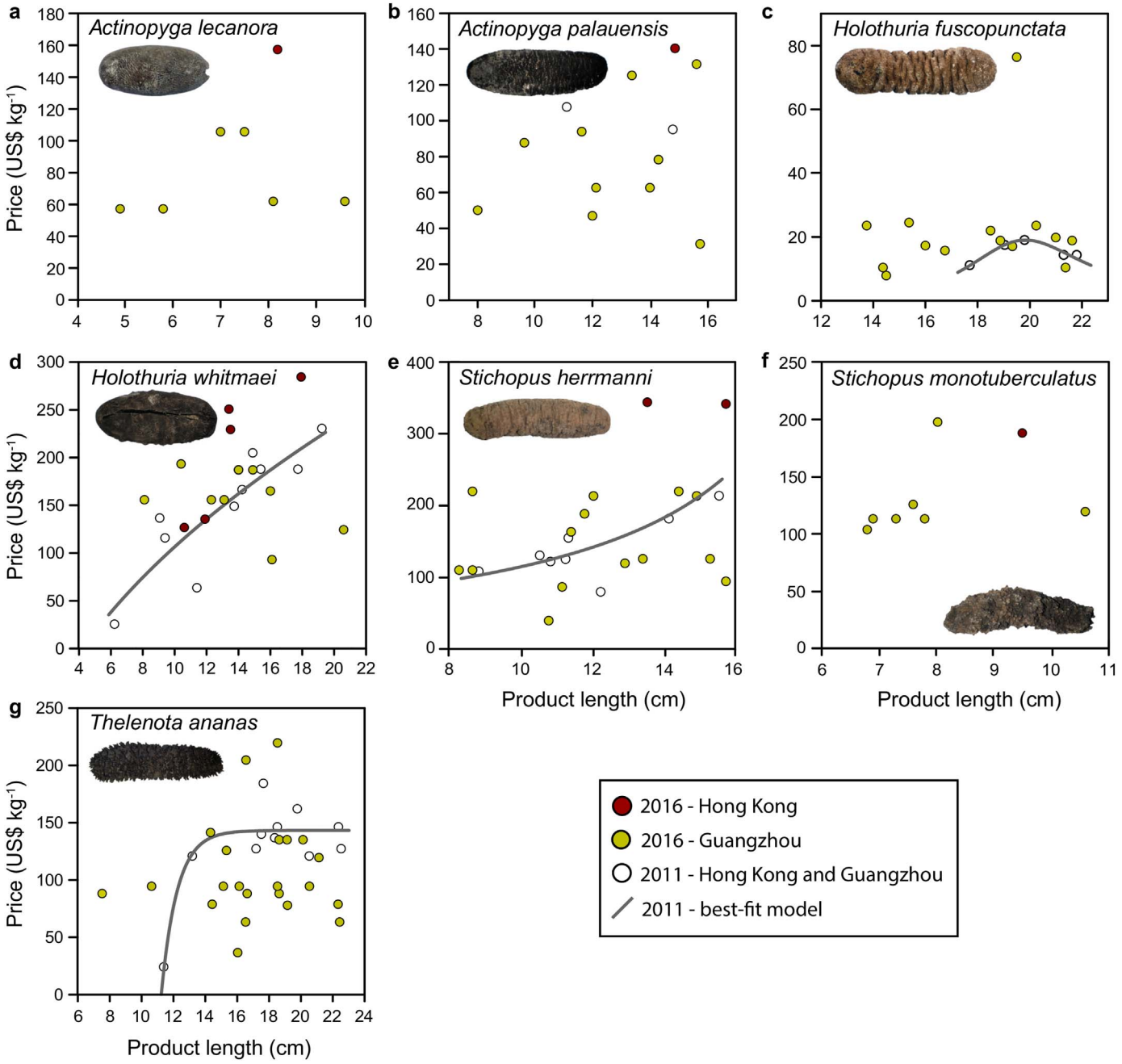

Fig. 3. Length vs price per kg relationships for seven beche-de-mer species, Actinopyga lecanora (a), Actinopyga palauensis (b) Holothuria fuscopunctata (c), Holothuria whitmaei (d), Stichopus hermanni (e), Stichopus monotuberculatus (f) and Thelenota ananas (g) in retail stores in Hong Kong (HK) and Guangzhou (G) in 2016 and 2011. All data are average lengths and prices of four individual specimens from each sampled lot. Dark red markers are 2016 data from Hong Kong stores; yellow markers are 2016 data from Guangzhou stores; white markers are 2011 data from Hong Kong and Guangzhou stores pooled (H. fuscopunctata, H. whitmaei, S. hermanni and T. ananas only). No significant length-price relationships were found for any of these seven species in 2016. Model curves for 2011 data (b, d, e, g) are the best fit by AIC selection. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

cucumber fisheries include bans on the use of scuba gear, minimum size limits, limited entry licensing, restricted fishing seasons and shortlists of permissible species. Minimum legal size limits for harvested species are generally supported by fishers, and can be effectively enforced at sites of export when products are dried and consolidated [30]. Retail prices of the high-value beche-de-mer species *H. fuscogilva*, *H. lessoni* and *H. scabra* clearly increased exponentially with body length. Despite small sample sizes and the inability to detect statistically significant relationships, the findings support the assertion that larger individuals of most sampled beche-de-mer species attracted higher prices than smaller individuals. For *H. fuscogilva*, *H. lessoni* and *H. scabra*, prices attained for small individuals were 2–3 orders of magnitude lower than the prices for large individuals.

In order to be an effective fishery control, size limits should be defined using species-specific information on growth, size at first reproduction and natural mortality rates [30]. However, exponentially higher prices for larger beche-de-mer should also provide economic rationale to decisions about appropriate minimum size limits [4]. The findings demonstrate that beche-de-mer product lengths below approximately 14 cm for *H. fuscogilva* and 10 cm for *H. lessoni* and *H. scabra* attracted comparatively low prices. Although there is evidently a market for these small individuals, limiting the harvest of these size

Table 2
Parameter estimates and fit results for morphometric relationships between product length (cm) and weight (g) based on the standard growth function, $y = ax^b$, where y is the weight in grams and x is the length in cm. Sample size of each species is denoted by n. For *Bohadschia vitiensis*, $p = 0.015$; for all other species, $p < 0.001$.

Species	*a*	*b*	*n*	r^2
Actinopyga lecanora	1.833	1.379	28	0.47
A. palauensis	2.053	1.564	44	0.60
Bohadschia argus	0.813	1.810	16	0.68
B. vitiensis	6.344	0.978	16	0.36
Holothuria fuscogilva	0.642	2.080	293	0.75
H. fuscopunctata	0.230	2.314	56	0.67
H. lessoni	0.152	2.538	60	0.81
H. scabra	0.099	2.725	320	0.84
H. whitmaei	1.263	1.887	60	0.74
Stichopus chloronotus	0.627	1.538	16	0.70
S. herrmanni	0.377	2.117	64	0.73
S. monotuberculatus	0.211	2.143	32	0.69
S. naso	0.119	2.297	12	0.80
Thelenota ananas	1.998	1.532	88	0.53
T. anax	0.537	2.021	19	0.59

classes in source countries may enhance the sustainability of both the wild stocks and the fishing communities that harvest them. Sea cucumbers are known to have low rates of natural mortality as adults [43,44], so allowing small animals to attain larger sizes in the wild is expected to improve the long-term economic performance of fisheries.

Aquaculture production of sea cucumbers, particularly sandfish (*H. scabra*), has gained momentum in recent years and the industry is forecast to expand rapidly [18–20,34]. A fundamental economic consideration in most aquaculture systems is the optimal size at which to harvest cultured animals. This generally involves a trade-off between the production costs for a given grow-out period and the prices attained for product of a given size [19,45]. Sandfish are often harvested from earthen ponds or sea pens at a small adult size of just 300–400 g fresh weight, which is the minimum market size that Chinese traders accept [46–49]. The enormously higher market prices for large individuals appears to provide justification for a shift in harvest strategy to longer culture cycles for which animals of at least 660–1050 g whole body weight are attained. For *H. scabra*, individuals of this size would yield beche-de-mer of at least 10 cm, based on the length-to-weight parameters presented here (Table 2) and conversion rates of about 5–8% [50,51]. It must be acknowledged however, that not all aquaculture operations are conducive to growing sea cucumbers for the several years required to attain large product sizes, either due the culture system and facilities, or the underlying fiscal conditions of the operation [34]. However, the findings might convince some producers to grow at least a proportion of their stock to large sizes that should attract premium prices. In this regard, the new size-price relationships should assist sea cucumber aquaculture operations in formulating more profitable grow-out and harvest strategies.

5. Conclusions

Despite Chinese domestic conditions favouring a downturn in demand for sea cucumbers, prices of tropical beche-de-mer species rose, on average, at a faster rate than other commodities between 2011 and 2016. Market demand remains relatively strong for beche-de-mer, suggesting that luxury seafoods in general will be increasingly sought after for Asian markets in spite of certain national policies. Market prices for several previously low- and medium-value beche-de-mer species significantly increased from 2011 to 2016, a trend that was evidently driven by increasing consumer demand for inexpensive, healthy seafood for everyday meals. Furthermore, the findings also indicate increased demand and potentially, increasingly limited supply of premium-grade beche-de-mer products.

The analysis of price trends across product sizes presented here can be applied for other species to inform both aquaculture and fisheries. Exponentially higher prices offered for large individuals of several high-value species provides justification for serious consideration of extending aquaculture grow-out periods to attain larger body sizes and higher value beche-de-mer. Since environmental resource sustainability is unlikely to be an effective marketing tool in Chinese markets, sustainable production must come from effective fishery management within producing countries. The higher values attained for large individuals of several high value species should provide adequate economic rationale for implementing large minimum size limits for several sea cucumber species harvested from the Indo-Pacific region.

Acknowledgments

This study was funded by the Australian Centre for International Agricultural Research through project FIS/2010/096. Financial support was also provided by the Wildlife Conservation Society Fiji. We give grateful thanks to Sailasa Tagica, Watisoni Lalavanua and Guanglin Wang for contributing to data collection. We thank an anonymous reviewer for his/her constructive comments, which helped to improve the manuscript.

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