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Chagos feels the pinch: assessment of holothurian (sea cucumber) abundance, illegal harvesting and conservation prospects in British Indian Ocean Territory

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ABSTRACT

1. Data are analysed from visual censuses of shallow-water holothurians (sea cucumbers) in 72 shallow water transects 100 m × 2 m within four atolls of Chagos. Mean holothurian abundance in Diego Garcia, where harvesting is absent, was 18.5 individuals/transect (all transects) and 55.4 individuals/transect (only those containing holothurians). In the three exploited atolls, mean abundance did not exceed 3.5 and 5.2 individuals/transect, respectively.
2. Comparison with data collected during this study and an earlier investigation reveals a marked decline over four years in both mean and maximum density of commercially valuable *Stichopus chloronotus* and *Holothuria atra* in Salomon and Peros Banhos, both exploited atolls, and also for *Holothuria nobilis* in the latter.
3. Holothurian counts were also made along an extensive transect (21 km × 4 m) encircling Salomon atoll. Abundance showed highly significant negative correlation with fishing pressure, the latter estimated using an ordinal (0–3) scale ($R_s = -0.605$, $P \leqslant 0.01$). Harvesting effects were not discernible using data from 200 m^2 transects.
4. While recent studies have shown Chagos is virtually pristine regarding contaminant levels, its holothurian resources are under increasing pressure. Results from this study, and examination of Sri Lanka's fishing activity in distant waters, point to heavy and illegal harvesting.
5. Stronger measures are needed to control the illegal fishery, to prevent holothurian abundances falling to the non-sustainable levels now prevalent across much of the Indo-Pacific, and to ensure that Chagos remains a biodiversity hotspot and environment of international renown. Use of smaller surveillance vessels would facilitate this.

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KEY WORDS: marine resources; fishery; poaching; coral reefs; Chagos Archipelago

INTRODUCTION

Of the atolls in the central Indian Ocean, those of the Chagos Archipelago are the most isolated and biologically diverse. There are 55 islands within five atolls, including the world's largest atoll, the Great Chagos Bank. Following the abandonment of the copra plantations, in 1973, most islands are uninhabited and have rarely been visited for 40 years. The only exception is Diego Garcia, part of which is a strategic military base with infrastructure to support long-range aircraft and ships that visit and reside for extended periods in the lagoon, which provides anchorage. On this atoll, in particular, marine harvesting is strictly prohibited.

In 1996, a research programme in Chagos (Sheppard and Seaward, 1999) assessed the atolls' biodiversity, their biogeographic role, and the degree of human impact including contaminant levels. Analysis of sediment and tissue samples (Everaarts *et al.*, 1999; Readman *et al.*, 1999) revealed that Chagos belonged to one of the world's least contaminated coastal areas, and the whole archipelago is effectively a protected area, with entry to a large proportion of its shallow reefs being prohibited under local conservation

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regulations. Fishing is mostly confined to offshore waters in Chagos and takes place under licence (Sheppard and Spalding, 2003). Even back in the 1990s, however, fishing pressure on reefal/inshore fisheries was mounting (Price, 1999).

A second major research effort took place in Chagos during 2006. One of the studies confirmed the uncontaminated nature of coastal waters (Guitart *et al*., 2007). Repeat rapid environmental assessments were also undertaken (Price and Harris, 2009). Among the study's findings was a significant increase in fishing/collecting on the islands. Holothurians (sea cucumbers), in particular, were being taken in increasing numbers by an illegal fishery operating out of Sri Lanka (Spalding, 2005, 2006). This harvesting pressure mirrors the extensive exploitation of holothurians occurring in several parts of the Indian Ocean (reviews: Lovatelli *et al*., 2004; Uthicke and Conand, 2005). However, apart from the survey of Posford Haskoning (2002), which did not include Diego Garcia, there appears to have been no holothurian population assessments in Chagos. An echinoderm study was undertaken in Diego Garcia in the early 1970s (Clark and Taylor, 1971), but this assessment was taxonomic rather than ecological.

The main aims of this study are to: (1) compare holothurian populations in an unexploited atoll of Chagos (Diego Garcia) with those of exploited atolls/islands (Salomon, Peros Banhos, Great Chagos Bank); (2) re-examine the same islands surveyed by Posford Haskoning (2002) in Salomon and Peros Banhos, to determine the nature and extent of any change in holothurian populations over a four-year period; (3) assess the likely role of harvesting vis-à-vis other possible factors influencing holothurian abundance; and (4) evaluate the conservation status of holothurian stocks in Chagos — a biodiversity hotspot of global conservation significance in a remote part the central Indian Ocean — against a background of regional or even global reduction of holothurian resources. The paper concludes with a largely qualitative examination of Sri Lanka's distant-water fishing activities, whose favoured destinations include the Chagos Archipelago.

METHODS

Holothurian populations were assessed during February/March 2006 at islands within Diego Garcia, Salomon, Peros Banhos and The Great Chagos Bank atolls (Figure 1). At each island, observations were undertaken during February/March 2006, the position of each site fixed using GPS. Water depths were generally up to 2.5 or 3 m below low water level. Qualitative details of habitat/substrate were also noted for every 100 m transect (below). In addition, percentage coral cover was recorded for each 10 m subdivision of these transects. The study is based on two complementary field methodologies.

100 m × 2 m transects

Holothurians were assessed in the four atolls by snorkelling along a total of 72 transects, mostly in the lagoon side of each atoll and island (Figure 1). Sites were chosen to include representative areas containing potentially suitable habitats (sandy areas, rubble and seagrass), although logistical constraints sometimes influenced site selection. Transects were 100 m long (each subdivided into ten units, 10 m in length) and 2 m wide, providing a survey area of 200 m^2. Counts were made for all species that could be readily identified in the field using identification guides (Rowe and Richmond, 1997; Price and Rowe, 2002). Otherwise they were recorded as 'sp(p)'. Identification to species is generally reliant on collection of specimens and microscopic examination of spicules and/or other calcareous structures (Clark and Rowe, 1971; Price and Reid, 1985). However, collections were not made since the study was primarily a population rather than taxonomic assessment. It is believed that any loss of taxonomic rigour is offset by the extra time generated for extra field surveys.

In Salomon atoll, sites surveyed included the four islands examined by Posford Haskoning (2002), Boddam, Anglaise, Passe and Takamaka. In the case of Peros Banhos atoll, only two of the (four) islands assessed by Posford Haskoning (2002) were among those surveyed in this study: Coin and Diamant.

21 km × 4 m transect

Exceptionally calm weather and clear waters on 11 March 2006 made it possible to count holothurians from an inflatable at speeds of *ca* 1–2 knots. The survey traversed sand and shallow coral reef within lagoonal waters among the islands of Salomon (Figure 2). Observations were made by two of the authors (ARGP, AH) to a total distance/width of 4 m (2 m each side of the inflatable), the total transect length being *ca* 21 km. GPS fixes were made periodically or when topography or bathymetry changed significantly. Overall abundance was the main data collected, although some holothurians could even be identified to species (e.g. *Stichopus chloronotus*), from the slow-moving inflatable.

Harvesting pressure

In Diego Garcia only recreational fishing with lines is permitted (Sheppard and Spalding, 2003); holothurian collecting is strictly prohibited. Strong penalties discourage violation, and it is believed to be absent or negligible on this atoll. Holothurian collecting on Diego Garcia was never observed during the survey, despite the very high abundances sometimes recorded, and despite their whereabouts known to Philippino workers who recognized that, in their country of origin, opportunity to exploit abundant holothurian resources would be readily seized.

Holothurian harvesting is also illegal on the atolls and islands beyond Diego Garcia: Salomon, Peros Banhos and Great Chagos Bank. Nevertheless it occurs, sometimes very intensively (Spalding, 2006; Figure 2). Heavy exploitation was reported in 1999, while the first direct observations and arrests of holothurian fishers by the Chagos authorities occurred in 2005 (Spalding, 2006). Holothurian collecting was not directly observed during the present study, but indirect evidence took the form of (unoccupied) fishing camps on islands, cleared vegetation, wooden seats, hessian sacks, burnt wood and other remnants of camp fires, shells of giant clams or other molluscs and discarded fishing equipment. In one island (Middle Brother, Great Chagos Bank), a freshwater well had been dug. To obtain an approximation of holothurian fishing intensity, notes on direct and indirect evidence for harvesting during 2005 and 2006 were kindly provided by BIOT/Marine Resources Assessment Group (MRAG Ltd). This was updated

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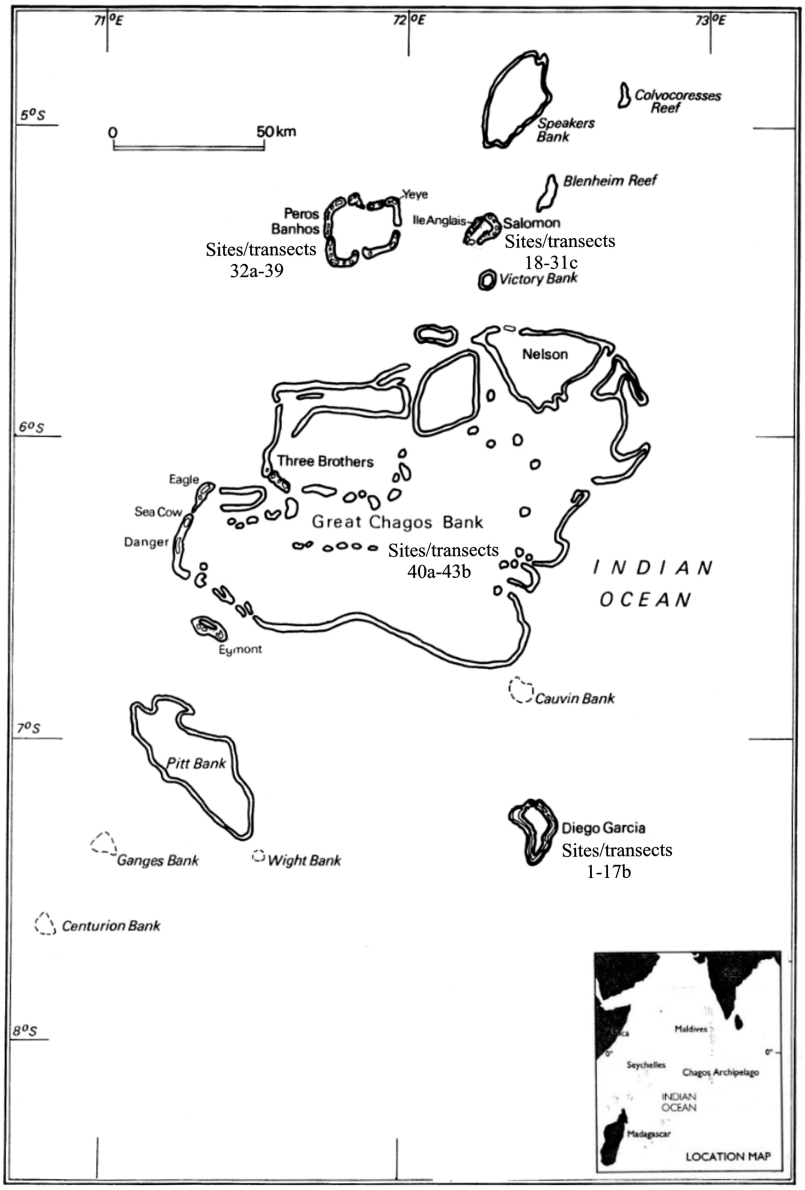

Figure 1. Map of Chagos Archipelago, showing location of the 72 sites surveyed for holothurians along 100 m × 2 m transects by snorkelling and visual censuses during Feb/March 2006; sites 1–17b (Diego Garcia), 18–31c (Salomon), 32a–39 (Peros Banhos), 40a–43b (Great Chagos Bank).

with observations on the islands and discussions with yachtsmen during this investigation. From this information, a preliminary, semi-quantitative index of holothurian fishing was developed (0: no evidence to 3: strong evidence, e.g. 10 fishers observed; Table 1).

RESULTS

Holothurian abundance, habitat and fishing effects in four atolls: 100 m × 2 m transects

Mean overall holothurian abundance (all species) was substantially higher for Diego Garcia, where harvesting is absent, than for the other three atolls, where illegal exploitation occurs at varying levels (Figure 3). This pattern is evident with data for all transects (which include those with zero abundance) and for transects having suitable habitat, i.e. where holothurians were present. Despite higher mean abundance in Diego Garcia, fewer of the sites examined in this atoll appeared to be suitable holothurian habitat (individuals present at 33% of the sites), compared with at Salomon (present at 55% of the sites), Peros Banhos (present at 62% of the sites) and the Great Chagos Bank (present at 100% of the sites).

Overall and individual species abundances varied markedly across sites/islands and atolls (Tables 2–5). Of the seven taxa recorded, *Holothuria atra* attained highest densities, reaching 167 individuals 200 m^{-2} at one site in Diego Garcia (Table 2). The abundance of *Holothuria scabra*, *Stichopus chloronotus* and *Bohadschia* sp. occasionally exceeded 10 individuals 200 m^{-2}, although few sites contained these species. Species encountered outside transects included: *Holothuria fuscogilva*, *H. fuscopunctata*, *Actinopyga echinites*, *Bohadschia marmorata*

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and *B. vitiensis*, as well as *Pearsonothuria graeffei* and *Thelenota ananas* (both in deeper water). Thus, a total of $\geqslant$14 taxa was recorded ($\geqslant$7 taxa within transects plus seven species outside), excluding several unidentified species also observed.

Possible associations between holothurian abundance and habitat type, determined as percentage coral cover, were also examined using data from the $200\,m \times 2\,m^2$ transects. Correlations were weak, and significant (two-tailed) only for one of the atolls (Diego Garcia: $N = 208$, $r = -0.139$, $P \leqslant 0.05$; Salomon: $N = 269$, $r = 0.076$, NS; Peros Banhos: $N = 159$, $r = -0.110$, NS; Great Chagos Bank: $N = 80$, $r = 0.066$, NS). No marked association between habitat type and abundance of individual species or holothurians overall was evident (Tables 2–5).

Overall holothurian abundance (Tables 3–5), using pooled data from the $200\,m \times 2\,m^2$ transects for the three exploited atolls, was not significantly correlated with fishing pressure (Table 1), based on a scale of 0–3 ($N = 51$, $R_s = -0.048$, $P > 0.05$, one-tailed). Absence of association was also evident with data for Diego Garcia included in the analysis, and for individual atolls. This contrasts markedly with other findings (below), which strongly suggest that fishing influences holothurian populations in Chagos.

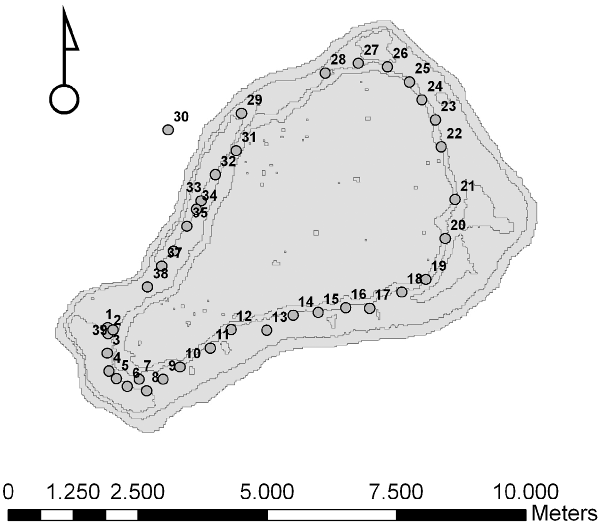

Figure 2. Location of continuous transect, $20\,570\,m \times 4\,m$ in Salomon atoll, along which holothurian counts were also made from aboard a slow-moving inflatable on 9 March 2006. (The location numbers refer to GPS fixes; location 30 is an outlier, probably reflecting an incorrectly recorded position.)

Change in holothurian abundance at Salomon and Peros Banhos (2002 versus 2006): 100 m × 2 m transects

Comparison of mean and maximum holothurian densities at Salomon and Peros Banhos within $200\,m^2$ transects during 2006 and 2002 indicate a marked decline in both means and maximum densities of *Stichopus chloronotus* and *Holothuria atra* in Salomon and Peros Banhos atolls over the four-year period (Table 6). This was also observed in Salomon atoll for *Holothuria nobilis*, a species absent from Peros Banhos in both investigations (Table 6). These results are consistent with holothurian fishing, especially given that harvesting is moderate to heavy on two of the four islands in Salomon atoll examined in the two surveys (fishing pressure scores for Passe 1–2, Takamaka 3, Boddam 0, Anglaise 0; Table 1). In the case of Peros Banhos, only two islands were common to the 2006 and 2002 investigations, both of which are associated with harvesting (fishing pressure scores for Coint 1, Diamant 3; Table 1).

Species abundance and fishing impacts in Salomon atoll: 21 km × 4 m transect

The total holothurian count (all species) within the transect area of 82 280 m^2 ($20\,570\,m \times 4\,m$) in Salomon atoll was 2146 individuals. Hence, the average density was 2146/82 280, or 0.026 individuals m^{-2}. This equates to a mean of 5.2 individuals $200\,m^{-2}$. Holothurian abundance shows highly significant negative correlation with fishing pressure ($N = 25$, $R_s = -0.605$, $P < 0.01$, one-tailed). This suggests that harvesting has a marked effect on holothurian populations within Salomon atoll.

DISCUSSION

Holothurian densities are known to be highly variable, both in Chagos (Posford Haskoning, 2002) and other regions of the Indo-Pacific (Conand and Mangion, 2002; Trianni and Bryan,

Table 1. Estimated harvesting pressure for holothurians for sites/islands examined in three atolls, based on 0–3 scale (0: none, 3: heavy, n/r: no record)

Salomon		Peros Banhos		Great Chagos Bank	
Island	Fishing pressure	Island	Fishing pressure	Island	Fishing pressure
Fouquet	2	Coin	1	Eagle	3
Takamaka	3	Parasol	n/r	Middle Brother	2
Ile de la Passe	1–2	Longue	0	N. Brother	n/r
Anglaise	0	Ile du Passe	1–2	S. Brother	n/r
Boddam	0	Diamant	3		
Mapou	1–2	Grande Ile Coquillage	1		
Sel	1–2	Petite Ile Coquillage	0		
Poule	1–2	Petite Soeur	n/r		
Sepulchre	1–2				
Diable	1–2				
Jacobin	1–2				

Values derived from information provided by BIOT/Marine Resources Assessment Group (MRAG Ltd) and visiting yachtsman. (At Diego Garcia, harvesting pressure for holothurians is absent or negligible.)

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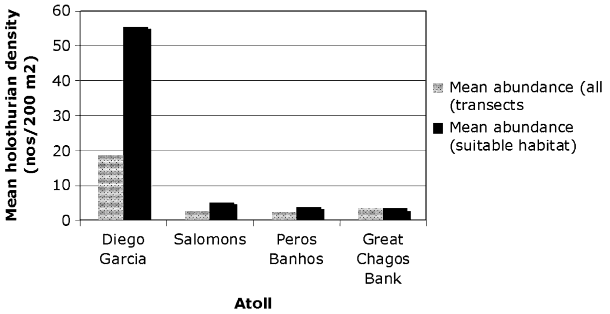

Figure 3. Mean abundance of holothurians on Diego Garcia (21 transects), Salomon (27 transects), Peros Banhos (16 transects) and Great Chagos Bank (8 transects) determined from visual censuses along 72 transects 100 m × 2 m (200 m^2); data shown for all transects and for transects with suitable habitat, i.e. where holothurians were present.

2004; Pouget, 2005). Patterns resulting from 72 transects 100 m × 2 m (Tables 2–5), and the 21 km × 4 m transect in Salomon atoll, are consistent with this. Collectively, the methods used are considered to have provided a reasonable approximation of holothurian abundances across the four atolls in Chagos that were examined. The similarity between mean abundance for Salomon atoll determined from 100 m × 2 m transects (Figure 3), and separate observations within the larger transect (5.2 individuals 200 m^{-2}), provides some support for this.

The relatively few holothurian taxa recorded (16) is partly a reflection that this investigation was principally an ecological assessment rather than a taxonomic study, and was limited to shallow water depths accessible to poaching. Clark and Taylor (1971), for example, reported 14 holothurian species from Diego Garcia. Clark and Rowe (1971) document 37 species for the Chagos–Maldives–Lakshadweep (Laccadive) region. However, both taxonomic studies examined a wider range of habitats and environmental conditions. Further studies in Chagos, particularly those involving collections and sampling a wider range of substrata and depths, would probably yield many more holothurian species than recorded here, especially on coral substrates too deep for poaching.

In Chagos, harvesting may have now become an important determinant of holothurian abundance. Holothurians, in general, are highly susceptible to fishing pressures due to their limited mobility, late maturity, density dependent reproduction, habitat preference and low rate of recruitment. The reduction in stocks in several parts of the Indo-Pacific (Lovatelli *et al*., 2004; Uthicke and Conand, 2005) is in accordance with this. Estimates of harvesting pressure on holothurians in Chagos (Table 1) are at present tentative, given that fishing effort is notoriously difficult to quantify (Price *et al*., 1998), especially when illegal. Nevertheless, several datasets and analyses in this study point to harvesting as a major influence on shallow-water holothurian populations in Chagos.

First, the complete or virtual absence of collecting in Diego Garcia correlates with high holothurian abundances, compared with much lower abundances in the poached atolls of Salomon, Peros Banhos and Great Chagos Bank (Figure 3; Table 1). Any differences in ecological conditions and habitat suitability in Diego Garcia compared with the other atolls could, of course, also potentially influence holothurian density.

Table 2. Holothurian abundance, Diego Garcia, along 21 transects 100 m × 2 m (mostly lagoon/sheltered waters) during February and March 2006

Site/transect and habitat	Lat.	Long.	Abundance (No. 200 m^{-2})					
			Stich. chloro.	*Bohad.* sp.	*H. scabra*	*H. atra*	*H. nobilis*	Total (all spp.)
1 Inner lagoon, nr accomm. sand, rubble	7 15.748	72 22.743	0	0	0	0	0	**0**
2 Turtle cove; rock/sand veneer, rubble, algae	7 25.845	72 26.080	0	0	0	0	0	**0**
3 Plantation (west); sand	7 21.19	72 28.06	0	0	0	0	0	**0**
4 Plantation (east); sand veneer over rock/algae	7 21.06	72 28.38	0	0	0	0	0	**0**
5 N Turtle cover (nr site 2); sand/rubble stones/algae	7 25.81	72 26.09	0	51	0	0	0	**51**
6 S tip (exposed); sand/rubble/rock/algae	7 26.59	72 26.04	0	0	0	0	0	**0**
7 'E cut' (1.5 nm NW Horsburgh Pt; rubble/coral/ rock/sand	7 22.18	72 28.95	0	0	0	0	0	**0**
8 E coast, lagoon side; sand & stone & coral	7 22.2	72 28.59	5	0	1	5	0	**11**
9a N entrance; sand/coral rubble	7 14.759	72 24.790	0	0	0	0	0	**0**
9b N entrance; sand/coral rubble	7 14.759	72 24.790	0	0	0	0	0	**0**
9c N entrance; sand/coral rubble	7 14.759	72 24.790	0	0	0	0	0	**0**
10 N entrance; sand/coral rubble	7 14.086	72 25.034	0	0	0	0	0	**0**
11 N entrance, East island; sand/rubble/rock	7 13.704	72 24.98	0	0	0	0	0	**0**
12 Stony Brook harbour; coral/rubble/algae (*Caulerpa*)	7 17.39	72 23.30	0	0	0	0	0	**0**
13 Stony Brook, N of harbour; coral/rubble/sand	7 16.94	72 22.63	0	0	0	0	0	**0**
14 Yacht Club/Patrol Boat; sand/coral rubble/algae	7 16.44	72 22.45	0	0	0	0	0	**0**
15a West coast, lagoon side, dump site/incinerator; tidal flat/silt/rock/coral	7 20.91	72 26.04	2	0	2	104	0	**108**
15b West coast, lagoon side, dump site/incinerator; sand/silt/rubble	7 20.91	72 26.04	0	0	1	0	0	**1**
16 West coast, lagoon side; tidal flat sand/rock	7 20.26	72 25.97	3	0	24	167	0	**194**
17a West coast, lagoon side; tidal flat sand/rock	7 19.20	72 25.77	4	0	1	16	0	**21**
17b West coast, lagoon side; sand/silt/+OM on surface?	7 19.20	72 25.77	0	1	1	0	0	**2**

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Table 3. Holothurian abundance, Salomon atoll, along 27 transects 100 m × 2 m during March 2006

Site/island/transect and habitat	Lat.	Long.	Abundance (No. 200 m^{-2})							
			Stich. chloro.	*Bohad.* sp.	*H. scabra*	*H. atra*	*H. nobilis*	*Holoth.* sp.	*Actinop* spp.	Total (all spp.)
(18) Takamaka Is, L; sand/coral	5 19.97	72 16.10	0	0	0	0	0	0	0	**0**
(19) Takamaka Is, L; sand/rubble/stone	5 20.04	72 16.10	0	0	2	0	0	0	0	**2**
(20a) Ile Fouquet, L; silt/rock/coral	5 20.16	72 16.02	2	1	1	4	0	0	0	**8**
(20b) Ile Fouquet, L; sand/silt/coral	5 20.24	72 15.99	2	0	2	17	0	0	0	**21**
(21a) Ile Fouquet/Anglais, S; coral/sand veneer over rock	5 20.439	72 12.809	0	0	0	0	0	0	0	**0**
(21b) Ile Fouquet, S; coraline algae/macroalgal turf	?	?	0	0	0	0	0	0	0	**0**
(22a) Ile de Passe, L; sand/coral	5 18.28	72 1.19	0	0	0	0	0	0	0	**0**
(22b) Ile de Passe, L; sand/coral	5 18.30	72 15.29	0	0	0	0	0	0	0	**0**
(23a) Ile Mapou, L; sand/coral	5 18.76	72 15.87	0	0	0	0	0	0	0	**0**
(23b) Ile Mapou, L; sand/coral/rock	5 18.68	72 15.82	0	0	0	0	0	0	0	**0**
(23c) Ile Mapou, L; sand/rock/coral	5 18.68	72 15.82 (near 23b)	0	0	0	1	0	0	1	**2**
(24a) Ile Supulchre, L; coral/sand	5 20.90	72 15.18	1	0	0	0	0	0	0	**1**
(24b) Ile Supulchre,, L; coral/sand/rock/stones	5 20.90	72 15.18 (near 24a)	0	0	0	0	0	0	0	**0**
(25a) Ile Jacobin, L; sand/silt & coral, rubble & stones	5 20.98	72 14.70	0	0	0	0	0	0	0	**0**
(25b) Ile Jacobin, L; sand/coral/rubble	5 20.98	72 14.70	1	0	0	0	0	0	0	**1**
(26a) Ile Sel, L; silt/coral/rubble	5 21.24	72 13.53	0	0	0	0	0	0	0	**0**
(26b) Ile Sel, L; sandy silt/coral/rock	5 21.24	72 13.53 (near 26a)	0	0	0	0	0	0	0	**0**
(27a) Ile Poule, L; coral/sand	5 21.52	72 13.25	0	0	0	0	0	0	0	**0**
(27b) Ile Poule, L; sand/rubble/coral	5 021.52	72 13.25 (near 27a)	1	0	0	0	0	0	0	**1**
(28a) Ile Anglais, L; sand/coral/silt	5 20.36	72 12.99	1	0	0	9	0	0	0	**10**
(28b) Ile Anglais, L; coral/rubble/sand	5 20.40	72 12.91	0	0	0	0	2	0	0	**2**
(29) E. Takamaka; sand/lagoon/rock	?	?	11	0	0	0	0	0	0	**11**
(30a) Ile Diable, L; coral/rubble/sand	5 20.78	72 12.24	2	0	0	1	0	0	0	**3**
(30b) Ile Diable, L; rock/rubble/coral/sand	5 20.78	72 12.24 (near 30a)	3	0	0	1	1	1 (?*H. fuscogilva*)	0	**5**
(31a) Ile Boddam, L; sand/rubble	5 21.71	72 12.67	2	0	0	0	0	1 (?*H. fuscogilva*)	0	**3**
(31b) Ile Boddam, L; coral/sand	5 21.68	72 12.61	0	0	0	1	0	1	0	**2**
(31c) Ile Boddam, L; sand	5 21.68	72 12.61 (near 31b)	0	6	0	0	0	0	0	**6**

L = lagoon side; S = seaward side.

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Table 4. Holothurian abundance, Peros Banhos atoll (lagoon side), along 16 transects 100 m × 2 m during March 2006

Site/island/transect and habitat	Lat.	Long.	Abundance (No. 200 m^{-2})							
			Stich. chloro.	*Bohad.* sp.	*H. scabra*	*H. atra*	*H. nobilis*	*Holoth.* sp.	*Actinop.* sp(p). (mostly *A. maurit.*)	Total (all species)
(32a) Parosol; sand/coral/rock & rubble	5 15.84	71 50.53	0	0	0	0	0	0	0	**0**
(32b) Parosol; rock/coral	5 16.20	71 51.86	0	0	0	0	0	0	0	**0**
(33a) Ile Longue; sand/rock/(much) coral	5 15.9	71 51.80	0	0	0	0	0	0	0	**0**
(33b) Ile Longue; rock/sand	5 16.20	71 51.86	0	0	0	0	0	0	0	**0**
(34a) Ile Diamont; coral/rubble/sand	5 15.16	71 46.50	2	0	0	1	0	0	0	**3**
(34b) Ile Diamont; rubble/rock/algae/silt	5 15.70	71 45.39	0	0	0	0	0	1	0	**1**
(35a) Petite Ile Coquillage; coral/rock	5 20.25	71 58.20	0	0	0	0	0	0	1	**1**
(35b) Petite Ile Coquillage; silt/rock/sand	5 20.40	71 58.30	0	0	0	0	0	0	6	**6**
(36a) Grande Ile Coquillage; sand/rock/coral/silt	5 22.05	71 58.22	3	0	0	7	0	0	0	**10**
(36b) Grande Ile Coquillage; coral/silt/rock/algae	5 14.76	71 48.89	0	0	0	1	0	0	0	**1**
(37a) Ile de Passe, Coquillage; rock/rubble/sand (limited/patchy/veneer)	5 14.76	71 48.89	0	0	0	0	0	0	0	**0**
(37b) Ile de Passe, Coquillage; sand/silt/rock/coral	5 14.76	71 48.89	0	0	0	0	0	0	1	**1**
(37c) Ile de Passe, Coquillage; sand/silt/rock/coral	5 14.76	71 48.89	0	0	0	0	0	0	0	**0**
(38a) Ile du Coin; rock/gravel/silt & algae	5 26.87	71 45.54	0	0	0	8	0	0	0	**8**
(38b) Ile du Coin; rock/gravel/silt & algae	5 26.755	71 45.543	0	0	0	5	0	0	0	**5**
(39) Petite Soeur; Ca algae	?	?	0	3	0	0	0	0	0	**3**

Factors such as natural variability, habitat effects and competition influence the distribution and abundance of these animals in Chagos (Posford Haskoning, 2002) and elsewhere (Conand and Mangion, 2002), and this must be taken into account. Holothurian abundance, as noted, was weakly but significantly negatively correlated with percentage coral cover in Diego Garcia. Otherwise associations with habitat/substrate type, i.e. habitat preference of different species, were not discernible, for any of the atolls. This may partly reflect the resolution of data recorded (Tables 2–5). (For example, it is known that holothurians such as *Stichopus chloronotus*, *Bohadschia* sp. and *Holothuria atra* generally live on sand, while species such as *Holothuria nobilis* and *Actinopyga echinites* prefer coral habitats.) A further point is that Diego Garcia's lagoon is much more enclosed and sheltered than the other atolls. However, while densities of holothurians were far greater in Diego Garcia, the finding that a far smaller proportion of sites contained holothurians in Diego Garcia would suggest that many of the habitats sampled in that atoll might provide *less* suitable ecological conditions (i.e. based on holothurian presence/absence). Its higher holothurian density, despite this, points to fishing pressure being an overriding determinant of holothurian abundance in the atolls of Chagos examined.

Second, analysis of data from the extensive area sampled around Salomon atoll (82 280 m^2) revealed highly significant negative correlation between harvesting pressure and holothurian abundance within that atoll. While not necessarily implying causality, a link between fishing and abundance seems likely, especially given other evidence of harvesting pressure. The absence of a fishing/abundance association in data from 100 m × 2 m transects in the three exploited atolls examined might partly reflect the fact that this scale of sampling (200 m^2) was insufficient to fully capture variability in holothurian densities and fishing/abundance interactions. Linked to this, the generally low abundances (Tables 2–4) might suggest that at least some of the islands within these atolls are more heavily exploited than reflected by the 0–3 fishing scores ascribed (Table 1), in which case strong correlation with abundance might not be expected.

Third, there is strong evidence of decline in abundance of three species (*S. chloronotus*, *H. atra*, *H. nobilis*) in Salomon atoll over the preceding four-year period (Table 6). A similar pattern for two species in Peros Banhos is also consistent with harvesting impact (Table 5). Fourth, photographs of part of the haul comprising an estimated 5000–7000 holothurians on Eagle Island, a Strict Nature Reserve, underlines the current economic importance of illegal harvesting in Chagos for illegal fishers (Spalding, 2006). The abundance from this single haul alone (6000 holothurians) approximates to complete stripping of between 133 333 and 60 000 m^2 of suitable shallow habitat, based on the maximum and minimum densities seen in the present survey (9 200 m^{-2} and 2 200 m^{-2}; Table 5).

Fifth, separate studies, involving rapid environmental assessment in 1996 and 2006, report a significant increase in shallow-water fishing in the Chagos Archipelago over a 10-year period, directed mainly at holothurians (Price and Harris, 2009).

Finally, an examination of Sri Lankan fishing data outside its own territorial waters provides indirect, yet strong evidence that holothurian populations in Chagos are being targeted by an illegal fishery. The number of poachers' boats captured in

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Table 5. Holothurian abundance, Great Chagos Bank atoll (lagoon side), along 8 transects 100 m × 2 m transects during March 2006

Site/island/ transect/ and habitat	Lat.	Long.	Abundance (nos 200 m^{-2})							
			Stich. chloro.	*Bohad.* sp.	*H. scabra*	*H. atra*	*H. nobilis*	*Holoth.* sp.	*Actinop.* spp.	Total (all spp.)
(40a) Eagle Island; rock/rubble/sand/silt	6 10.83	71 20.48	9	0	0	0	0	0	0	**9**
(40b) Eagle Island; rock/coral/algae/sand	6 10.63	71 20.53	1	0	0	0	0	0	1 (*A. mauritiana*)	**2**
(41a) Middle Brother; rock/coral/rubble/sand	6 9.29	71 31.05	0	0	0	1	0	0	2	**3**
(41b) Middle Brother; sand/rock	6 9.38	71 31.05	0	0	0	1	0	0	0	**1**
(42a) N. Brother; coralline algae/rock/coral	6 8.24	71 30.27	2	0	0	0	0	0	1	**3**
(42b) N. Brother (close to 41a); coralline algae/rock/coral	6 8.24	71 30.27	1	0	0	1	0	0	2	**4**
(43a) South Brother; coral/rock/coralline algae	6 10.18	71 32.36	1	0	0	0	0	0	4 (incl. 1 *A. mauritiana*	**5**
(43b) South Brother; coral/rock	6 10.20	71	1	0	0	0	0	0	0	**1**

Table 6. Comparison of holothurian densities in Chagos determined during this study and an earlier investigation (Posford Haskoning, 2002), both from 200 m^2 transects; values converted to No. ha^{-1}, by multiplying by 50, for comparability with Posford Haskoning data (2002; Table 4.11)

Species	Atoll	This study		Posford Haskoning (2002)	
		Mean density (No. ha^{-1})[c]	Max. density (No. ha^{-1})	Mean density (No. ha^{-1})[c]	Max. density (No. ha^{-1})
S. chloronotus	Salomon[a]	70 (48)	550 (550)	1528	4500
	Peros Banhos[b]	16	150	1308	3500
H. atra	Salomon[1]	50 (63)	450 (850)	408	3500
	Peros Banhos[b]	69	400	2440	7950
H. nobilis	Salomon[a]	10 (6)	100 (100)	83	150
	Peros Banhos[b]	0	0	0	0

[a]First Figs. (this study) are mean abundances for the same four islands examined by Posford Haskoning (2002): Boddam, Anglaise, Passe and Takamaka; numbers in parenthesis are means for all islands within Salomon atoll examined in this study.
[b]Abundances for Peros Banhos (this study) are for all islands examined, two of which (Coin, Diamant) correspond with the four islands assessed by Posford Haskoning (2002): Coin, Diamant, Pierre, Poule.
[c]From all 200 m^2 transects (including ones yielding zero abundances) in this study, and presumably also in the study of Posford Haskoning (2002).

Chagos by the BIOT Fisheries Protection Vessel, *Pacific Marlin*, over the last 15 years has averaged about three or four annually, most of which were Sri Lankan. These boats transport groups of fishers to and from the islands of the northern atolls and Great Chagos Bank. Within their shallow waters fishers glean holothurians (and other species), using snorkelling and, increasingly, scuba. Catches are dried and salted and after a few weeks, Sri Lankan boats return to Chagos to pick up fishers and their catches. The arrest rate of *ca* 50 fishing boats of all kinds over 15 years may seem appreciable, but, owing to limited monitoring and surveillance, it is unknown how this sample relates to the overall number of poaching vessels. Moreover, its impact on reducing overall harvesting pressure on holothurian populations in Chagos is unclear, but may not be substantial.

The true extent of holothurian poaching in Chagos may be estimated by indirect means, for example from the situation in Sri Lanka itself. In the north of that country, there has been a long-standing, modest holothurian fishery, in the shallows between Sri Lanka and India, an area which is now deemed politically unstable. Southern parts of Sri Lanka only became a target area for holothurians about 14 years ago, but the fishery soon collapsed because of a lack of regulation.

The initial Sri Lanka harvests comprised approximately 50 holothurian species, the preferred species being *H. edulis* and *H. atra*. Catches were sold mainly to Singapore buyers, who created the market, and who initially paid about 1 Rupee (1 US\$ ≈ 116 Sri Lankan Rupees) for each animal. Prices rose to 5 Rupees as supplies dwindled (Kumara *et al.*, 2005). As shallow areas were fished out, deeper waters were targeted with scuba. Subsequently, the remaining shallow waters of Sri Lanka became over-exploited, and the industry collapsed due to over-fishing in only three years.

Following exhaustion of holothurian stocks in Sri Lanka, fishers dispersed to more distant waters. 'The Chagos Archipelago, the Laccadive Islands and the Andaman Islands' are the main source areas now (Kumara *et al.*, 2005). Because the bulk of the trade is from poaching, details of fishing location, effort and seasonality are hard to obtain. But some details such as export figures are available. There is negligible consumption of these animals in Sri Lanka itself, and because there is almost no local fishery left, exports roughly equal the catch brought in to the country.

Total holothurian exports from Sri Lanka fluctuate between 100 000 and 300 000 kg year^{-1} (Kumara *et al.*, 2005). These figures are dry weight: the live or wet weight is over ten times higher. Average annual landings of *ca* 200 000 kg dry weight therefore equate to some 2 million kg live or wet weight. (The fluctuations in the landings are a result of the discovery and rapid stripping of newly discovered beds.) This live weight represents *ca* 4 million animals year^{-1}, if all are assumed to be fully-grown adults; the actual figure is probably nearer 5–6 million animals, because many will be immature sub-adults, and some species are smaller. Demand from SE Asia is such that prices today range from 40 to 50 Rupees each, while over 1000 Rupees are paid for certain rare and highly desired (and sometimes deep-water) species. Of much conservation concern is that demand is rising from Asian countries at the same time that wild stocks are diminishing. It is likely that, with ever-increasing prices, pressure by poaching on any and all remaining viable shallow habitat fisheries will increase still further.

Of the three main areas poached, the Lakshadweeps (Laccadives) are closest to Sri Lanka, but the Indian Navy around those islands undoubtedly acts as a deterrent. The Andamans are a similar distance from Sri Lanka, as is Chagos, and they are also Indian islands and inhabited. Between Sri Lanka and Chagos are the extensive Maldives, but it is understood that fishermen caught operating in Maldivian waters are met with very 'robust' treatment. Hence, Sri Lankan fishermen apparently prefer to avoid that archipelago. Some undoubtedly risk fishing in Seychelles waters, but the latter are mainly inhabited islands and support their own artisanal fishers, who are reluctant to share their catch with poachers. The same applies to East Africa and Madagascar. The Saya de Malha Bank, and Nazareth Bank are possibilities, but only with scuba and only over relatively limited areas that are sufficiently shallow. Of the various options, therefore, one of the main sources at present seems to be the wide open and almost entirely unguarded shallows, islands and waters of the northern Chagos atolls and the Great Chagos Bank. Further confirmation comes from colleagues in Sri Lanka who have asked boats arriving with holothurians about the origin of their catches, and who have been told that their origin is indeed Chagos.

The number of boats sailing to Chagos waters can be approximated. The size of the potential fleet of suitable boats is considerable. Hambantota (one of 14 fishing districts in Sri Lanka), has three of the 10 fully fledged harbours and is the base for 240 such boats (Amarasinghe, 2006). Thus, the total number of artisanal fishing boats in Sri Lanka of over 10 m and capable of putting to sea for several weeks at a time probably exceeds 1000. Indirect support for this comes from the large number (2618) of 'multi-day' boats (with inboard engines) in Sri Lanka in 2006/7 (Ministry of Fisheries and Aquatic Resources, 2008), a number which actually increased as a result of the aid following the tsunami of 26 December 2004.

The quantity of sea cucumbers landed and recorded in Sri Lanka, averaging 200 000 kg per year (dry weight) can be roughly translated into numbers of full boat loads. The 200 t dry weight is equivalent to about 66 boat landings per year, if each of these 10–15 m boats is carrying sea cucumbers only and assuming each is loaded with 3 t of the dried product. In reality, the number of boats will be several times greater if they were filled only to a safer level, if they return before maximum capacity is reached, or if they carry a mixture of sea cucumbers and, say, reef fish, shark or turtles as usually is the case. Between 100 and 200 boats returning to Sri Lanka each year with sea cucumbers is not implausible.

It is impossible to tell how many Sri Lankan vessels containing holothurians come from Chagos rather than from the other main poaching grounds. But even if fishing effort is divided evenly between the three major poaching grounds, the number would still be 30–60 from Chagos every year. Set against this number, only 10–15% are intercepted.

Anecdotal, supporting evidence of this level of poaching comes from yacht owners anchored in Chagos, who report that they see many illegal fishing boats each year. At the time of this survey most yacht owners reported that they had no means of communicating sightings to the *Pacific Marlin*, which could be 100 km or more away in another part of the extensive BIOT waters. Furthermore, yachts report poachers disappearing when the *Pacific Marlin* arrives, only to reappear as little as one day after its departure. Some may, of course be poaching reef fish too, rather than solely holothurians. However, evidence collectively confirms that holothurian poaching in shallow waters of Chagos is high and sustained. As Kumara *et al.* (2005) note, the nature of the illegal industry makes it impossible to come by accurate figures. But between 20 and 50 boats per year poaching on Chagos reefs and lagoons, for holothurians alone, is entirely possible, indeed likely. More frequent patrolling and visits to the islands of Chagos, through use of one or more small boats, would help discourage holothurian poaching.

Reduction of a major marine resource in one of the world's most important marine areas is not the only reason for concern. Being largely detritus feeders, holothurians play an important role in the recycling system of sedimentary habitats (Uthicke *et al.*, 2004), including sandy banks and lagoons of coral reefs, thereby 'conditioning' the substratum. More specifically, as Michio *et al.* (2003) note: 'Commercially fished holothurians have important functions in nutrient recycling, which increases the benthic productivity of coral reef ecosystems. Thus, removal of these animals through fishing may reduce the overall productivity of affected coral reefs.' Holothurians probably play a pivotal role in maintaining ecosystem integrity and resilience of coral reef systems.

Reduced fishing effort is a conservation measure urgently needed for holothurian populations and fisheries across much of the Indian Ocean. Greater use of 'no-take' marine protected areas is one means of facilitating this and helping to ensure greater sustainability of stocks, as demonstrated by the higher abundances reported for Diego Garcia, an unexploited atoll in Chagos. Marine reserves can also be beneficial for holothurian conservation elsewhere (Roberts and Hawkins, 2000; Lincoln-Smith *et al.*, 2006).

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