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Abundance and distribution of commercial sea cucumber species in the coastal waters of Sri Lanka

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Abstract – The sea cucumber stocks off the east and northwest coasts of Sri Lanka were estimated by surveying 1307 km^2 and 1779 km^2 by an underwater visual census (UVC) in June and October 2008 respectively. The presence of twenty-five sea cucumber species belonging to seven genera; *Actinopyga, Bohadschia, Holothuria, Pearsonothuria, Stichopus, Thelenota* and *Acaudina* was identified in five hundred sampling sites randomly selected in each area. The overall average density (± SD) of sea cucumbers was higher in the northwest (350 ± 648 ind ha^{-1}) than in the east (90 ± 130 ind ha^{-1}) and low-value species were predominant in both survey areas (79 ± 125 ind ha^{-1} in the east, 244 ± 488 in the northwest) when compared with medium (10 ± 34 ind ha^{-1}, 105 ± 175 ind ha^{-1}, respectively) and high-value category (<2 ind ha^{-1}). The estimated total biomass in the northwest (13 024 t) was roughly four times greater than the east (3027 t). *Holothuria edulis* was the most abundant species in numbers while *Holothuria atra* had the highest stock biomass in both areas. Sea cucumber densities were significantly different among the habitat ($p < 0.001$) and depth categories. The highest density was reported in rocky habitat associated with seagrass and / or macroalgae. The density of low-value species was significantly high in 1–10 m depth category ($p < 0.001$) in the northwest while other commercial groups were dominant in 20–30 m depth range in both areas. Temporal banning of the fishery for high and medium-value species would be a better management option to avoid further stock depletion.

Key words: *Holothuria edulis* / *Holothuria atra* / Echinoderm / Density / underwater visual census (UVC) / Sri Lanka / Indian Ocean

1 Introduction

Sea cucumbers (Class Holothuroidea, Phylum Echinodermata) are a highly diverse group of marine invertebrates which play an important ecological role in benthic communities as deposit feeders (Preston 1993). Moreover, many species of sea cucumbers are edible and during the last two decades, the fishing pressure over this marine resource has been increased due to higher demand for beche-de-mer in the Asian markets. This has led to severe overexploitation of some commercially important species in many parts of the Indo-Pacific region (Conand et al. 2006; Choo 2008; Conand 2008; Kinch et al. 2008).

The sea cucumber fisheries throughout the world have been characterized by boom and bust cycles, with biological overexploitation often occurring before economic overexploitation (Preston 1993; Conand 1997). Over-harvesting of sea cucumber species can now be considered as a worldwide phenomenon (Conand 2008). Furthermore, the recovery of depleted populations is slow and sporadic. Therefore, information on stock structure and ecology of sea cucumbers are essential for the efficient and durable management of this resource throughout the world (Kinch 2002; Choo 2008).

The sea cucumber fishery was introduced to Sri Lanka by the Chinese and beche-de-mer appeared to be one of the commodities taken to China for centuries (Hornell 1917). Since 1980's fishing activities have expanded rapidly and presently it is confined to the north, east and northwest providing significant contribution to the livelihoods of coastal communities. There are no records of local consumption of sea cucumbers in Sri Lanka and the entire annual production is currently exported to Singapore, Hong Kong and China. Based on recent statistics, export production reached a peak of 273 t, worth about US$ 3 million, in 1997 and was followed by a drastic drop to almost half of this volume in 2003 (Dissanayake et al. 2010).

The fishing activities are greatly influenced by the monsoon winds, hence harvesting off the northwestern coast occurs intensively during the northeast monsoon (from October to April) and in the north and east fishing is undertaken during the southwest monsoon period (from May to September).

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No special gear or net is devised exclusively to catch sea cucumbers and they are mainly harvested by hand picking either through scuba or skin diving (Dissanayake and Wijerathne 2007). Relatively little information is available on the biology and ecology of sea cucumbers around the island. However, available information in the other parts of the Indian Ocean suggests that the distribution is highly variable among different habitat but these animals widely inhabit shallow water seagrass beds and coral reefs (Choo 2008).

The sea cucumber fishery in Sri Lanka is primarily artisanal and neither regulations nor precautionary approaches have been adapted so far except issuing diving and transportation license. As the fishery has developed without baseline biological data or routine monitoring, the resource status is unknown and un-quantified. Despite the observations by fishers of local depletion of sea cucumbers, particularly, the high-value species, no systematic study has been conducted in Sri Lanka to assess the status of sea cucumber populations or to evaluate the sustainability of the fishery. Therefore, it is timely to assess these populations in order to provide a foundation for management of the local fishing activities.

In the absence of reliable long term fishery dependant data, a stock survey is the only viable method for determining the status of fished populations. An underwater visual census (UVC), a non-destructive, fishery independent method (Curtis et al. 2004), was carried out to assess the status of sea cucumber stocks in the two geographical regions; northwest and east coast of Sri Lanka. This approach has been successful for estimating the abundance of reef-associated fishes (Sale et al. 1984), spiny lobster (Pitcher et al. 1992) and sea cucumbers in Great Barrier Reef and New Caledonia (Skewes et al. 2002; Uthicke et al. 2004a; Purcell et al. 2009).

2 Materials and methods

2.1 Survey area

The survey was carried out in the eastern and northwestern coastal waters of Sri Lanka. The east coast survey area was between 8°17'–6° 50' N and 81° 25–82° E where the distance of the study area along the shore was 190 km. The northwest coast study area was between 7°55'N –8°55' N latitudes and 79° 35' E –79° 57' E longitudes and the study area extended 112 km along the shore (Fig. 1). Due to logistical and practical constraints, the study was confined to 1–30 m depth resulting in survey area of 1307 km^2 off the east coast and 1779 km^2 off the northwest coast. Two surveys were carried out at the beginning of each fishing season by temporarily closing the commercial fishing activities. Thus the east coast survey started in early June 2008 and the northwest coast survey was in early October 2008 with the survey period extending up to 4 weeks on each occasion.

An initial description of the survey area was formulated from interviews with fishers, researchers, collectors and exporters. Nautical charts were used as the basis for the surveys by importing scanned, digitized, geo-referenced charts into a geographic information system (GIS) to set up a geo-database and demarcate the survey areas.

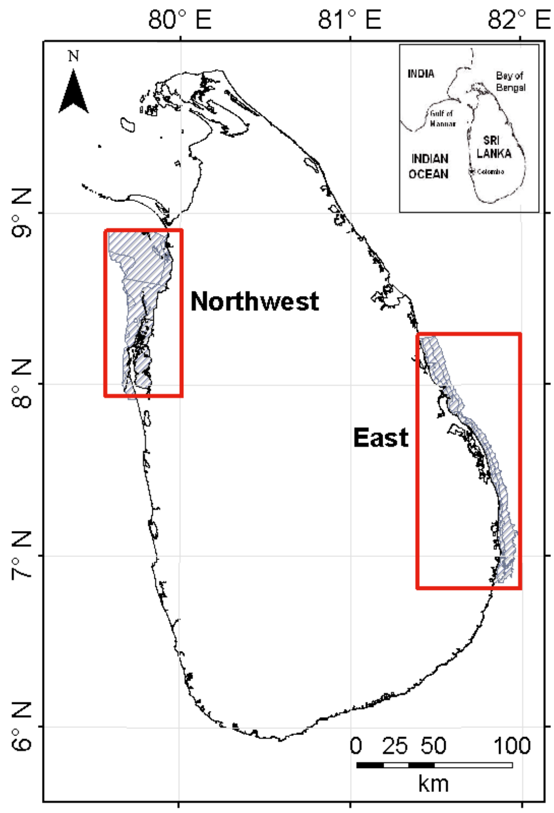

Fig. 1. Map of Sri Lanka, showing two sea cucumber survey areas off the east and the northwest coasts.

2.2 Pilot study

A pilot study was carried out off the east coast to select the best transect dimension with two goals; 1) gather maximum information on sea cucumber abundance and bottom habitat characters 2) select practically convenient transects for the divers. Eight transect dimensions which belong to four transect categories were used for this survey (Table 1). An area of 600 m^2 was surveyed by each transect dimension using different transect numbers (n). The number of transects in each transect dimension were equally allocated among the three survey boats except for the 150 m^2 transect category where the allocation was done in a 3:3:2 ratio. The time required for surveying each transect was calculated by taking the difference between total dive time (time between the departure and return to the boat including survey time) and dive time (time between the departure and return to the boat without doing transect). Dive time was measured from random dives in sampling sites and time measurements were recorded by the onboard staff.

The variance was considered the main determinant for selecting a feasible transect dimension as all the other factors affecting the survey (survey time, survey divers, survey boats and financial allocations) were fixed. By considering the safety of the divers, maximum number of transects which could be covered per boat (2 divers onboard) per day were decided to be 8. The mean abundance and variance were calculated with respect to each transect dimension.

Table 1. Different transect categories (m^2), transect dimensions (length x width combination) and number of transects (n) used to cover 600 m^2 in each transect dimension during the pilot survey carried out off the east coast of Sri Lanka.

Transect category (m^2)	Transect dimension (length x width) (m^2)	Number of transect (n)
50	25 × 2	12
	50 × 1	12
100	50 × 2	6
	100 × 1	6
150	75 × 2	4
	150 × 1	4
200	100 × 2	3
	200 × 1	3

2.3 Survey proper

Due to lack of information on bottom habitat characters and bathymetry of the survey areas, sampling sites were allocated randomly throughout each survey area to cover all the possible sea cucumber habitat and to increase the precision of the surveys. We allocated 500 sampling sites into each survey area using Hawth's tool (http://www.hawthstools.com) integrated into a geographic information system (GIS). Both day (400 sites) and night (100 sites) diving activities were carried out in the northwest while only day diving was carried out in the east due to security constraints during the study period.

The survey employed rapid marine assessment technique that has been used for sea cucumber surveys in the Torres Strait (Long et al. 1996). Field work was undertaken by a team of divers operating from small boats and locating sampling sites using a portable global positioning system (GPS) device. On each sampling occasion one or two divers swam along a 100 m transect, collecting sea cucumbers on a 1 m strip to each side of the transect line. Based on the visual estimates on percent coverage of sand, rubble, coral, terrestrial rock, mud, seagrass and macroalgae within each transect, 11 habitat types were described (sandy, seagrass, macroalgae, sandy habitat with rocks/corals, sandy habitat with macroalgae, sandy habitat with seagrass, rocky habitat with algae/seagrass, muddy habitat, sandy and muddy habitat with corals, muddy and sandy habitat, muddy habitat with macroalgae).

2.4 Size and weight measurements

All sea cucumbers collected during the surveys were brought to the base camp where they were individually weighed and measured for total length. The body length was measured to the nearest 1 cm and weighed to the nearest 1 g using an electronic balance. The animals were allowed approximately 2 min to drain before being weighed. Both the whole body weight and gutted body weight were taken.

2.5 Data analysis

Average density (ind ha^{-1}) of each sea cucumber species was calculated from site counts (per unit area) and the total study area. The standing stock estimates were based on the product of mean density, survey area and the average weight from size frequency data collected during the surveys. Thus surveys produced standing stock estimates in terms of live weight. The density distribution of different sea cucumber species was mapped using Arcinfo integrated with geographical information system (GIS). Species densities in different depth categories were compared using one-way analysis of variance (ANOVA). The Kruskal Wallis test was performed to investigate the density of sea cucumber species in relation to different habitat types. The statistical analyses were performed using R version 2.8.1 (R Development Core Team 2009 http://www.rproject.org).

Two approaches were used to estimate the indicative maximum sustainable yields (MSY) in this study.

1. According to Gulland (1971); $MSY = x\ MB$. The x scaling factor, is based on the logistic function which assumes that population growth is highest at intermediate population sizes; accordingly x should be set to 0.5. But various authors have suggested that the *MSY* calculated using this formula is an overestimate so that x should be reduced as a conservative measure (Perry et al. 1999). Garcia et al. (1989) and Woodby et al. (1993) recommended $x = 0.2$ (i.e. reducing *MSY* by half from that predicted using the logistic assumption) and this approach was used in this analysis. This model requires only B (biomass) and M (natural mortality).
2. The 2nd approach is to determine optimal catch rates (to use an estimate of the optimal fishery mortality rate – F_{opt}) based on natural mortality, such that $F_{opt} = 0.6\ M$ (Perry et al. 1999). The exploitation rate u, being the proportion of the population fished for a given F can be calculated as; $u = F/Z\ (1–e^{-z})$ where Z is the total mortality rate ($Z = M + F$). Here $MSY = u\ x\ B$; where B is the biomass.

Though the use of $F_{opt} = 0.6\ M$ for calculating exploitation rate for invertebrates is arguable, these two approaches have been used to produce indicative *MSY* estimates for sea cucumber fisheries in Alaska (Woodby et al. 1993), Moreton Bay (Skewes et al. 2002), Torres Strait (Skewes et al. 2006) and Seychelles (Aumeeruddy et al. 2005).

As the mortality rates of holothurians are difficult to estimate, the published estimates of natural mortality (Conand 1990; Uthicke et al. 2004a) for tropical holothurian species were used when estimating MSY.

3 Results

3.1 Pilot study

Transects of 150 m and 200 m length were not feasible as divers were not able to cover 8 transects when the transect lengths were greater than 100 m. There was little pattern in variance among the remaining transect dimensions (Table 2). However the lowest variance and *CV* were observed in 100 × 2 m transect dimension. In addition to the lowest *CV* and variance, the 100 × 2 m transect covered the greatest area per transect hence 100×2 m was chosen as the transect dimension for subsequent use.

Table 2. Mean density (ind transect^{-1}), variance, coefficient of variation (CV) and time ± SD (minutes) required to cover each transect dimension in the pilot survey.

Transect category (m^2)	Transect dimension (length x width) (m^2)	Mean (Nos/ transect)	Variance	CV	Time ± SD (min)
50	50 × 1	0.33	0.67	2.48	6.4 ± 0.7
	25 × 2	0.37	1.11	2.85	6.2 ± 0.7
100	100 × 1	1.00	1.09	1.04	9.2 ± 1.2
	50 × 2	0.66	0.97	1.49	8.0 ± 1.4
150	150 × 1	0.75	0.78	1.18	11.2 ± 1.7
	75 × 2	0.63	1.12	1.68	10.2 ± 1.5
200	200 × 1	1.00	1.33	1.15	12.3 ± 1.5
	100 × 2	1.30	0.66	0.62	11.3 ± 1.6

Table 3. Scientific name, English name, commercial value, temporal (day/night) distribution of sea cucumber species observed off the east (EC) and the northwest (NW) coasts of Sri Lanka during two surveys in June and October 2008 (Dissanayake et al. 2010, completed).

No	Scientific name	English name	Value	Time	Area
1	*Actinopyga echinites*	Deep water redfish	Medium	D,N	NW, EC
2	*Actinopyga mauritiana*	Surf redfish	Medium	D	EC
3	*Actinopyga miliaris*	Blackfish	Medium	D,N	NW, EC
4	*Bohadschia atra*	Tigerfish	Low	D,N	NW, EC
5	*Bohadschia maculisparsa*		Low	N	NW
6	*Bohadschia marmorata*	Brownfish	Low	N	NW
7	*Bohadschia* sp. “lines”		Low	D,N	NW, EC
8	*Bohadschia vitiensis*	Brownfish	Low	D,N	NW, EC
9	*Holothuria atra*	Lolly fish	Low	D,N	NW, EC
10	*Holothuria edulis*	Pinkfish	Low	D,N	NW, EC
11	*Holothuria fuscocinerea*		No*	D	EC
12	*Holothuria fuscogilva*	White teatfish	High	D	NW, EC
13	*Holothuria hilla*		No*	D	NW
14	*Holothuria isuga*		Low	D	NW, EC
15	*Holothuria leucospilota*	White threadsfish	No*	D	NW, EC
16	*Holothuria nobilis*	Black teatfish	High	D	NW, EC
17	*Holothuria scabra*	Sandfish	High	D,N	NW
18	*Holoturia spinifera*	Brown sand fish	Medium	N	NW
19	*Holothuria* “pentard”	Flower teatfish	High	D	NW, EC
20	*Pearsonothuria graeffei*	Flowerfish	No*	D	NW, EC
21	*Stichopus chloronotus*	Greenfish	Medium	D,N	NW, EC
22	*Stichopus herrmanni*	Curryfish	Medium	D,N	NW, EC
23	*Thelenota ananas*	Prickly redfish	Medium	D	NW, EC
24	*Thelenota anax*	Amberfish	Medium	N	NW
25	*Acaudina molpadioides*		Low	D,N	EC

(*) The species categorized under “No commercial value” are not presently exploited off the coastal waters of Sri Lanka. However, these four species are exploited in other nations and categorized as low-value species.

3.2 Observed species

A total of 25 sea cucumber species belonging to seven genera (*Actinopyga, Bohadschia, Holothuria, Pearsonothuria, Stichopus, Thelenota* and *Acaudina*) were identified during the surveys (Table 3). Of these 16 species were common to both east and northwest areas, three species were unique to the east and six species were found only in the northwest. Except for *H. hilla, H. fuscocinerea, H. leucospilota* and *P. graeffei,* all the other species are commercially exploited in Sri Lanka and categorized as “high-value” (species with a commercial value greater than US$ 40 kg^{-1} dry weight), “medium-value” (US$ 15 to 40 kg^{-1} dry weight) and “low-value” (less than US$ 15 kg^{-1} dry weight) based on the export market value (Table 3). The high-value species include *H. scabra, H. fuscogilva, H. nobilis* and *Holothuria* “pentard”. Species

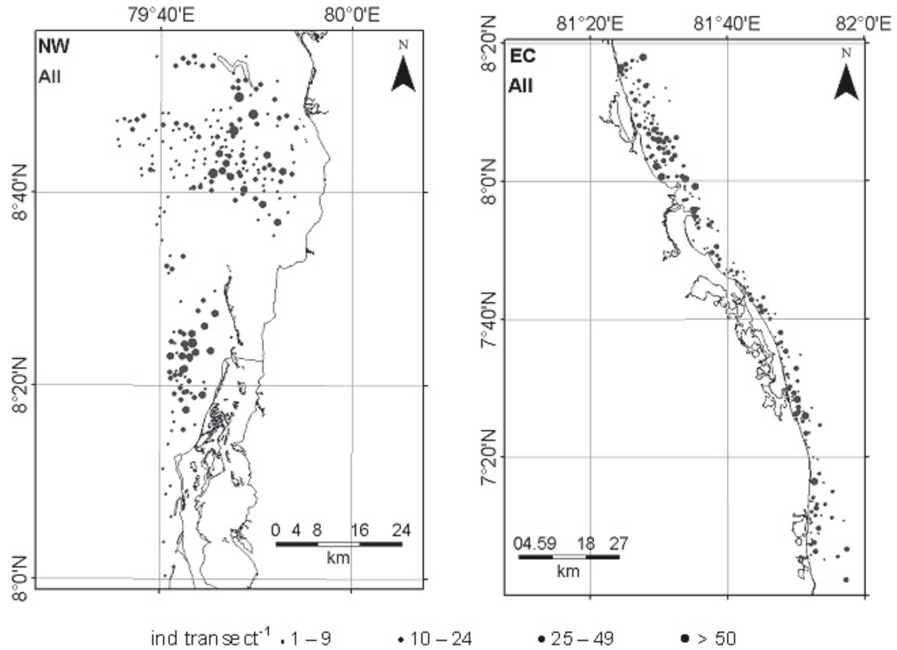

Fig. 2. Average density (ind transect^{-1}) and spatial distribution of all sea cucumber species off the northwest (NW) and the east (EC) coasts of Sri Lanka during two surveys in June and October 2008.

belonging to the genus *Actinopyga, Stichopus, Thelenota* and *H. spinifera* are considered as medium-value species and the rest belong to the low-value category. Temporal and spatial variations of sea cucumber diversity were revealed. *H. spinifera, T. anax* and two *Bohadschia* species *(Bohadschia maculisparsa* and *Bohadschia marmorata)* were recorded only at night whilst others were found either in the day or both day and night. The species diversity comparison between the two survey areas showed that the northwest area (22 species) was more diverse than the east (19 species).

3.3 Abundance and spatial distribution

A total of 2640 sea cucumbers were counted from the northwest survey and 872 from the east. The overall average density (± SD) of sea cucumbers was higher in the northwest (350 ± 648 ind ha^{-1}) than in the east (90 ± 130 ind ha^{-1}, Table 4). Low-value species were predominant in both survey areas (79 ± 125 ind ha^{-1} in the east and 244 ± 488 in the northwest) and species of medium value were relatively abundant (10 ± 34 ind ha^{-1} in the east and 105 ± 175 in the northwest) when compared with high-value species (<2 ind ha^{-1}). The result illustrates that the abundance of sea cucumbers varied markedly among the survey sites within the survey area as well as between the survey areas (Fig. 2). Sea cucumbers were highly abundant in some survey sites while others were less abundant giving patchiness of spatial distribution and this was common in the northwest. However, it was hard to see any systematic pattern of the distribution within the survey areas.

The abundance of low-value species was heavily weighted by the presence of large numbers of *H. edulis* which was the most dominant species both in east (40 ± 87 ind ha^{1}) and northwest (138 ± 346 ind ha^{-1}). *H. edulis* was reported at 29% of sampling sites in the northwest and 22% in the east. The distribution of this species within the northwest survey sites was highly heterogeneous and the highest densities were concentrated close to the lagoon mouth and the northern part of the survey area. The distribution of *H. edulis* seemed to be more even in the east (Fig. 3).

H. atra was the second highest species with an average density of 90 ± 252 ind ha^{-1} in the northwest and 24 ± 54 ha^{-1} in the east. This species was observed around 22% of sampling sites in both areas and distribution pattern was much similar to *H. edulis* (Fig. 3). *H. spinifera* which is a nocturnal species restricted only to the northwest survey area, was the next most dominant species (70 ± 34 ind ha^{-1}). The mean densities of *Bohadschia* species ranged between 4 to 5 ind ha^{-1} in the northwest whilst it was 6 to 7 ind ha^{-1}in the east. Species belonging to the genus *Actinopyga* were less abundant when compared with the other genera (5 ind ha^{-1} in both east and northwest). The density of teatfish (*H. fuscogilva, H. nobilis, H. "pentrad"*) was found to be less than 1 ind ha^{-1}in both areas while it was 1 ± 16 ind ha^{-1} for *H. scabra* in the northwest.

H. edulis was the most abundant species in numbers followed by *H. atra* in both areas (Table 4). The total abundance of sea cucumbers was 62.3 × 10^6 (in numbers) in the northwest and 11.9 × 10^6 (in numbers) in the east.

3.4 Distribution in relation to depth and habitat types

Sea cucumbers were found in most of the habitat defined under the methodology. The densities (ind transect^{-1}) were reported to be changed significantly among the habitat

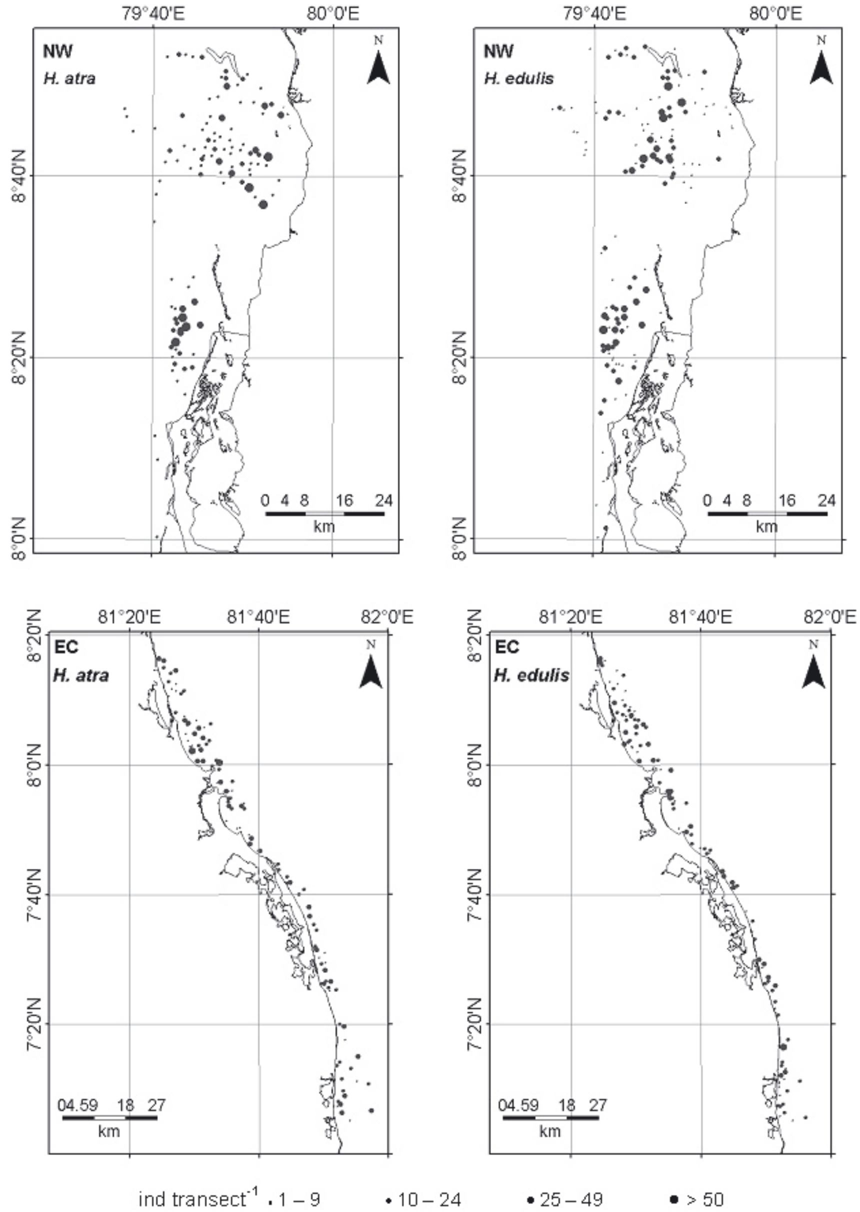

Fig. 3. Average density (ind transect^{-1}) and spatial distribution of *Holothuria atra* and *Holothuria edulis* off the northwest (NW) and the east (EC) coasts of Sri Lanka during two surveys in June and October 2008

(p < 0.001, Fig. 4). The highest densities were recorded in rocky or coral habitat with seagrass and / or macroalage while the lowest were reported in muddy and sandy habitat and this was common in both survey areas.

H. atra, *H. edulis* and *S. chloronotus* were mostly found in shallow depth range of 1–10 m in the northwest while in the east *H. atra* and *H. edulis* were found in 10–20 m depth class and *S. chloronotus* was in 20–30 m (Table 5). Two species belonging to genus *Bohadschia* were common in 20–30 m depth range. In addition, the densities of commercial group were dominant in 10–30 m depth range in both the survey areas except in the low-value species in the northwest. The density of low-value species was significantly high in shallow depth category in the northwest ($p < 0.001$).

3.5 Total biomass and maximum sustainable yield (MSY)

In the northwest, the highest total biomass was reported by *H. atra* (4798 t) subsequently followed by *H. spinifera*, *T. anax* and *H. edulis* (Table 6). Even in the east, *H. atra* had the highest total biomass and two species belonging to the genus *Bohadschia* (*B. vitiensis* and *Bohadschia* sp. "lines") seemed to be the next dominant (558 t and 529 t, respectively). Standing stock estimates of high-value species rarely exceeded 150 t in both areas. The total biomass in the northwest survey area (13 024 t) was roughly 4 times higher than the east survey area (3027 t). MSY fluctuation trends were much similar to the described standing stock fluctuation trends above. But

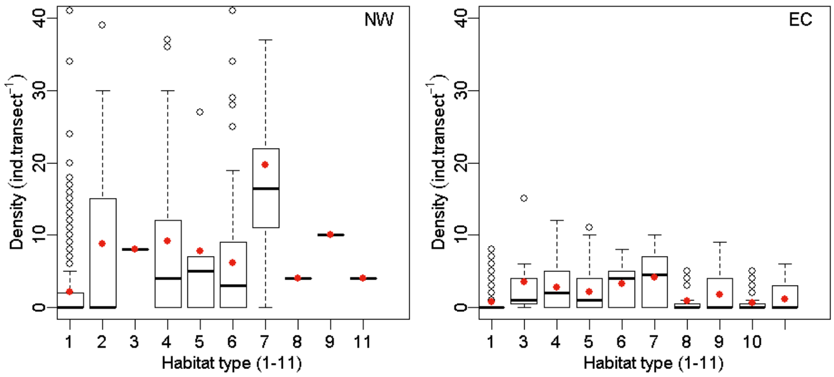

Fig. 4. Density (ind transect^{-1}) of all sea cucumbers species in the different habitat types (1: sandy habitat, 2: seagrass habitat, 3: macroalgae, 4: sandy habitat with rocks/corals, 5: sandy habitat with macroalgae, 6: sandy habitat with seagrass, 7: rocky habitat with macroalgae /seagrass, 8: muddy habitat, 9: sandy and muddy habitat with corals, 10: muddy and sandy habitat, 11: muddy habitat with macroalgae) off the northwest (NW) and the east (EC) coasts of Sri Lanka during two surveys in June and October 2008. Filled circle represents the mean density in each habitat.

Table 4. Average density ± SD (ind ha^{-1}) and the total abundance of individual sea cucumber species and major commercial groups off the east and the northwest coasts of Sri Lanka.

	East coast		Northwest coast	
Species / group	Density (ind ha^{-1})	Total abundance (ind.10^6)	Density (ind ha^{-1})	Total abundance (ind.10^6)
Holothuria atra	24 ± 54	3.2	90 ± 252	16.0
Holothuria edulis	40 ± 87	5.2	138 ± 346	24.6
Holoturia spinifera	0	0	70 ± 34	12.4
Holothuria fuscogilva	1 ± 6	0.1	0.3 ± 5	0.1
Holothuria nobilis	0 ± 4	0	0.1 ± 2	0.0
Holothuria scabra	0	0	1.4 ± 16	0.2
Other *Holothuria* sp.	2 ± 15	0.3	3 ± 21	0.6
All *Holothuria* sp.	67 ± 109	8.8	302 ± 491	53.9
Bohadschia vitiensis	6 ± 27	0.7	3 ± 20	0.6
Bohadschia marmorata	0	0	5 ± 38	0.9
Bohadschia sp. “lines”	7 ± 30	0.9	4 ± 26	0.7
All *Bohadschia* sp.	13 ± 44	1.7	13 ± 56	2.3
Stichopus chloronotus	5 ± 26	0.7	5 ± 25	0.9
Stichopus herrmanni	0	0	0.6 ± 10	0.0
All *Stichopus* sp.	5 ± 26	0.7	5 ± 25	0.9
Thelenota anax	0	0	26 ± 47	4.5
All *Thelenota* sp.	0	0	26 ± 47	4.5
Actinopyga echinites	2 ± 13	0.3	2 ± 15	0.3
Actinopyga miliaris	3 ± 16	0.4	2 ± 14	0.4
All *Actinopyga* sp.	5 ± 22	0.7	4 ± 29	0.7
All Sea cucumber species	90 ± 130	11.9	350 ± 648	62.3
High-value species	1 ± 7	0.1	1 ± 17	0.3
Medium-value species	10 ± 34	1.4	105 ± 175	18.5
Low-value species	79 ± 125	10.4	244 ± 488	43.5

Table 5. Average density (ind transect^{-1}) of numerically dominant sea cucumber species, major commercial groups and all sea cucumbers in different depth categories (0–10 m, 10–20 m and 20–30 m) off the northwest (NW) and the east (EC) coasts of Sri Lanka. Average density in three different depth categories was compared by ANOVA test.

Species	Area	Depth categories (1–10 m)	(10–20 m)	(20–30 m)	*p* value
Holothuria atra	NW	3.41	0.83	0.15	<0.0001
	EC	0.34	0.67	0.56	0.005
Holothuria edulis	NW	3.62	2.09	3.09	0.067
	EC	0.70	1.02	0.46	0.063
Stichopus chloronotus	NW	0.20	0.08	0.00	0.075
	EC	0.04	0.11	0.42	<0.0001
Bohadschia sp. "lines"	NW	0.02	0.12	0.12	0.096
	EC	0.00	0.25	0.40	<0.0001
Bohadschia vitiensis	NW	0.00	0.11	0.27	0.006
	EC	0.03	0.15	0.44	<0.0001
All Sea cucumbers species	NW	7.86	3.94	4.18	0.0002
	EC	1.16	2.43	2.90	<0.0001
High-value Species	NW	0.07	0.00	0.12	0.028
	EC	0.00	0.01	0.17	<0.0001
Medium-value Species	NW	0.54	0.65	0.30	0.663
	EC	0.04	0.28	0.83	<0.0001
Low-value Species	NW	7.20	3.34	3.76	0.0001
	EC	1.12	2.15	2.06	<0.0001

A Bonferroni correction for multiplicity is used, each *p*–value can be compared with 0.05/18 = 0.0028 to maintain a family wise error rate of 0.05 for the entire table.

Table 6. Total biomass (t) and maximum sustainable yield, MSY (t y^{-1}) for different sea cucumber species off the east and the northwest coasts of Sri Lanka (MSY estimate on first approach is indicated in MSY_1 column and the second approach is in MSY_2 column).

Species Name	*M*	East coast Biomass (t)	East coast MSY_1 (t y^{-1})	East coast MSY_2 (t y^{1})	Northwest coast Biomass (t)	Northwest coast MSY_1 (t y^{-1})	Northwest coast MSY_2 (t y^{-1})
Holothuria atra	0.8	945	151	258	4798	768	1309
Holothuria edulis	0.8	413	66	113	1951	312	532
Holoturia spinifera	0.6	0	0	0	2241	269	531
Holothuria fuscogilva	0.5	153	15	32	105	10	22
Holothuria scabra	0.6	0	0	0	204	25	48
Bohadschia vitiensis	0.6	558	67	132	416	50	99
Bohadschia marmorata	0.6	0	0	0	294	35	70
Bohadschia sp. "lines"	0.6	529	63	125	448	54	106
Stichopus chloronotus	0.8	85	14	23	111	18	30
Thelenota anax	0.5	0	0	0	2141	214	442
Actinopyga echinites	0.6	152	18	36	149	18	35
Actinopyga miliaris	0.6	192	23	45	166	20	39
Total		3027	417	764	13024	1793	3263

MSY estimate from method 1 always had the lower value than the method 2.

3.6 Population structure

The length frequency (%) distribution of numerically dominant species; *H. atra* and *H. edulis* were analyzed (Fig. 5). The length of *H. atra* ranged between 7.5 and 52.5 cm and the most frequent length category was 17.5 cm and 22.5 cm in the northwest and the east, respectively. Meanwhile, a common weight category of 75 g was observed as the highest frequency in survey areas. The mean length and weight of *H. atra* collected from the east (23.3 ± 1.3 cm, 111 ± 6 g) were slightly greater than the values reported from the northwest (21.4 ± 1.5 cm, 93 ± 4 g).

In the case of *H. edulis*, the most frequent length and weight classes were 17.5 cm and 20 g respectively in both survey areas. Although the mean weight of *H. edulis* was similar in both survey areas (41 g), the mean length was slightly greater in the northwest (17.1 ± 4.9 cm) than the east (16.2 ± 1.1 cm).

4 Discussion

The sea cucumber diversity in the present study (25) was lower than the observation made by Clark and Rowe (1971) where 75 sea cucumber species have been recorded in intertidal areas of Sri Lanka. The relatively few holothurian taxa in

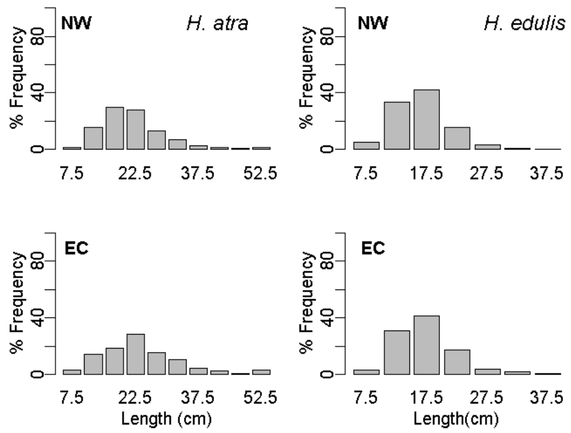

Fig. 5. Length frequency (%) distribution of *Holothuria atra* (n_{NW} = 848, n_{EC} = 1294) and *Holothuria edulis* (n_{NW} = 544, n_{EC} = 728) off the northwest (NW) and the east (EC) coasts of Sri Lanka during two surveys in June and October 2008.

this study might be due to many reasons and most likely reasons are; rare abundance due to overexploitation, inadequate sampling and the problems associated with visibility due to their foraging behavior. In terms of species diversity, the northwest area is more diverse than the east. Due to security reasons, night diving activities were not allowed in the east during the study period. Hence nocturnal species were not encountered in the east and this could be one reason for discrepancy on species diversity between two survey areas.

At present, 21 sea cucumber species are commercially exploited in Sri Lanka and this is within a relatively high range of some other sea cucumber exploiting countries; China (27), Indonesia (35), Philippines (26), Solomon Islands (29) and Madagascar (27) (Conand 2001; Choo 2008; Kinch et al. 2008). The ranking of sea cucumbers based on commercial value is highly subjective (Toral-Granda 2007; Conand 1989; James and James 1994). Though four species (*H. hilla, H. fuscocinerea, H. leucospilota* and *P. graeffei*) which are not commercially exploited in Sri Lanka were categorized as no-value species, they were considered as low-value category in other sea cucumber producing nations (Conand 2008; Purcell 2010).

Sea cucumber densities were known to be highly variable in the northwest (350 ind ha^{-1}) and the east (90 ind ha^{-1}). Comparison of these densities with other studies indicated that the populations were not as depleted as in the Milne Bay (21 ind ha^{-1}), Timor MOU Box (27 ind ha^{-1}) and the Torres Strait (Skewes et al. 2006; Skewes et al. 2002; Skewes et al. 1999). However, the overall density in each area was much lower than the densities of marine protected areas or better managed fishing grounds in; Heron Island (8460 ind ha^{-1}), Moreton Bay (1035 ind ha^{-1}) and Solomon Islands (1115 ind ha^{-1}) (Klinger and Johnson 1994; Skewes et al. 2004; Buckius et al. 2010).

The low-value species were more abundant than the medium and high-value species in both areas. Similar observations were made by population surveys in other countries including Solomon Islands, Philippines, Indonesia, Papua New Guinea and New Caledonia (Purcell et al. 2009). The density of low-value species in Sri Lanka was quite low when compared with the Heron Island (6420 ind ha^{-1}) and Solomon Islands (677 ind ha^{-1}). The comparison made for high-value category with the above mentioned localities (2040 ind ha^{-1}, 438 ind ha^{-1} respectively) confirmed the greater reduction of this resource in both northwest and east.

Lower densities of Sri Lankan sea cucumbers compared to the marine protected areas of other localities are probably indicative of heavy fishing pressure applied both historically and in recent times and such reduction in stocks due to severe fishing pressure was common in several parts of the Indo-Pacific region (Lovatelli et al. 2004; Uthicke and Conand 2005). Differences in ecological conditions and habitat suitability may have potential influence on the reported lower holothurian densities when compared to other localities. Further, sheltering or burying behavior of some species (Purcell et al. 2009) may have affected the visibility during the surveys, resulting in underestimated stock densities. Similarly, low population densities in the east were due to lack of estimates for nocturnal species, over exploitation and differences in ecological and habitat conditions in those areas. However, due to lack of past records on sea cucumber densities or even catch data it was hard to do any local comparison with survey results but the reduction of high and medium-value species was in accordance with anecdotal evidences from fishers in two areas.

H. atra was in fact the most common and abundant sea cucumber species in most parts of the Indo-Pacific region (Conand and Muthiga 2007) including Fringing reef (Pouget 2005), Reunion Island (Conand and Mangion 2002) and Solomon Islands (Buckius et al. 2010). *H. edulis* was reported as the highest abundant species off the coastal waters of Sri Lanka followed by *H. atra*. The highest abundance of *H. edulis* could be due to high level of recruitment, habitat suitability and lower level of exploitation compared to the other species.

The patchiness of distribution is quite common in sea cucumbers and this phenomenon has been previously observed in; La Grande Terre in New Caledonia (Purcell et al. 2009), the Torres Strait (Skewes et al. 2006), Milne Bay Province (Skewes et al. 2002) and most part of the western Indian Ocean (Conand 2008). The patchy distribution of sea cucumbers could be linked with their feeding and bottom habitat characteristics (Uthicke and Karez 1999; Hammond 1983).

The observed pattern of distribution in different depth categories was mainly due to differences in habitat selection by species. The higher abundance of low-value species in shallow waters has been previously reported by Conand (1990); Purcell et al. (2009) and Kinch et al. (2008). According to Mercier et al. (2000) high-value species were common in deeper areas and the results of the present study is consistent with their findings. Further the lower abundance of high and medium-value species in shallow waters likely to be caused by increased harvesting pressure from the commercial divers who commonly descend to 20 m depth to harvest sea cucumbers.

The habitat preference of sea cucumbers varied greatly e.g. some species (*T. ananas*, *H. nobilis* and *B. argus)* live among coral reefs while others seek shelter in sandy bottoms and seagrass (Conand 1990; Purcell et al. 2009; Conand 2008). However, high densities of sea cucumbers in coastal seagrass beds, soft and hard substrates of coral reefs have been previously reported by Kinch et al. (2008) and present results are also supported for their findings. Burial in sediments and living under the rocks, corals and inside the crevices are the most common self-protecting behaviors of sea cucumbers (Purcell 2010). So the high densities of sea cucumbers in rocky and coral areas could be an adaptation for protection specially from predators, waves and currents. The main food sources of sea cucumbers are bacteria, microalgae and dead organic matter (Yingst 1976; Massin 1982; Moriarty 1982). Hence high abundance of sea cucumbers in seagrass beds and macroalgae habitat could be due to the richness of detritus and nutrients in those areas. Very few animals were present on open sand and this finding is consistent with the observations made by Moriarty (1982) and Massin and Doumen (1986).

The observed differences in size frequency disctribution could be due to factors such as fishing pressure, survey sampling depths, environmental factors (Uthicke and Benzie 1999) and substrate types (Mercier et al. 2000).

Purcell et al. (2009) postulated that, as a rough guide, population densities below 100 ind ha^{-1} could be classified as "low" and densities below 30 ind ha^{-1} to be at a "critical level" at which populations may fail to repopulate effectively. According to this, all the sea cucumber species except *H. edulis* in the northwest belong to one of the above categories. Therefore it would appear timely to implement a management plan to avoid further depletion and even a collapse of the Sri Lankan sea cucumber fishery.

As the densities of high and medium –value (except for *H. spinifera*) sea cucumber species are below the critical level in both areas, temporal banning of the fishery for these species would be a better management option.

Further, limiting the total allowable catch (TAC) could be considered as implemented in Northern Territory, Torres Strait and Queensland (Kinch et al. 2008). Though simple fisheries models have been used to estimate indicative MSY for sea cucumber fishery (Aumeeruddy et al. 2005), the estimates can only be used as an indicator of the potential annual yield that could be gained from this fishery given stable recruitment. Due to underline model assumptions and the other application problems of these models such as availability of fewer data (Conand 1990) and unawareness of potential for an "Allee-effect" (Uthicke et al. 2004a), the optimal catch rate could be lower than the calculated MSY. Hence management plans based on MSY could have adverse effect on the stock structure (Uthicke et al. 2004a,b). Further, previous studies revealed that TAC even 5% of the standing stock biomass could lead to stock depletion (Uthicke et al. 2004a). Hence the lower exploitation rate (e.g. 1–3%) can be considered when implementing TAC off the coastal waters of Sri Lanka. However, to implement a system of TAC for the sea cucumber fishery in Sri Lanka more work is required including regularization of reporting and monitoring of commercial landings.

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