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RESEARCH ARTICLE

Assessing abundance and catch selectivity of *Octopus cyanea* by the artisanal fishery in Lakshadweep islands, India

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Abstract – Subsistence fishery for cephalopods contributes significantly to the local economy of several Asian, African and island states. In addition to being unregulated and undocumented, recent studies indicate that low-scale fisheries can have detrimental effects on marine ecosystems. In the Lakshadweep islands, men, women and children have been involved in spear fishing for octopus for a long time, but there is a paucity of information on the biology and fishery of the octopus species in Indian waters. In this study, we estimated the population abundance, morphometry and sex ratio of *Octopus cyanea*. Moreover, we examined whether the current octopus spear fishing activity displayed size or sex selectivity, given that larger individuals are easier to spot and brooding females spend more time in crevices. *O. cyanea* surveys were conducted by snorkeling in the lagoons of Kavaratti and Agatti islands between November 2008 and April 2012. The estimated mean density of *O. cyanea* was 3 and 2.5 individuals per hectare in Agatti and Kavaratti, respectively. Individual mean weight was 923.36 g and 846.26 g in Agatti and Kavaratti and the male:female sex ratio 1.35:1 and 3.8:1, respectively. Comparison between visual counts and fisheries landings indicated that fishing effort was concentrated in areas of high juvenile abundance but without female-bias. Constructing a long-term database of fishery catches will help with stock assessment and understanding the factors that influence octopus populations. Implementation of a lower size limit of 500 g would act as a precautionary measure against catching very small octopuses.

Keywords: Cephalopods / *Octopus cyanea* / artisanal fishery / selectivity / Lakshadweep / India

1 Introduction

Globally, artisanal fisheries employ 24 times more people, consume lesser amounts of fuel, yield higher catch per ton of fuel used and have lower bycatch compared to commercial fisheries for the same amount of fish caught (Jacquet and Pauly, 2008). Subsistence fisheries for cephalopods contribute significantly to the local economy of several Asian, African and island states (Boyle and Rodhouse, 2005). Artisanal octopus fisheries in the Mediterranean (Tsangridis et al., 2002) and Atlantic (Hernandez-Garcia et al., 1998) employ pots and traps to take advantage of the fact that octopuses use crevices for shelter. Hooks and baits are used to catch octopus in Chile (Defeo and Castilla, 1998), South Africa (Oosthuizen, 1993) and Mexico (Solís-Ramírez, 1997). Octopuses are caught by spear fishing in Hawaii (Van Heukelem, 1983), Tanzania (Guard and Mgaya, 2002), Madagascar (Benbow and Harris, 2011) and India (Silas et al., 1985). Recent studies indicated that even low-scale fisheries can impact the marine ecosystem and may lead to loss of habitat complexity, reduction of biomass (Polunin and Roberts, 1996; Coblentz, 1997; Roberts and Hawkins, 1999; Russ, 2002; Hawkins and Roberts, 2004) and overharvesting (Seijo et al., 1998). Moreover, several artisanal fisheries are unregulated and lack the comprehensive information required for fisheries management (Dalzell, 1998).

Spear fishing for octopus is an age-old tradition practiced in most of the Lakshadweep islands (Arabian Sea), with men catching octopuses from lagoons by diving, while women and children glean through reefs during low tides (Silas et al., 1985; Appukuttan et al., 1989). This fishing activity is sporadic and it is practiced by only about 12% of the fishermen on each island (Hoon et al., 2002). The catches are generally for self-consumption or for use as bait, and any surplus is sundried and sold (Silas et al., 1985; Nair and Apte, 2013). Maximum annual yields of 963 ton and 139 ton and Catch per Unit Effort (CPUE) of 2.9 and 0.5 were estimated for Agatti and Kavaratti

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islands, respectively, for the year 2009 (Nair and Apte, 2013). The islanders have observed a decline in catches over the years and they ascribe it to increased fishing efforts and damage to reefs during fishing (Nair and Apte, 2013). Because larger individuals are easier to spot and brooding females spend more time in crevices, artisanal fisheries could be size- and sex-selective (Herwig et al., 2012). Selective harvest of brooding females during peak periods of spawning could have irrevocable effects on the recruitment rate of the species (Guard, 2003), especially because octopuses are semelparous (Mangold, 1987). Furthermore, large-scale bleaching and coral mortality has been recorded in Lakshadweep during the years 1998 (Arthur, 2000), 2010 (Kumar and Balasubramanian, 2012) and recently in 2016 (Singh, 2016), adding to the pressure on octopus habitats.

Octopus cyanea is a reef-associated species, commonly occurring in the shallow tropical waters of the Indian and the Pacific Oceans (Robson, 1929). Found mostly in intertidal reefs and at depths of up to 25 m (Norman, 1984), this large benthic species can weigh over 6000 g and has a lifespan of 12–15 months post settlement from the plankton stage (Van Heukelem, 1973, 1983; Boyle, 1990). Although spring and summer are peak reproductive seasons for *O. cyanea*, spawning occurs throughout the year (Herwig et al., 2012). Females lay about 300 000 eggs (Van Heukelem, 1983) with the number of eggs being proportional to body size (Oosthuizen and Smale, 2003). The species is harvested throughout its distribution range and it is of considerable commercial value to artisanal fisheries (Boyle and Rodhouse, 2005). Various biological aspects such as feeding, growth rate, metabolism, length-weight relationship, life history and reproductive biology have been investigated by several authors in Hawaii (Wells and Wells, 1970; Van Heukelem, 1973, 1976, 1983), Tanzania (Guard and Mgaya, 2002), Madagascar (Humber et al., 2006; Raberinary and Benbow, 2012) and Australia (Herwig et al., 2012). However, there is a lack of information on the biology of the species from Indian waters. Considering the unregulated nature of octopus fishing in the Lakshadweep islands and the delicate state of the reefs, assessment of the species under exploitation is critical for putting into place management measures.

Owing to the temporal, spatial and gear selectivity associated with commercial fisheries or the use of predator diet analysis for quantification of octopus populations (Boyle and Rodhouse, 2005), direct visual census counts were considered most suitable for the present study, similar to other authors (Altman, 1967; Mather, 1982, 1988; Oosthuizen and Smale, 2003; Katsanevakis and Verriopoulos, 2004). Visual *O. cyanea* detection was facilitated by good visibility in Lakshadweep waters, as well as by the tendency of octopuses to change shape or color when they encounter an observer. In addition, midden piles composed of inedible prey that remain in front of den entrances help to locate octopuses (Leite et al., 2009).

In this study, the abundance of *O. cyanea* in the lagoons of Lakshadweep islands was estimated and morphometric parameters such as size, length-weight relationship and sex ratio of the species were assessed. Moreover, to investigate the selectivity of Lakshadweep octopus fisheries, we compared the size composition and sex ratios of octopuses found in visual surveys with those in local fishermen's catches. The survey data obtained through sampling over the entire lagoon provided an overall assessment of the available resource, while the data from the local fishermen's catches, which were associated with fishing in certain prime locations of the lagoon, represented the portion of the available resource that was being used.

2 Materials and methods

2.1 Study area

The Lakshadweep archipelago (8°–12°30′ N and 71°–74° E) is located at the northern end of the Laccadive–Chagos ridge in the Arabian Sea about 120–240 nautical miles from the west coast of the Indian mainland. The total land area is 32 km^2 spread over 36 islands and the total lagoon area is around 4200 km^2 spread over 11 atolls, three reefs and five submerged sand banks (Attakoya, 2000). The height of the land above the sea level is generally 1–2 m without any major topographical features. Most island atolls have a north–south orientation with a shallow lagoon on the west side and a steep rocky shore on the east side. Oceanography patterns of the islands are greatly influenced by the West Indian Coastal Currents, which reverse direction seasonally based on monsoon winds (Shankar and Shetye, 1997).

The islands experience a tropical humid climate, with an average rainfall of about 1640 mm between June and October (Reddy et al., 2013). Surface water temperature varies between 28°C and 38 °C, while salinity ranges from 34 to 39.4 (Jeyabaskaran, 2006). The Lakshadweep islands experience semi-diurnal tides with a spring tidal range of 1.2 m and neap tidal range of 0.3 m (Chandramohan et al., 1993). Hurricanes are likely to occur in the Arabian Sea during pre- and post-monsoon months. These waters are known to harbour about 114 species of seaweed, six species of seagrass, 603 species of fish, 41 species of crabs, 585 species of gastropods, 153 species of bivalves, 24 species of Cephalopoda, 41 species of sponges, four species of turtles and several cetaceans (Tripathy, 2002; Ravinesh and Bijukumar, 2015). Coconut cultivation, tuna fishing and tourism are the major economic activities of the islanders. The present study was conducted in Kavaratti (10°33′ N 72°36′ E) and Agatti (10°51′ N 72°11′ E) islands. Kavaratti has a lagoon area of 4.96 km^2 and a land area of 4.22 km^2, while Agatti has a lagoon area of 17.5 km^2 and a land area of 3.84 km^2 (Attakoya, 2000) (Fig. 1).

2.2 Visual surveys

O. cyanea populations in each lagoon were monitored using transects spaced ≥200 m apart in a stratified random sampling design (Krebs, 1989). A 100 m-long rope was laid down and the area spanning 10 m on either side of the rope was surveyed in a parallel-track search pattern; i.e. in an overlapping back-and-forth manner, thus forming a 100 × 20 m strip-transect. The sample size was set to ensure: (a) minimum coverage of 1% of the potential octopus habitat in each lagoon and (b) coefficient of variation of *O. cyanea* density estimates ≤30% in each lagoon for effective detection of temporal population trends. The lagoons were divided into 1 km^2 grid cells and four transects per grid cell were placed in areas dominated by coral reefs, while only one transect per grid cell was surveyed in areas dominated by sand and seagrass, because such areas are not preferred habitats of *O. cyanea* (Forsythe and Hanlon, 1997). Given that octopus fisheries are

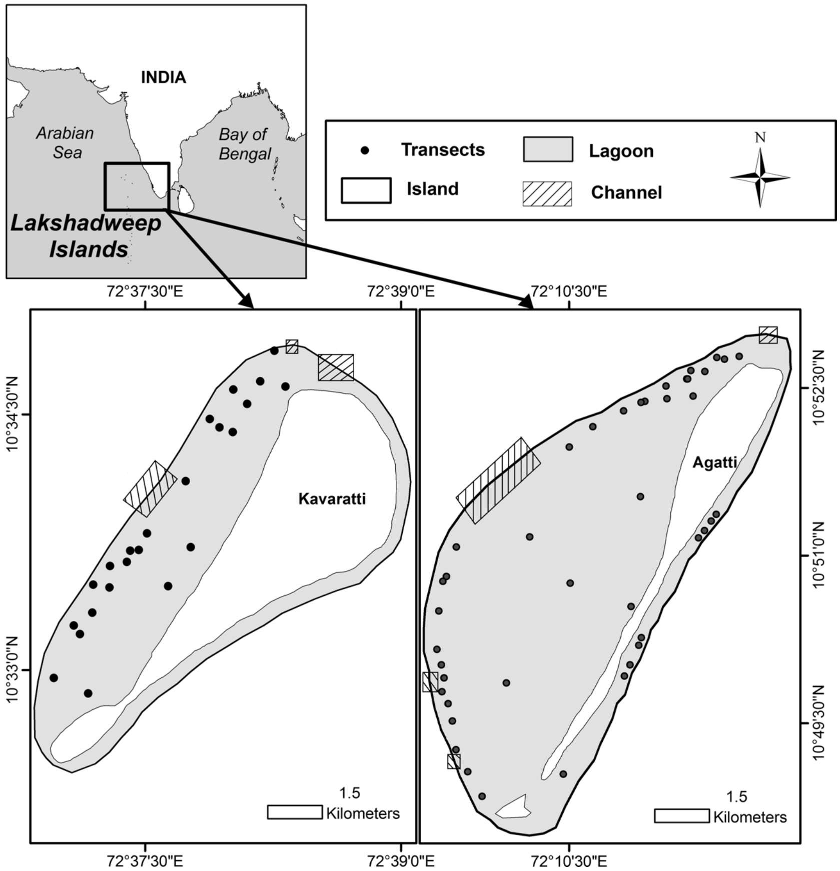

Fig. 1. Map showing location of Lakshadweep islands in the Arabian Sea, distribution of transects in the lagoon and location of lagoon channels in Agatti and Kavaratti islands of Lakshadweep.

constrained by depth owing to the nature of spear-fishing and gleaning techniques (Silas et al., 1985; Appukuttan et al., 1989), we surveyed only the lagoon and intertidal areas of the two islands.

To facilitate repeated monitoring, the start and end points of each transect were marked by planting colored rubber floats and recording their GPS locations. Sampling was conducted during three survey periods: S1: November 2008 to April 2009; S2: November 2009 to April 2010; and S3: November 2011 to April 2012. During each survey period, 66 transects – 23 in Kavaratti and 43 in Agatti (Fig. 1), were monitored twice. First monitoring of all 66 transects took three months to complete (November–January) which was followed up by a second repeat monitoring (February–April) and data from both these counts were combined to generate the data for each survey period. The depths of the surveyed areas varied from 0.5 to 3 m. Visual counting of *O. cyanea* was carried out by snorkeling along lagoon transects and by walking in intertidal areas during low tide. Each transect took 2 h to complete and was monitored by a two-member team composed of an experienced fisherman from the respective island and a researcher. The team was the same for each transect and survey season. Sighted individuals were collected and taken to the laboratory for morphological measurements. Mantle length (*ML* = dorsal mantle length), measured using a 1 mm graduated tape, weight (*TW* = total body weight), obtained using a spring balance graduated with 50 g intervals, and sex, determined by the hectocotylus on the third right arm of males (Norman, 1991), were recorded. Additionally, individuals caught by other local fishermen were collected and measured. Species were identified based on the guidelines in Carpenter and Niem (1998) and Norman (1991).

2.3 Commercial catch sampling

There are no fish landing centers on the islands and also, a large part of the octopus catch gets used up as bait on the fishing boat itself. Hence, most of the commercial catch data was obtained by opportunistic sampling at the beach when boats land and from catch obtained from local restaurants on the respective islands, throughout the survey period. Additionally, all the octopuses caught by the experienced fishermen of the survey team, from locations outside the transect area post-survey, were also included.

2.4 Analysis

The mantle lengths and weights of octopuses from survey data and commercial catch data were converted into quartile ranks (the lowest 25% scored 1, next 25% scored 2 and so on) and the ranks were averaged to generate four combined size

Table 1. Mean values and standard errors (*SE*) for *O. cyanea* derived from visual strip transects (density estimates) and commercial catch sampling (mantle length and body weight) carried out around Agatti and Kavaratti islands (Arabian Sea) during three survey periods; *CV* coefficient of variation; *N* number of individuals.

Island	Survey period	Density (ind per ha)				Mantle length (cm)			Weight (g)		
		Mean	*SE*	*CV*	*N*	Mean	*SE*	*N*	Mean	*SE*	*N*
Agatti	Overall	3.0	0.5	0.16	136	11.53	0.18	216	923	39.62	216
	2008/09	3.1	0.8	0.26	53	10.08	0.2	106	644	34.58	106
	2009/10	2.4	0.6	0.26	21	11.00	0.44	21	934	102.55	21
	2011/12	3.6	0.7	0.2	62	13.38	0.23	89	1253	68.92	89
Kavaratti	Overall	2.5	0.5	0.21	62	10.16	0.24	143	846	61.01	143
	2008/09	4.2	0.9	0.21	39	9.92	0.26	119	680	48.19	119
	2009/10	1.8	0.4	0.21	17	10.75	0.69	20	1685	236.2	20
	2011/12	1.3	0.3	0.21	6	14.5	0.65	4	1588	430.3	4

categories (1 indicating smallest and 4 indicating largest) of individuals. The categories for body weight were: 1: <450 g, 2: 450–799 g, 3: 800–1199 g, 4: ≥1200 g and for mantle length: 1: <8 cm; 2: 8–10.9 cm; 3: 11–12.9 cm; 4: ≥13 cm. For visual surveys mean density (individuals per ha), mean mantle length (cm) and weight (g) of *O. cyanea* were estimated across years at the island level and for each survey season separately. Normality was tested by a Shapiro-Wilk test beforehand and non-parametric tests were conducted when normality was rejected.ANOVA was performed to compare mean densities between the two islands and among the three survey seasons, followed by Student–Newman–Keuls tests when significant differences were revealed by ANOVA. Mean weights were compared between islands and among the three survey seasons by Kruskal–Wallis tests and post hoc Mann–Whitney *U* tests. To assess the proportion of the four octopus size categories across the survey periods a chi-square test followed by a contingency table analysis was performed (Beasley and Schumacker, 1995). Linear regression analyses were carried out to investigate the biometric relationships between log-transformed mantle length and log-transformed body weight. Analysis of covariance (ANCOVA) and post-hoc pair wise comparisons were performed to determine whether the regressions differed among islands, surveys seasons and sexes (5% test level). Deviations from the 1:1 sex ratio and difference in sex ratio between the islands were tested using a chi-square test (Zar, 1999).

Female and male individuals of *O. cyanea* attain sexual maturity at around 600 g and 320 g, respectively (Guard and Mgaya, 2002). The sex-specific data were grouped into adult and immature stages using these threshold values. Then, we compared the distribution of individuals across size classes and maturity stages of octopuses encountered during the survey (availability) with those caught by local fishermen (use) to test the hypothesis that fishing activity in the region was biased towards larger individuals and adult females. Ivlev's selectivity index (Ivlev, 1961) followed by a chi square test was used for this comparison. This index ranges from −1 to +1, with negative values indicating avoidance or rejection, 0 indicating no selection and positive values indicating preference or active selection. All statistical analyses were performed using Microsoft Excel and SPSS 16.0.

3 Results

3.1 Density

All 198 octopuses encountered during the visual surveys were identified as *O. cyanea*. Mean density per survey period ranged from 2.4 to 3.6 individuals per ha for Agatti and 1.3 to 4.2 individuals per ha for Kavaratti (Tab. 1). The precision of density estimates was high (CV range 0.2–0.26 for Agatti and 0.21 for Kavaratti). There was no significant difference in density between the two islands ($F = 0.56$, $df = 1, 64$, $p > 0.05$). Around Agatti, the density of *O. cyanea* did not vary among the three survey periods ($F = 0.67$, $df = 2, 126$, $p > 0.05$), while this was not the case for Kavaratti ($F = 4.97$, $df = 2, 66$, $p < 0.05$); the densities found in the winters of 2009/10 ($p < 0.05$) and 2011/12 ($p < 0.05$) were less than half the value estimated for 2008/09. No octopuses were detected in the central deep part of the lagoon, which was dominated by sand and seagrass.

3.2 Morphometry

During the study, 359 specimens were collected during visual transects and from fishers and subsequently measured. The pooled estimated average ML and TW of *O. cyanea* were 11.53 cm and 923 g for Agatti and 10.16 cm and 846 g for Kavaratti (Tab. 1). The largest individuals sampled in Agatti and Kavaratti weighed 3400 g and 3500 g, respectively. Comparison of weight between the two islands revealed that the octopuses in Agatti were significantly larger ($U = 12853$, $Z = -2.694$, $p < 0.05$) than those in Kavaratti (Fig. 2).

The body weights of *O. cyanea* differed significantly across the three survey periods (Agatti: $\chi^2(2) = 54.29$, $p < 0.05$; Kavaratti: $\chi^2(2) = 21.62$, $p < 0.05$) with mean TW increasing over time for Agatti (2008/9 (S1) < 2009/10 (S2): $U = 695$, $Z = -2.71$, $p < 0.05$; S2 < 2011/12 (S3): $U = 642$, $Z = -2.23$, $p < 0.05$) and an increase between 2008/9 (S1) and 2009/10 (S2) ($U = 508$, $Z = -4.1$, $p < 0.05$) followed by no change between S2 and 2011/12 (S3) ($U = 39$, $Z = -0.04$, $p > 0.05$) for Kavaratti.

Also, there were significant differences in the proportion of the four size categories across the survey periods ($N = 359$, $\chi^2(6) = 95.02$, $p < 0.05$). For the survey period 2008/09, over

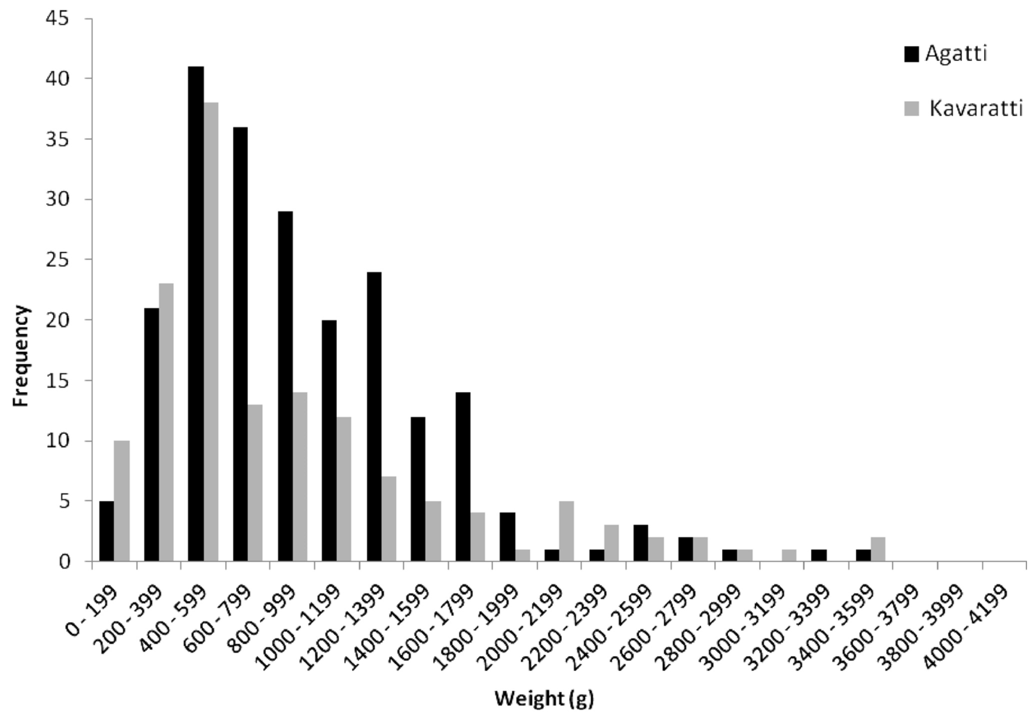

Fig. 2. Body weight frequency distributions for *O. cyanea* sampled from Agatti and Kavaratti Islands pooled over three survey periods (11/2008–4/2009; 11/2009–4/2010; 11/2011–4/2012).

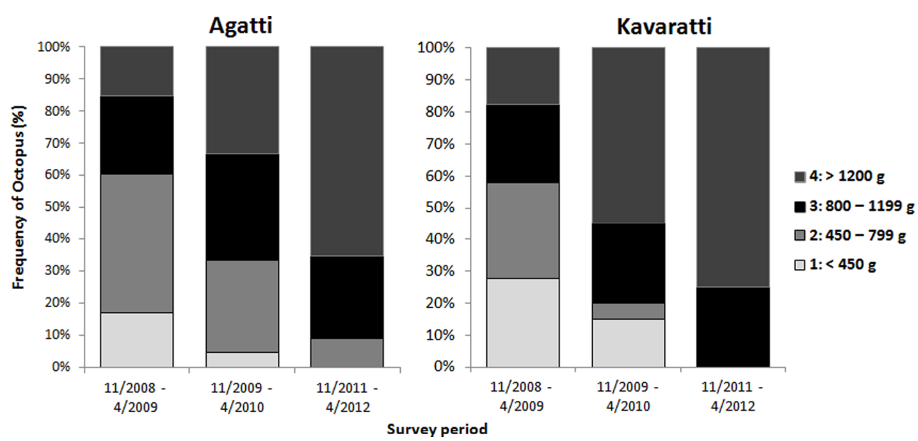

Fig. 3. Comparison of body weights of *O. cyanea* encountered during visual surveys during three survey periods for Agatti and Kavaratti Islands (Arabian Sea).

36% of octopuses belonged to size class 2 ($N = 82$, $p < 0.05$), 23% to size class 1 ($N = 51$, $p < 0.05$) and only 16% to size class 4 ($N = 37$, $p < 0.05$). Although, the proportion of size categories did not vary much in 2009/2010, the proportion of size class 4 ($N = 61$, $p < 0.05$) was comparatively higher and no octopuses of size class 1 were detected in 2011/12 (Fig. 3).

ANCOVA revealed significant differences in length-weight relationships across survey periods ($F = 19.26$, $df = 2$, 255, $p < 0.05$) but not between sexes ($F = 0.09$, $df = 1$, 134, $p > 0.05$) or islands ($F = 2.37$, $df = 1$, 356, $p > 0.05$). Post hoc tests showed there were significant differences between successive survey periods ($p < 0.05$). Hence, separate length-weight relationships were fitted for each survey period combining the data from the two islands (Fig. 4, Tab. 2). The values of the b coefficients were all <3 indicating negative allometric growth in this species, with greater increase in ML per unit increase in TW.

3.3 Sex ratio

For studying the sex ratio, gender information of 137 octopuses (85 males and 52 females) obtained from visual surveys and commercial catch data was analyzed. Sex ratios could not be compared between survey periods due to lack of data from 2008/09 and low sample size for 2011/12. The male: female sex ratio was 1.35:1 for Agatti and 3.8:1 for Kavaratti.

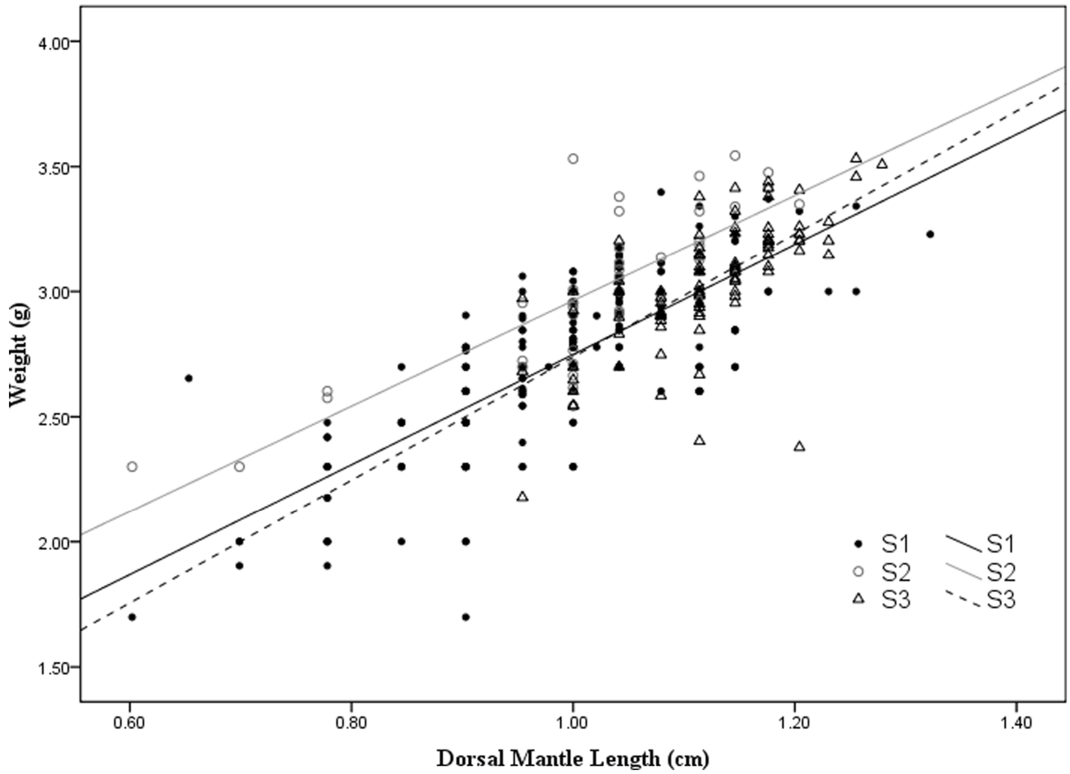

Fig. 4. Logarithmic plot of the linear regression analysis between total weight and dorsal mantle length for *O. cyanea* combining data from Kavaratti and Agatti islands.

Table 2. Parameter estimates of dorsal mantle length (*ML*) − total weight (*TW*) relationships log (*TW*) = *a* + *b* log (*ML*) for *O. cyanea* by survey period. 95% confidence intervals (*CI*).

Survey period	*N*	*a*	*CI(a)*	*b*	*CI(b)*	r^2
2008/09	225	0.55	0.29 to 0.80	2.20	1.94–2.45	0.57
2009/10	41	0.86	0.34 to 1.37	2.11	1.61–2.60	0.65
2011/12	93	0.28	−0.33 to 0.89	2.45	1.91–2.99	0.47

The proportion of males and females in the octopus population of Agatti did not deviate from the 1:1 ratio ($N = 108$, $\chi^2 = 9.97$, $p > 0.05$), but the Kavaratti population was dominated by males ($N = 29$, $\chi^2 = 9.97, p < 0.05$) and was significantly higher than that of Agatti ($\chi^2 = 4.66$, $p < 0.05$).

3.4 Selectivity

Overall, ML and TW measurements of 331 *O. cyanea* individuals-193 individuals from fishers' landings and 138 individuals from the visual surveys were analyzed for determining size-selectivity pooling individuals across years and islands. A positive value of Ivlev's selectivity index (Fig. 5a) indicated that small individuals (<450 g weight and <8 cm mantle length) were over-represented in the catch data relative to the survey data ($N = 54$, $\chi^2 = 6.60$, $p < 0.05$), while the other size classes were landed in proportion to their availability. For exploring sex-based selectivity, the data of 137 octopuses were assessed − 73 from fishers' landings and 64 from the visual surveys. This sample comprised 12 immature females, 40 adult females, 7 immature males and 78 adult males. Immature and adult female octopuses yielded a positive Ivlev's selectivity index value (Fig. 5b), indicating they might have been targeted selectively during fishing, compared to individuals in other stages of maturity. However, the results of the chi square test indicated that the proportion of females in the catch data was not significantly different from that in the survey data ($\chi^2 = 2.76$, $p > 0.05$).

4 Discussion

In this study we found an average density of 2.5 and 3.0 *O. cyanea* individuals per ha (0.25 and 0.3 ind./1000 m^2) in Lakshadweep which is five times lower than what was found for the same species in Hawaii (1.2 ind./1000 m^2) (Sims and Stimson, 1998) and for other tropical octopus species, such as *Octopus insularis* (1.12–8.8 ind./1000 m^2) in Brazil (Leite et al., 2009) and *Octopus briareus* (7.9 ind./1000 $m^2 \pm 0.36$) in the Bahamas (Aronson, 1986). This difference might be explained by restricted availability of preferred prey or lack of

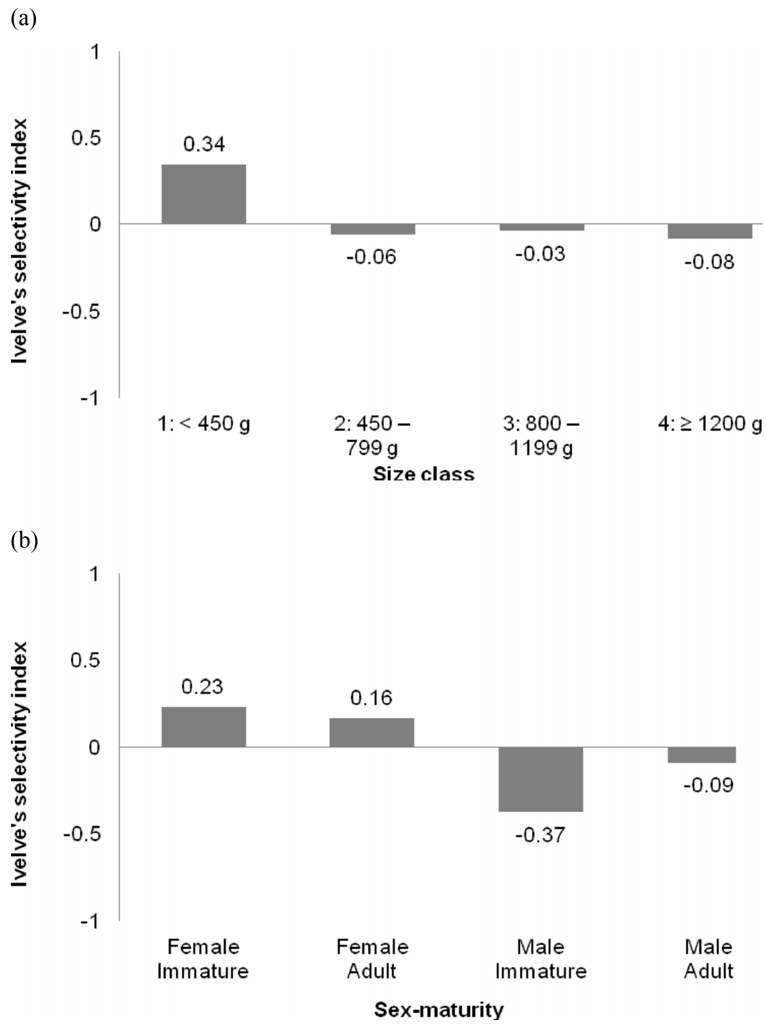

Fig. 5. Ivlev's selectivity index comparing (a) the mantle length and (b) sex-maturity of individuals in fishermen landings with those of individuals encountered in visual surveys of *O. cyanea*; −1 avoidance; +1 preference; 0 no selection.

shelter considering *O. cyanea* is a relatively large octopus. Another reason for the low densities observed in this study could be biased sampling due to the monsoon during which the rough waters make fishing and sampling activities impossible.

Over the study period, the density of octopus did not vary in Agatti, while a considerable reduction in octopus density was found in Kavaratti between 2009/10 and 2011/12. Moreover, there was an increase in octopus weight between 2008/09 and the following two survey periods for both islands, due to a significantly high percentage of the largest size class (>1200) during the survey period 2011/12. Environmental parameters (tide and visibility) were similar across the sampling periods, except for an elevated sea surface temperature (SST) during S2 (winter 2009/10), which led to a coral bleaching event in 2010 (Kumar and Balasubramanian, 2012). Research has indicated that higher temperature within the thermal range of a species leads to higher food intake (Mangold and Boletzky, 1973) and, consequently, greater growth (Van Heukelem, 1976; Forsythe, 1993; Semmens et al., 2004). Although several parameters such as age, sex, feeding rate and prey availability influence growth (Van Heukelem, 1973, 1976, 1983), the observed increase in mean weight because of elevated SST warrants further investigation. The differences observed between the islands could be because the larger lagoon of Agatti might sustain greater densities and sizes of octopus (Yarnall, 1969; Aronson, 1986) and show greater resilience to drastic environmental fluctuations that can influence octopus populations (Guard and Mgaya, 2002).

Mean weight of *O. cyanea* in Lakshadweep (923 g in Agatti) was higher than what has been recorded for the same species in Tanzania (478 g in Mtwara; Guard and Mgaya, 2002), Madagascar (805–823 g; Raberinary and Benbow, 2012) and Australia (851 g; Herwig et al., 2012). However, the size of the largest individual caught was much lower than the 5000, 6000 and 11700 g reported for Madagascar (Raberinary and Benbow, 2012), Hawaii (Van Heukelem, 1973) and Tanzania (Guard and Mgaya, 2002), respectively. The octopus fisheries in these locations are comparable because they are primarily concentrated in shallow reefs, intertidal areas and exposed reef flats. The octopus fisheries in Australia and Hawaii are low-intensity subsistence fisheries similar to those in Lakshadweep, while those in Tanzania and Madagascar are more intensive and commercialized. Moreover, the mean annual SST values in Australia (24.6 °C) and Hawaii (25.9 °C) are lower than those in

Tanzania (27.9 °C), Madagascar (28.1 °C) and Lakshadweep (28–38 °C). The greater mean weight observed in Lakshadweep can possibly be ascribed to relatively low fishing intensity and higher SST. Because our surveys were limited to the shallow waters of the lagoon, we might have missed larger individuals, which are found in deep waters (Guard and Mgaya, 2002; Raberinary and Benbow, 2012).

Results of the weight-frequency distribution analyses revealed that the lagoon population was dominated by small (<450 g) and medium-sized (450–799 g) individuals in 2008/09. The preference of juveniles for shallow areas might be due to the warmer temperature of lagoon waters and protection from larger predators (Katsanevakis and Verriopoulos, 2004; Leite et al., 2009). Additionally, the higher percentage of juveniles inside the lagoons may also be a result of the abundance of preferred food items, such as crustaceans, bivalves and gastropods (Forsythe and Hanlon, 1997) that are abundant in the reef substrate. Lagoons may thus act as "nurseries" for young individuals in the population and provide protection to them (Katsanevakis and Verriopoulos, 2004; Leite et al., 2009; Bouth et al., 2011).

The negative allometry in the length-weight relationships is in accordance with the results for other cephalopod species such as *Octopus vulgaris* (Smale and Buchan, 1981; Sanchez and Obarti, 1993; Quetglas et al., 1998; Gonzalez et al., 2011; Angeles Torres et al., 2017), *Eledone moschata* (Silva et al., 2004; Akyol et al., 2007; Sifner and Vrgoc, 2009; Angeles Torres et al., 2017), *Octopus defilippi* (El-Ganainy and Riad, 2008) and *Octopus membranaceus* (Yedukondala Rao and Mohana Rao, 2013). The exponent of the length-weight relationship of *O. cyanea* obtained in this study (b: 2.11–2.45) is similar to the coefficient estimated for Tanga ($b = 2.75$), Mafia ($b = 2.25$) and Mtwara ($b = 2.49$) in Tanzania (Guard and Mgaya, 2002), where the climate and mean SST (27.9 °C) are similar to those in Lakshadweep.

Contrary to our hypothesis that larger octopuses would be targeted more, the results indicate that small-sized individuals (<450 g) accounted for significant proportions of fisher's landings, even though the lagoon population was dominated by small and medium-sized octopuses (450–799 g). Unlike the market-driven demand for catching smaller octopuses in Tanzania (Guard and Mgaya, 2002), no such size preference exists in Lakshadweep. The concentration of fishing efforts in areas where small-sized octopuses are abundant might be a reason for the higher proportion of individuals from that size class in fishery catch and this requires further investigation.

Even with a male-dominated population, fishing activity might have been biased towards females, with a greater number of immature and adult females being caught compared to male octopuses. Over the three years of the study, we encountered only one brooding female in Agatti lagoon. Adult females of *O. vulgaris*, *Octopus dofleini* and *O. cyanea* are known to migrate to deeper waters for brooding and this phenomenon is called "depth refuge" (Smale and Buchan, 1981; Hartwick et al., 1984; Whitaker et al., 1991; Sanchez and Obarti, 1993; Guard and Mgaya, 2002; Guard, 2003; Oosthuizen and Smale, 2003; Raberinary and Benbow, 2012). Because most brooding females might be located in deeper waters outside the lagoon (Guard and Mgaya, 2002; Raberinary and Benbow, 2012), they appear to be safe from exploitation by the present artisanal octopus fishery in Lakshadweep. With a CPUE of 2.9 and 0.5 for Agatti and Kavaratti (Nair and Apte, 2013), respectively, the current fishery appears to be non-intensive. However, sampling limitations during the surveys due to the monsoon might have influenced the results of this study and further investigations are required.

4.1 Conclusions and relevance for management

Preliminary results of the comparison of *O. cyanea* individuals caught by the fishery in the Lakshadweep islands with those observed in shallow areas by visual transects suggested that the fishing efforts might be concentrated in areas with an abundance of juvenile individuals and could be female-biased. However, the results are uncertain as samples sizes were small. As bleaching continues to affect the reefs in Lakshadweep, it is important to adopt management measures to ensure ecological sustainability of the fishing activity. Constructing and maintaining a long-term database of fishery catches will help with stock assessment and understanding the factors that influence octopus populations. Because lagoons are sanctuaries for juvenile individuals, a lower size limit of 500 g (Guard and Mgaya, 2002) will act as a precautionary measure against catching very small octopuses. Creating temporary no-take zones (NTZ) evidently increased the density and biomass of octopuses in Morocco (FAO, 1997), Madagascar (Humber et al., 2006) and Argentina (Navarte et al., 2006). Once the peak recruitment periods are identified, NTZs can be implemented for a few months to increase the CPUE (Humber et al., 2006; Navarte et al., 2006; Raberinary and Benbow, 2012). Moreover, the reefs should be protected from damage caused by gleaning, overturning of coral heads in search of octopuses and anchoring of boats inside the lagoon (Silas et al., 1985; Hoon et al., 2002; Hoon and Tamelander, 2005).

The present research suffers from certain drawbacks such as sampling of only lagoon waters and absence of seasonal density estimations and reproductive stage data, which limited our inference and conclusions. Nonetheless, we attempted to collect the information necessary to study the present abundance of the species and assess whether there might be selectivity in the artisanal *O. cyanea* fishery in Lakshadweep. In future, this research can be expanded to deeper waters and replicated at other islands in the Lakshadweep archipelago to provide a better understanding of the factors governing *O. cyanea* abundance and to monitor future changes in its population because of fishing, habitat degradation and climate change. Carrying out spatially-explicit management strategy evaluation can help to optimize future surveying efforts (Harford and Babcock, 2016).

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