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Reproduction in *Sepia aculeata* Van Hasselt, 1835 along the Andhra Pradesh coast, off the western Bay of Bengal

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Abstract

Sepia aculeata Van Hasselt, 1835 is a commercially important cuttlefish in Indian seas with limited studies on its biology from the Indo-Pacific region. This study, observed the reproductive biology of *S. aculeata* from samples landed by the trawl fishery operating off the coast of north Andhra Pradesh, off the western Bay of Bengal. A total of 3511 samples were studied, of which 2241 were females having dorsal mantle length (DML) ranging from 8.7 to 21.4 cm and weight from 78 to 901 g and 1260 were male specimens of DML ranging from 7.9 to 21.9 cm and weight from 54 to 738 g. Females dominated the landings with a sex ratio of 1.78. The length at first maturity was estimated at 14.3 and 12.6 cm DML for females and males, respectively. Both sexes spawned throughout the year with two significant peaks from July to October and from December to February with minor intermittent peaks. The absolute fecundity ranged from 330±1.44 x 10^2 eggs, with a relative fecundity of 75±8.94 x 10^2 eggs 100 g^{-1} body weight. The results of this study may be used as inputs in assessing the stock of *S. aculeata* in the study region.

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Introduction

Cephalopods are one of the noteworthy components of global marine capture fisheries with intermittently distributed fisheries and landings in the world's oceans. Cephalopod landings constitute almost 3.78% of the world's total fisheries production (FAO, 2020). The demand for cephalopod import is enormous in the south-east Asian countries as it is a much sought-for commodity in these countries. Almost 761 species of cephalopods are distributed throughout the world's oceans (Appeltans *et al.*, 2012). *Sepia officinalis, Sepia aculeata, Sepia pharaonis, Sepia latimanus, Sepia kobiensis* and *Sepiella inermis* are some of the commercially important species among the 115 cuttlefish species reported so far (Ried *et al.*, 2005). The needle cuttlefish *Sepia aculeata* is one of the most commercially valuable species. Several studies have been carried out on this species in the Asian region, primarily from Thailand, including length at first maturity, spawning season and fecundity (Chotiyaputta, 1980; Charoensombat *et al.*, 2013). The sex ratio, spawning season, Gonado-somatic index and fecundity of needle cuttlefish from both the Andaman Sea and the Gulf of Thailand were reported by Kaewbud *et al.* (2016). Length frequency distribution of the needle cuttlefish from the Bay of Bengal, Bangladesh were described by Siddique *et al.* (2016).

In India, on average cuttlefish contributed 45% to the total cephalopod catch (2.1 lakh t) during the last decade (CMFRI, 2019). During the same period (2008-18), the average annual landing of cephalopod was about 3177 t in Andhra Pradesh. Among the cephalopods, cuttlefishes contributed 67.64%, while *S. aculeata* in cuttlefish fishery along the Andhra coast contributed about 33% (Jasmin *et al.*, 2018). Several studies have also been carried out on the species from India. The exploitation status of the species and spawning season were studied from all over India by Silas *et al.* (1985). Rao (1997) studied the exploitation status and biology of the species from the Karnataka coast. Nalwa *et al.* (2005) described the length-weight relationship, morphometry and biology of the species from Mumbai. The fishery and stock status of *S. aculeata* from Andhra Pradesh, western Bay of Bengal was studied by Jasmin *et al.* (2018)

Being a commercially valuable species with good domestic and international demand, *S. aculeata* fishery needs to be managed effectively to ensure the sustainability of its stock in Indian waters. To frame a sustainable fishery management plan for a tropical country like India, which has a multispecies-multi-gear nature of the fishery, it is necessary to assess the stock and study the biological characteristics of different species. Though they form an important component of marine landings, studies focused on the biology and fishery of cuttlefish from the Andhra Pradesh coast, especially that of *S. aculeata*, are lacking. Therefore, the present study deals with some aspects of the reproductive biology of the needle cuttlefish, *S. aculeata* off the Andhra Pradesh coast. The results presented in this communication will immensely help in managing the cuttlefish resources and in framing species-specific management measures to ensure the sustainability of needle cuttlefish stock in the region.

Materials and methods

For the present study , from January 2015 to December 2017, a total of 2241 female and 1260 male specimens of *S. aculeata* were collected at monthly intervals from Visakhapatnam (17.7092°N; 83.2707°E) and Kakinada (16.98404°N; 82.27939°E) landing centres of Andhra Pradesh (Fig. 1). The dorsal mantle length (DML) of individual specimens was measured from the neck of the body to the end of cuttlebone spine to the nearest millimetre by using a measuring scale and the total weight to the nearest mg by digital balance. The study on spawning periodicity and ova diameter (30 ovaries of different maturity stages) of intra-ovarian eggs were carried out from preserved ovaries, as described by Clark (1934) and Prabhu (1956). A four-stage maturity staging was done (Stage I - Immature, II - Maturing, III - Mature and IV - Spent) following Silas (1985) with 10 ovaries studied in Stage I, 8 in Stage II, 7 in Stage III and 5 in Stage IV. The measured ova were grouped into 0.1 mm class intervals and their frequency polygons were drawn graphically. Maturity stages were recognised on the basis of the colour and size of the paired nidamental glands and the size of the single ovary and ova. For knowledge of the spawning period, the data on the percentage of various stages of maturity in different months was collected for 30 months, which was pooled for 12 months and represented graphically. The gonado-somatic index (GSI) was calculated using the equation *GSI = (Weight of gonads × 100)/ Total body weight* (Vladykov, 1956). The minimum size at which they attained maturity was determined based on examining the specimens in maturity stages III and IV (Silas, 1985). Data collected for 36 months was pooled and the percentage of cumulative frequency was graphically plotted against the length groups, and the length at which 50% of the population was found to be mature was taken as the length at first maturity (King, 1995). The length at first maturity for male and female were analysed separately. Fecundity was estimated gravimetrically by counting the ova from the whole gonad of 51 mature ovaries of *S. aculeata* (Rao, 1997). The relative fecundity was obtained by dividing the absolute fecundity by the total body weight of specimens.

Results

A total of 3511 specimens of *S. aculeata* were collected, of which 2241 were females of length ranging 8.7 to 21.4 cm (average 14.64 cm) and 1260 were male specimens ranging from 7.9 to 21.9 cm (average 12.7 cm). The weight recorded was 78-901 g (average 360.89 g) for females and 54-738 g (average 213.58 g) for males.

Sex ratio and size at maturity

Analysis of data for the monthly sex ratio (Fig. 2) for *S. aculeata* revealed the dominance of females in the fishery with an average sex ratio of 1:1.78 (male: female), except in March when males were numerically higher than females. The size-based sex ratio showed a male dominance up to 130 mm, beyond which females dominated the fishery. The statistical analysis also strengthens the results with high significance (Table 1). Based on the examination of 1299 females and 544 males in the maturity stages of III and

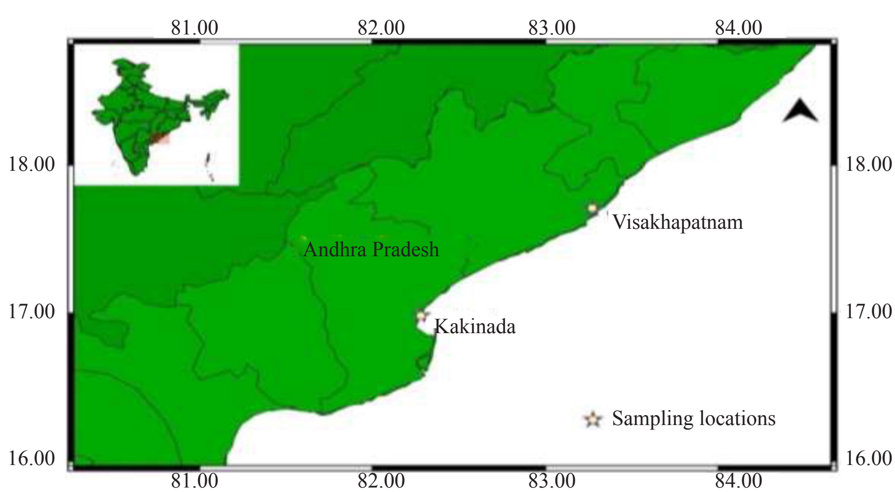

Fig. 1. Map showing the sampling sites in Andhra Pradesh

Table 1. Month-wise sex ratio of *S. aculeata*

Month	Female	Male	Observed sex ratio	Chi-square (p value)
Jan	354	141	2.511	0.000*
Feb	231	118	1.958	0.000*
Mar	128	151	0.848	0.169
Apr	79	62	1.274	0.152
Jun	196	131	1.496	0.000*
Jul	296	203	1.458	0.000*
Aug	190	110	1.727	0.000*
Sep	188	96	1.958	0.000*
Oct	195	78	2.500	0.000*
Nov	134	82	1.634	0.000*
Dec	250	88	2.841	0.000*

* Significant at 5% level

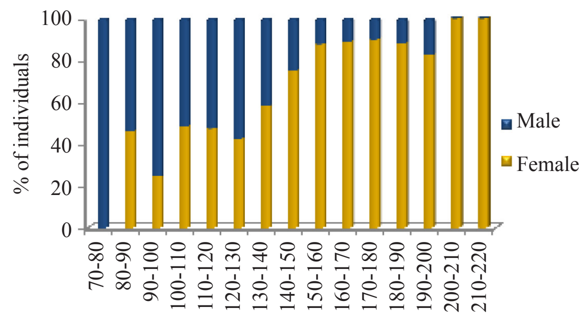

Fig. 2. Size-based sex ratio of *S. aculeata*

above, the matured specimens were seen from 90 mm (minimum size at maturity); the length at first maturity (L_m) was estimated at 13.95 cm for the pooled samples, 14.3 cm dorsal mantle length for females and 12.6 cm for males (Fig. 3).

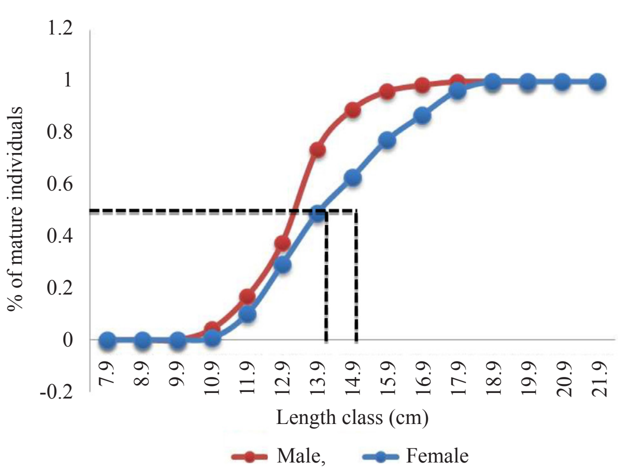

Fig. 3. Length at first maturity in *S. aculeata*

Spawning season

The mature ovaries were recorded throughout the year, peaking from July to February. Spent stages were also observed throughout the year except for October and November. This indicated that the species spawned throughout the year with two significant peaks during July to October and December to February, with intermittent minor peaks (Fig. 4-5).

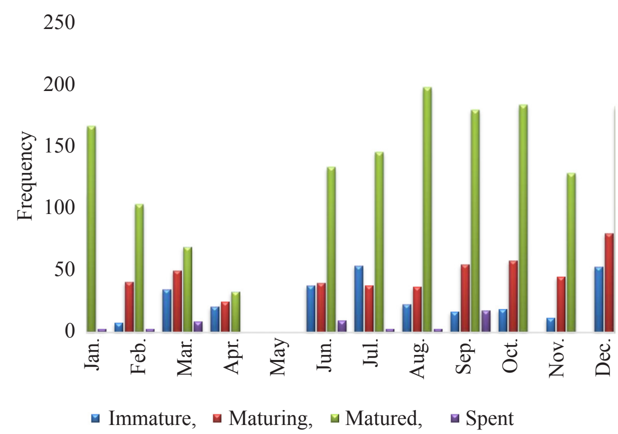

Fig. 4. Month-wise percentage distribution of maturity stages (Female)

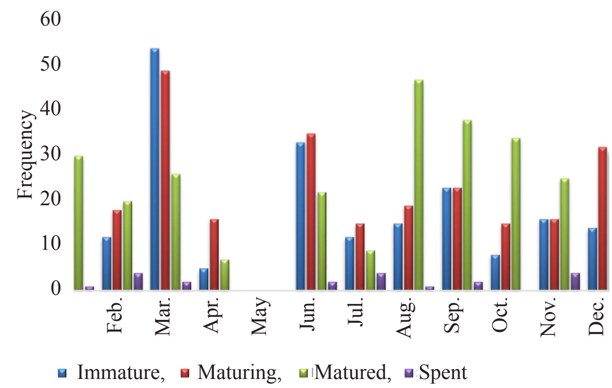

Fig. 5. Month-wise percentage distribution of maturity stages (Male)

Gonado-somatic index

The GSI estimated from the measurement of 459 female and 423 male specimens fluctuated from 1.78 to 3.66 and 1.42 to 1.71 for females and males, respectively. A prominent peak was observed during February, followed by a decline in March. This indicated peak spawning during the winter season from December to February (Fig. 6). Still, there was no significant variation in male GSI values, showing a slight peak between August and December. The length-wise analysis of GSI for females did not indicate significant variation, ranging between 2.03 and 2.93 (Table 2). The values increased with size in females till it attained length at first maturity, *i. e.* 140 mm.

Fecundity

The fecundity was estimated based on measuring eggs from gonads of 51 females ranging from 115-195 mm in length and 179-690 g total weight. Each gonad consisted of three types of eggs: bigger size (0.9-0.6 mm), medium size (0.5-0.4 mm) and smaller size (0.3-0.2 mm). The transparency of the eggs increased with the size (Fig. 7). The potential fecundity of females, having an ovary weight of 8-16 g, was 180-1030 eggs, with an average of 330 eggs. The relative fecundity of the species ranged from 1-2 eggs g^{-1} of body weight (100-200 eggs 100 g^{-1} body weight, with an average of 74 eggs). Fecundity did not show a linear relationship with the length and weight of specimens.

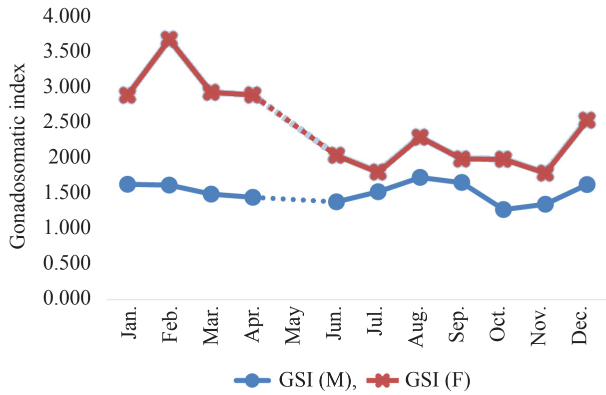

Fig. 6. Month-wise gonado-somatic index

Table 2. Length-wise gonado-somatic index of females

Length class (mm)	Avg. gonad weight (g)	Avg. Total weight (g)	GSI
111-120	5.600	191.400	2.926
121-130	6.200	233.167	2.659
131-140	7.413	269.744	2.748
141-150	7.776	346.310	2.245
151-160	8.500	393.492	2.160
161-170	9.508	451.916	2.104
171-180	10.782	521.763	2.066
181-190	12.516	615.844	2.032
191-200	15.667	676.286	2.317
201-210	19.100	830.000	2.301

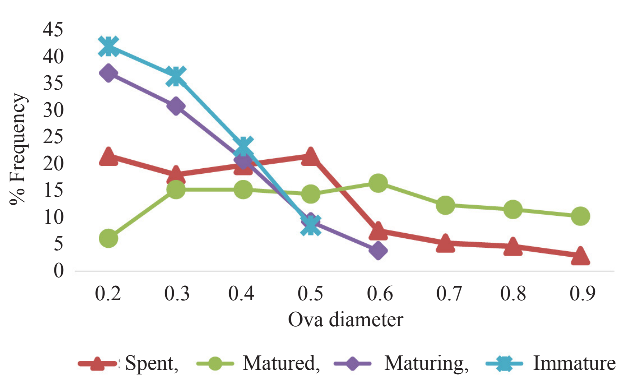

Fig. 7. Ova diameter frequency of *S. aculeata*

Ova diameter

The ova diameter frequency polygon was drawn to know the condition in different maturity stages. Only immature (0.1 to 0.3 mm) and maturing (0.4-0.5 mm) ova were observed in stage I. About 60-80% ovary was with immature ova. In stage II, the ova diameter increased up to 0.6 mm and about 40-50% ovary was occupied by medium-sized maturing eggs. In stage III, about 50% the, of ovary was occupied by mature ova (0.6-0.9 mm), about 30% by medium-sized eggs and the rest 20% by small-sized immature ova. In stage IV, *i.e.* spent stage, very few eggs were present.

Discussion

Our study dealt with the reproductive biology of *S. aculeata* off Visakhapatnam along the western Bay of Bengal. The dominance of females, recorded in the catches, is probably due to sex-specific aggregation for spawning, which differs substantially in size from species to species and even from population to population, ranging from the gathering of few to hundreds of thousands of individuals (Schnell and Clayton, 2019) or larger size of females that are more vulnerable to gear. Results of earlier researchers support these findings, namely Silas *et al.* (1985) at Kakinada (1:1.33), Madras (1:1.38) and Kochi (1:1.13) and Rao (1997) at Mangalore reported (1:1.3) a female dominance in *S. aculeata* samples from commercial fisheries. Cuttlefish (Sepiida) are characterised by separate feeding grounds (usually offshore) and the inshore spawning grounds. Their ontogenetic migrations are relatively pretty short (tens to low hundreds of kilometres). Still, they could result in a substantial seasonal variability in abundance, especially in their localised spawning grounds. For example, *S. apama* in Australian waters shows a convergence in a specific area for breeding by adults during winter, and young and juveniles forage over a much wider area for the rest of the year (Hall and Hanlon, 2002). *S. officinalis* in English Channel shows a seasonal migration where juveniles and subadults spend the autumn and winter in deep, warm waters. During spring, the matured ones move to their spawning ground along the French coasts of Normandy, where the mature males reach almost a month ahead of females. Mating and spawning occur during summer only in shallow waters (Bloor *et al.,* 2013). Therefore, the ecology of cephalopods does indicate the potential for aggregation by sex, which in turn can lead to sex-specific capture in commercial fisheries. Hence, detailed studies need to be conducted to confirm for sex specific aggregations in the study region and their impact on the population if such aggregations are targeted.

The length at first maturity estimated from the present study was the highest observed in females for *S. aculeata* from Indian waters (Table 3). The geographical variation in L_m for *S. aculeata* across the Indian coast has been indicated by Silas *et al.* (1985). Variations in the estimates of lengths of first maturity of the species from earlier reports may be due to the different factors such as spatial distribution of sampling, the period over which samples are collected and the method used to categorise the specimen as mature or immature (Hunter and Macewicz, 2003). However, the present result is very close to the observation from Mumbai and Cochin waters by Silas *et al.* (1985). The minimum size at maturity (MSM) observed was 90 mm for pooled samples (male and female) which is similar to the Charoensombat *et al.* (2013) in which the MSM of males was 71.9 mm and females was 94.4 mm in the Gulf of Thailand.

The maturity stages were studied with the help of a four-point standardised scale for maturity stages following Silas (1985). The spawning was observed to be year-round with two peaks: December to February and July to October. The GSI values of females further support this finding during the winter season. The mature and spent specimens of both sexes were found almost throughout the year, indicating the species to spawn throughout the year. Earlier studies also support the present findings, wherein they reported that mature specimens were observed throughout the year with a peak during November to February by Charoensombat *et al.* (2013) and February to April by Nalwa *et al.* (2005) and October to March

Table 3. Estimates of length at first maturity of *S. aculeata* from different regions of India

Location	Sex	Lm (mm)	Authors
Visakhapatnam	M	77	Silas *et al.* (1985)
	F	102	Silas *et al.* (1985)
Mandapam	M	83	Silas *et al.* (1985)
	F	110	Silas *et al.* (1985)
Madras	M	100	Silas *et al.* (1985)
	F	118	Silas *et al.* (1985)
Cochin	M	124	Silas *et al.* (1985)
	F	130	Silas *et al.* (1985)
Bombay	Pooled	99	Nalwa *et al.* (2005)
	F	130	Silas *et al.* (1985)
Mangalore	Pooled	86	Rao (1997)
Andhra Pradesh	M	126	Present study
	F	143	

by Rao (1997). Prolonged spawning/spawning throughout the year is a feature quite typical to tropical fish species and is a key factor in their resilience (Vivekananda, 2017).

The absolute fecundity of the species ranged from 180-1030 eggs and the relative fecundity from 100-200 eggs 100 g^{-1} of body weight for the ovary weighing 8-16 g. It was also observed that the fecundity did not show a linear relationship with the length and weight of the species. Rao (1997) reported that the mature ovary of the *S. aculeata* contained 206-1568 eggs and no relation between size and fecundity. Nalwa *et al.* (2005) reported absolute fecundity between 214 and 4143 eggs, which were comparable, except for the maximum range recorded in the present study. The fecundity (1644 eggs) from the Gulf of Thailand (Charoensombat *et al.,* 2013) was the closest to the present study. The ova diameter study in *S. aculeata* was done by Rao (1997) for the Mangalore region. In that study, the diameter of mature ova ranged from 1-5 mm and the mean diameter was 3.392 mm, which showed a smaller range compared to this study. They reported that mature eggs showed an unimodal distribution while the present study revealed a distribution without a prominent mode or peak as they are batch spawners.

With the ever-increasing demand for cuttlefish resources, proper management plans are paramount to avoid over-exploitation. The fishing effort can be regulated and the minimum legal size implemented to avoid growth overfishing and maintain healthy fish stocks besides ensuring better income for Andhra Pradesh fishers. Biological concerns must be addressed before deciding on the duration and period of the closed season. Considering the sex-based size differences, low fecundity and moderate resilience of this species to fishing pressure, the minimum legal size (MLS) of the species could be fixed at 90 mm (*i.e.* minimum size at maturity) dorsal mantle length to ensure that immature fishes survived to grow and spawn at least once in their lifetime. Similar recommendations were seen in the policy briefs of different states of India like Kerala (Pillai, *et al.,* 2009; Mohamed *et al.,* 2014), Karnataka (Rohit *et al.,* 2016), Tamil Nadu (Sivadas *et al.,* 2017) and Andhra Pradesh (Menon *et al.,* 2018) for the sustainable catch of cephalopod species.

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