



Biometry and size distribution of *Crambionella annandalei* and *Chrysaora* spp. along the coast of Andhra Pradesh, India

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Abstract The biometry and seasonal size distribution of the medusae, *Crambionella annandalei* and *Chrysaora* spp. were investigated from fortnightly gillnet landings between January 2017 and December 2018 along the West coast of the Bay of Bengal. Although both taxa exhibited strong patterns of seasonality in abundance and growth, being commonest and smallest in summer, *C. annandalei* were largely absent in the monsoon and post-monsoon seasons, while *Chrysaora* spp. could be recorded throughout the year in a variety of size groups. There was a strong cohesion in pattern between years, suggesting that the monsoon impacts populations of both species, albeit in slightly different ways. We

provide rare, field-based measurements of growth for both species that are in broad agreement with the data published for similar taxa elsewhere: our length–weight data provide useful contributions to baseline information.

Keywords Bay of Bengal · Bell diameter · Growth · Scyphozoa · von Bertalanffy growth curve

Introduction

Jellyfish are key constituents of coastal and marine ecosystems representing potentially important marine resources that can become problematic when in enormous numbers. Polyps of scyphomedusae are generally found in shallow coastal waters where the planulae settle and when strobilation is completed, ephyrae are liberated and develop into young medusae (Omori and Nakano 2001; Lucas et al. 2012). Many species appear to be opportunistic and are able to tolerate wide changes in their physical and biological environment, which means they have potential for rapid colonization and population expansion (Ozdemir et al. 2019).

Understanding the population dynamics, seasonality and reproductive plasticity of medusae requires information about the size structure of populations and temporal changes in size (Lucas 2001; Lies et al. 2015). Although research on jellyfish has increased in

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recent years, our knowledge of the dynamics and ecosystem role of populations remains scanty in most parts of the oceans, and this precludes an accurate integration of jellyfish into functional ecosystem models. This is especially true in tropical waters, where few studies have been conducted and where field samplings are generally inadequate. Indeed, it could be argued that studies on the life history, biology, population dynamics and ecology of jellyfish are desperately needed in these areas (Ozdemir et al. 2019). As a first step to redressing this knowledge gap in the western Bay of Bengal, we provide information on seasonal changes in the jellyfish populations caught using gillnets along the coast of Andhra Pradesh.

Materials and methods

Study area

Like other parts of the northern Indian Ocean, seasonal changes in the Bay of Bengal are strongly influenced by monsoons, and the year can be divided into four seasons: summer (March–May), pre-monsoon (June–August), monsoon (September–November) and post-monsoon (December–February) (Behera et al. 2017). The Western Bay of Bengal experiences seasonal changes in sea surface temperature (SST), with peaks being observed in summer (May) and troughs during the post-monsoon season (December and January) (Abhra et al. 2018). Wind-driven coastal upwelling and increased river run-off are noted during July and August which leads to elevated phytoplankton biomass (92 mg m^{-2}) if relatively low productivity ($0.3 \text{ gC m}^{-2} \text{ d}$; Gomes et al. 2000).

Gillnet fishing supports the livelihoods of most of the small-scale fishers living along the coast of Andhra Pradesh. These nets are made from polyamide monofilaments: fine nylon fibres (0.16–0.32 mm or 210D/1/3–210D/6/3) are woven into nets with a mesh of 20–40 mm, while thicker fibres (2 mm) are used to make nets with a mesh of 130–200 mm, catching small and large pelagic fishes, respectively. Locally, the gillnets have a variety of different names (Naram Vala, Chandua Vala, Pethulu Vala, Joga Vala, Siraga Vala, Attukula Vala, Kathiruvula Vala, Polusu Vala, Disco Vala) and they are operated from motorized as well as non-motorized fishing boat (Ramaraio et al. 2002).

Samples were collected from gillnets (mesh size: 26–50 mm) at depths of 5–50 m operated by motorized boats fortnightly from different locations along the coast of Andhra Pradesh, India between January 2017 and December 2018 (Fig. 1). Four to six hauls were performed at each location per sampling day. On capture, the contents were examined, weighed and sorted to separate jellyfish from other biota. Subsamples of randomly selected medusae were photographed and identified following Behera et al. (2020a; b), Morandini and Marques (2010) and Ras et al. (2020). Individuals of each species in each subsample were counted and weighed (wet weight) using an electronic balance with a precision of 0.01 g. Numbers of each species per haul were estimated by multiplying the subsample using a raising factor based on medusae subsample weight to total sample weight ratio, which was multiplied by the number of hauls to obtain total individual numbers of each species per sampling day. The bell diameter (BD, distance between opposite lappets) was measured (mm) using a measuring tape.

While a number of different jellyfish species were caught in the gillnets off Andhra Pradesh (*Chiropsoides buitendijki*, *Carybdea* sp., *Aequorea* sp., *Lyncorhiza malayensis*, *Cyanea nozaki*, *Rhopilema hispidum*, *Catostylus perezii*, *Cephea* sp., *Lobonemoides robustus*), catches were dominated by *Crambionella annandalei* and possibly several species of *Chrysaora*. Similar observations have been made by Behera et al. (2018). Owing to problems with the accurate identification of *Chrysaora* specimens (see Morandini and Marques 2010; Bayha et al. 2017; Ras et al. 2020), length and weight data (diameter) were pooled across individuals by month. Temporal changes in the mean size of both *Chrysaora* spp. and *C. annandalei* were tested using single-factor ANOVA. Length–weight relationships (LWRs) were calculated using the equation, $W = aL^b$ (Le Cren 1951), where W is wet weight in gram (g) and L is the bell diameter in centimetres (cm).

The monthly size frequency distributions of *Crambionella annandalei* and *Chrysaora* spp were analysed using the ELEFAN 1 module of FiSAT, software version 1.2.0. (Gayanilo et al. 1995), and the von Bertalanffy growth model (VBGM) (Beverton and Holt 1956) was used to estimate growth parameters as:

$$L_t = L_\infty \left(1 - e^{-k(t-t_0)} \right)$$

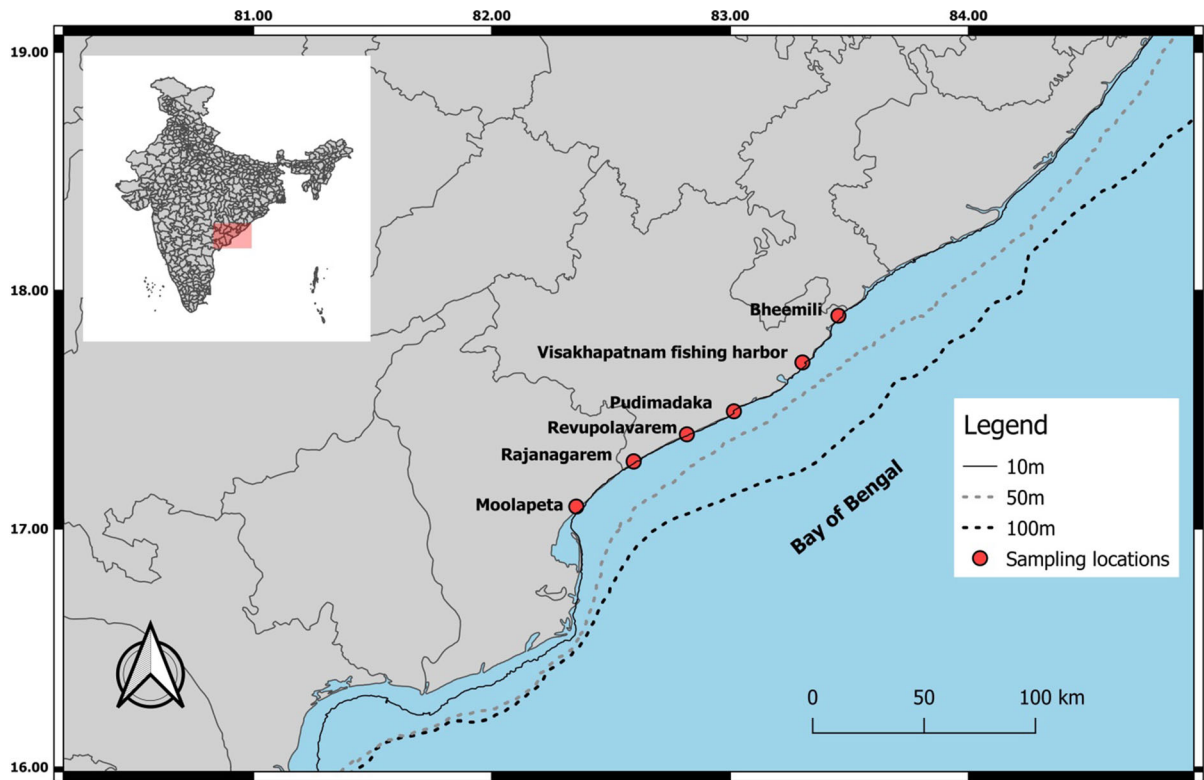


Fig. 1 Map depicting sampling sites of medusae along the coast of Andhra Pradesh (Red circles: sampling locations)

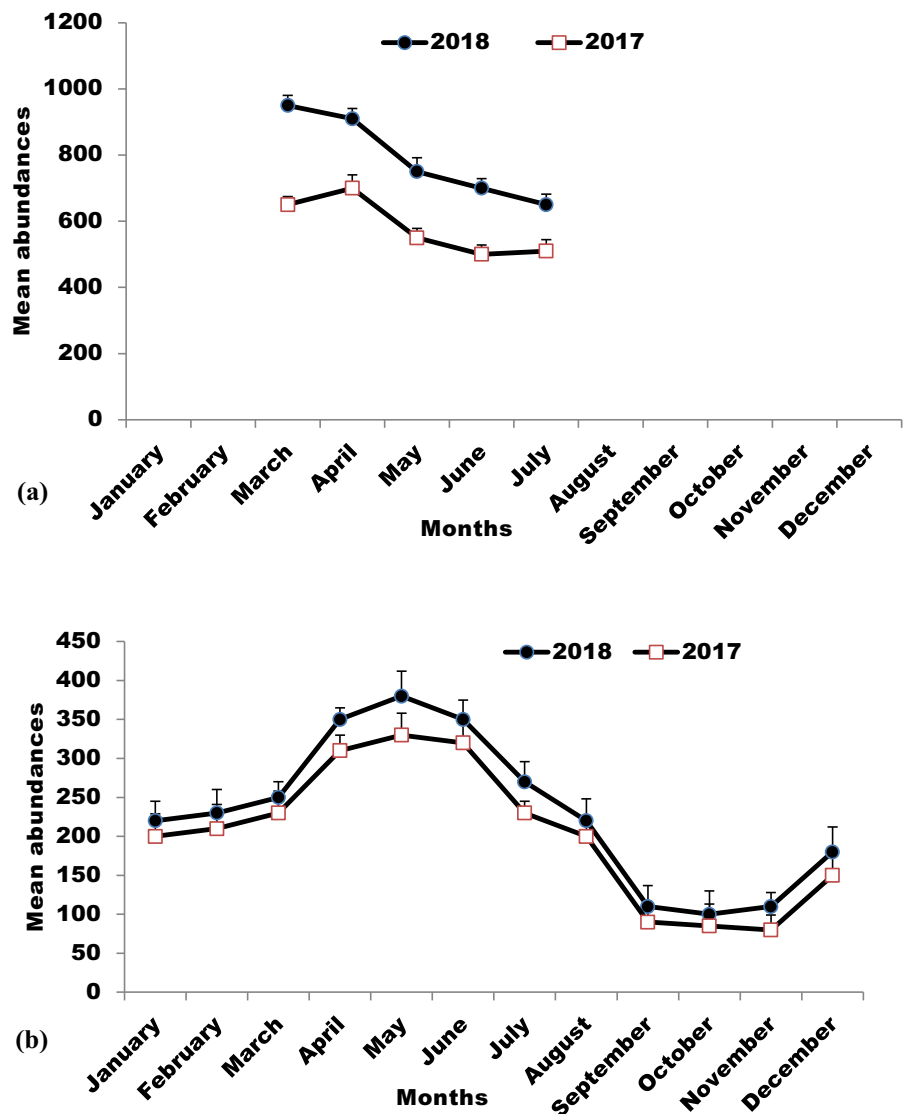
where L_t is the length at age t , L_∞ is the asymptotic length, i.e. the mean length the animal would reach if they were to grow indefinitely (and similar to the size of the largest specimens), K is the growth coefficient, t is the age at size L_t and t_0 is the age at which the organisms would have had zero size (initial condition parameters). Growth performance index (Phi) was estimated from the final estimates of L_∞ and K (Munro and Pauly 1983).

Results

Crambionella annandalei was found in coastal waters at depths between 10 and 45 m from March to July in both 2017 and 2018, and it was absent during monsoon and post-monsoon months (Fig. 2a). The highest mean abundances of *C. annandalei* caught per gillnet were observed in April (700 ± 6) and March (950 ± 4) for the year 2017 and 2018, respectively (Fig. 2a). The bell diameter of collected specimens ranged from 20 to 326 mm and wet weight from 13.6 to 1750 g (Table 1).

In 2017, small individuals (20–39 mm, 40–59 mm) were absent in the pre-monsoon months, whereas in summer, all size groups were present (Fig. 3a). During 2018, the occurrence of medusa of all sizes was observed in both summer and during the pre-monsoon months (Fig. 3b). During summer, animals between 60 and 79 mm were dominant (Fig. 3a, b); however, during pre-monsoon in 2017 and 2018, size classes of 300–319 mm and 260–279 mm, respectively, were abundant (Fig. 3a, b). In 2017, the mean bell diameter increased from 108 ± 4 mm in March to 214 ± 3 mm in July; corresponding values for 2018 were 115 ± 3 mm and 222 ± 2 mm, respectively (Fig. 4a). There were significant monthly differences ($F = 18.26$, $DF = 245$, $p < 0.01$) in mean bell diameter. The highest mean wet weight (677.54 ± 30 g) was observed in July and lowest (189.14 ± 20 g) in March in the year 2017, whereas equivalent values for 2018 were 225.53 ± 28 g and 643.53 ± 16 g, respectively (Fig. 5a). The relationship between length (diameter) and weight was described (overall) by the relationship $W = 0.20L^{2.570}$ ($R^2 \geq 0.993$, $p < 0.01$),

Fig. 2 Monthly changes (with errors bars—SE) in catches per gill net of **a** *C. annandalei* and **b** *Chrysaora* spp. for the year 2017 and 2018



though this differed between years: $W = 0.21L^{2.558}$ ($R^2 = 0.989$, 2017), $W = 0.19L^{2.585}$ ($R^2 = 0.998$, 2018) and were highly significant. The growth parameters estimated by VBGF of *C. annandalei* were: $L_{\infty} = 34.60$ cm, $K/\text{year} = 1.50$, $t_0 = -0.0255$, $t_{\max} = 1.97$, $\Phi = 3.25$. The growth of medusae varied from 1.16 to 0.29 mm day⁻¹: average growth rate, 0.64 mm day⁻¹ (Fig. 6a).

Although *Chrysaora* spp. occurred in coastal waters at depths of 5–50 m throughout the year (Fig. 2b), populations displayed a strong seasonality in abundance, being most common in May during both years: 330 ± 7 in 2017, 380 ± 9 in 2018. In the month of November (80 ± 6) and October (110 ± 8),

the lowest numbers per gillnet were observed in the years 2017 and 2018, respectively (Fig. 2b). Their bell diameter ranged from 55 to 289 mm and wet weight from 10 to 558 g (Table 1). Catches tended to be dominated by smaller animals in summer (100–119 mm in 2017, 80–99 mm in 2018; Fig. 3c, d), while in the pre-monsoon and post-monsoon months, individuals between 180 and 199 mm were most abundant (Fig. 3c, d). The maximum mean bell diameter in 2017 was 192 ± 1.67 mm (August), while in 2018 it was 193 ± 1.68 mm (July) (Fig. 4b); the minimum mean bell diameter was noted in April (118 ± 4.47 mm and 95 ± 4.47 mm, respectively) of both years (Fig. 4b). There was a significant change in

Table 1 Seasonal variations of bell diameter–weight relationship (BWR) parameters of *Crambionella annandalei* and *Chrysaora* spp. from Andhra Pradesh waters, India: *N* (number of samples used only for measurements), *a* intercept of relationship, *b* slope of relationship, CI confidence interval and *r*² coefficient of determination

Species	<i>N</i>	Length range (mm)	Mean ± SE	Weight range (g)	Mean ± SE	<i>a</i>	95% CI <i>a</i>	<i>b</i>	95% CI <i>b</i>	<i>r</i> ²
<i>Crambionella annandalei</i>	Overall	246 20–326	184.91 ± 8.91	13.6–1750	579.94 ± 6.06	0.2012	0.192–0.209	2.570	2.555–2.585	0.993
	Summer	145 20–326	165.32 ± 10.18	18–1750	503.96 ± 1.98	0.216	0.191–0.249	2.547	2.498–2.596	0.9796
	Pre-monsoon	101 65–323	217.31 ± 17.92	13.6–1680	705.66 ± 9.27	0.182	0.1827–0.1859	2.601	2.601–2.651	0.989
<i>Chrysaora</i> spp.	Overall	340 55–289	172.95 ± 3.65	10–558	173.71 ± 1.33	0.105	0.0861–0.1287	2.661	2.590–2.732	0.937
	Summer	90 55–289	159.06 ± 5.45	14–438	130.76 ± 7.59	0.163	0.152–0.168	2.729	2.576–2.884	0.937
	Pre-monsoon	76 58–225	189.78 ± 10.53	110–325	168.49 ± 8.31	0.084	0.0762–0.0942	2.34	2.301–2.412	0.896
	Monsoon	78 57–255	186.79 ± 5.07	99–325	185.29 ± 4.51	0.0643	0.0380–0.1081	2.351	2.238–3.000	0.848
	Post-monsoon	96 57–289	195.35 ± 2.68	10–558	207.68 ± 11.84	0.216	0.209–0.301	2.981	2.929–3.291	0.948

Lengths are represented as bell diameter in mm: length range, mean length with mean ± SE and weights are wet weight range in g with mean weights with ± SE

bell diameter with time ($F = 15.88$, $DF = 339$, $p < 0.01$).

The lowest mean wet weights observed in April were 100.25 ± 5 g and 115.35 ± 7 g for the year 2017 and 2018, respectively. The highest mean wet weight observed was 238.92 ± 11 g in December and 240.32 ± 13 g in November for 2017 and 2018, respectively (Fig. 5b). The relationship between length (diameter) and weight was described (overall) by the relationship $W = 0.1053L^{2.661}$ ($R^2 \geq 0.937$, $p < 0.01$), though this differed between years: $W = 0.112L^{2.636}$ ($R^2 = 0.9365$, 2017), $W = 0.098L^{2.687}$ ($R^2 = 0.938$, 2018). The growth parameters estimated by VBGF of *Chrysaora* spp. were: $L_{\infty} = 30.40$ cm, $K/\text{year} = 2.80$, $t_0 = -0.0002$, $t_{\max} = 1.07$, $\Phi = 3.41$. The growth of medusae varied from 1.63 to 0.16 mm day⁻¹: average growth rate, 0.66 mm day⁻¹ (Fig. 6b). The relationship between bell diameter and wet weight was highly significant during both the observed seasons for *C. annandalei* ($R^2 \geq 0.979$, $p < 0.01$) and in all observed seasons for *Chrysaora* spp. ($R^2 \geq 0.848$, $p < 0.01$) (Table 1).

Discussion

The data presented here reveal that *Crambionella annandalei* was only caught during summer and in the first two months of the pre-monsoon period: it was completely absent in the landings from August onwards. An earlier study from the same region by Behera et al. (2020a, b) noted the occurrence of highest blooms of this species during summer, which gradually dissipated after the arrival of south-west monsoon due to heavy rainfall. Although the exact reasons for the pronounced seasonality that is observed for this species is unknown, it is likely to be linked to both regional and local circulation patterns, and their interaction with the species intrinsic life history (e.g. Pitt 2000; Purcell 2007), about which nothing is known. Strobilation probably occurs some months prior to the first appearance of small medusae in the gill nets, which means that it could be linked to factors associated with the monsoon and post-monsoon period. Kripa et al. (2018) have reported that spawning and recruitment of the Indian oil sardine (*Sardinella longiceps*) depends on the onset of the monsoon along the south-west coast of India, while the

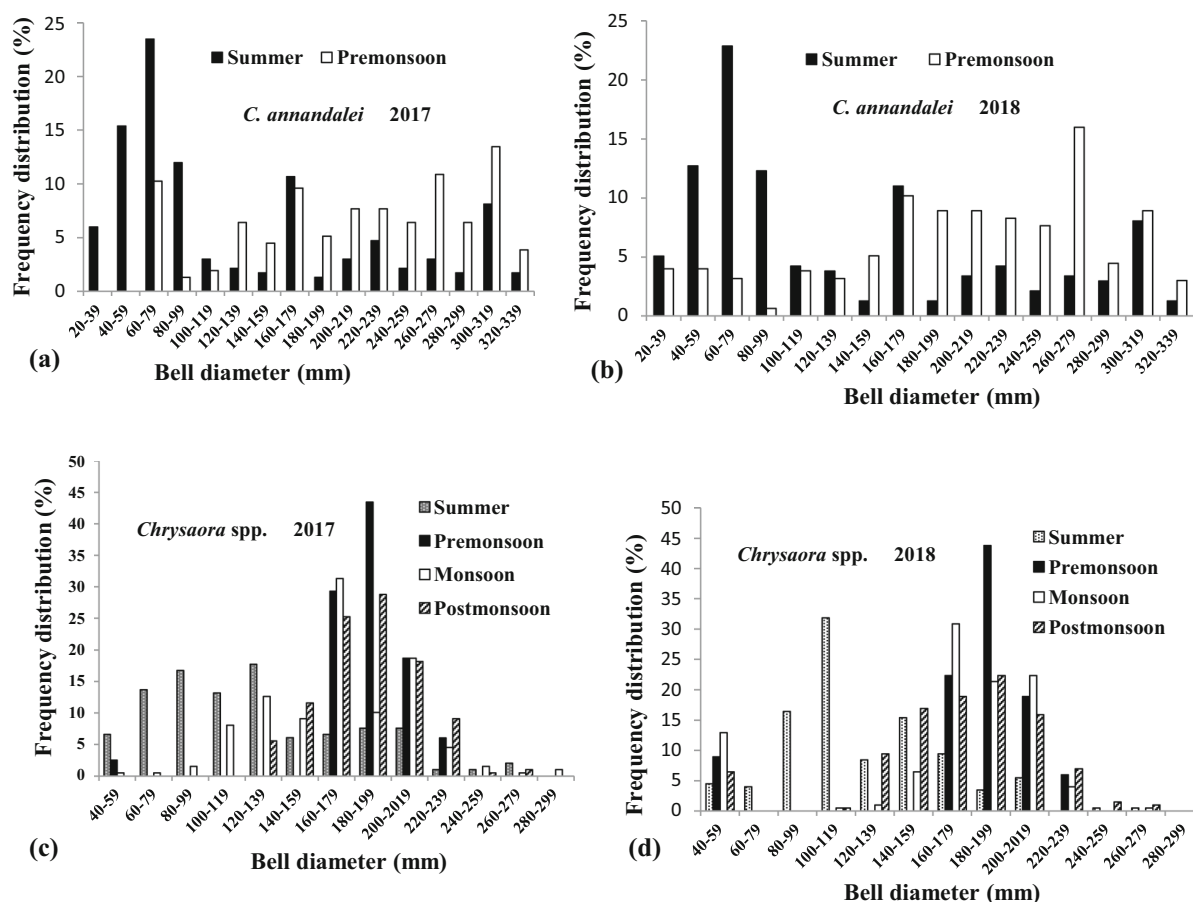


Fig. 3 Seasonal size distribution of *C. annandalei* (a 2017, b 2018) and *Chrysaora* spp. (c 2017, d 2018) for the year 2017 and 2018

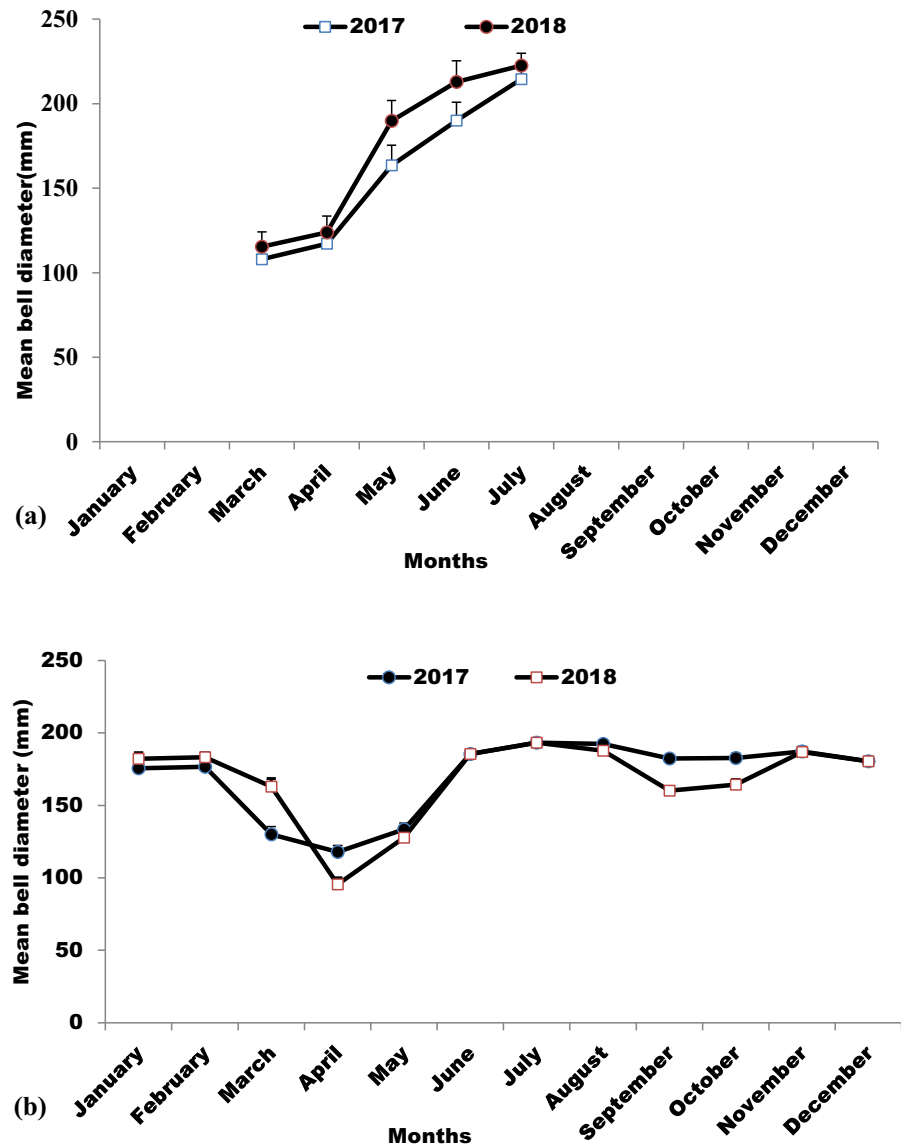
intensity of the monsoon influences the maturity, spawning and recruitment of Hilsha shad (*Tenualosa ilisha*) in the northern Bay of Bengal (Giri et al. 2019). During the summer monsoon, rainfall decreases surface water salinity in the region, and salinity is known to influence the strobilation of some scyphozoans (*Chrysaora pacifica*, *Nemopilema nomurai* and *Rhopilema esculentum*) in the East Asian Marginal Seas (Takao and Uye 2018). Adult *Catostylus mosaicus* cannot survive extremely low salinities (Loveridge et al. 2021), though Pitt and Kingsford (2003) revealed that there is no relationship between its recruitment and rainfall off SE Australia. That said, these latter authors did note that recruitment of *C. mosaicus* was sometimes observed following periods of heavy rainfall and they proposed that physical or biological changes associated with run-off may promote the recruitment of medusae (Pitt and Kingsford 2003). It should be remembered that *Crambionella*

and *Catostylus* are both Catostylidae, and that both genera enjoy a coastal distribution, being frequently found in brackish waters (Jarms and Morandini 2019).

Although salinity changes may trigger strobilation of *C. annandalei*, it is temperature that is typically associated with the release of ephyrae by scyphistomae (Lucas et al. 2012), and lowest temperatures in the western Bay of Bengal are noted in the postmonsoon. The species grows progressively from early summer (March) to reach a maximum size by July, before largely disappearing from the coast. It is similar, in this regard, to many other species of temperate Scyphozoa, whose population decline often following reproduction, senescence and dissipation (Pitt et al. 2014; Billet et al. 2006).

The growth rates of *C. annandalei* ($0.29\text{--}1.16\text{ mm day}^{-1}$) are consistent with those reported for *Nemopilema nomurai* (0.92) by Kawahara et al. (2006), while the estimated growth coefficient

Fig. 4 Monthly changes of mean bell diameter (with errors bars—SE) of *C. annandalei* **a** and *Chrysaora* spp. **b** landed by gill nets for the year 2017 and 2018

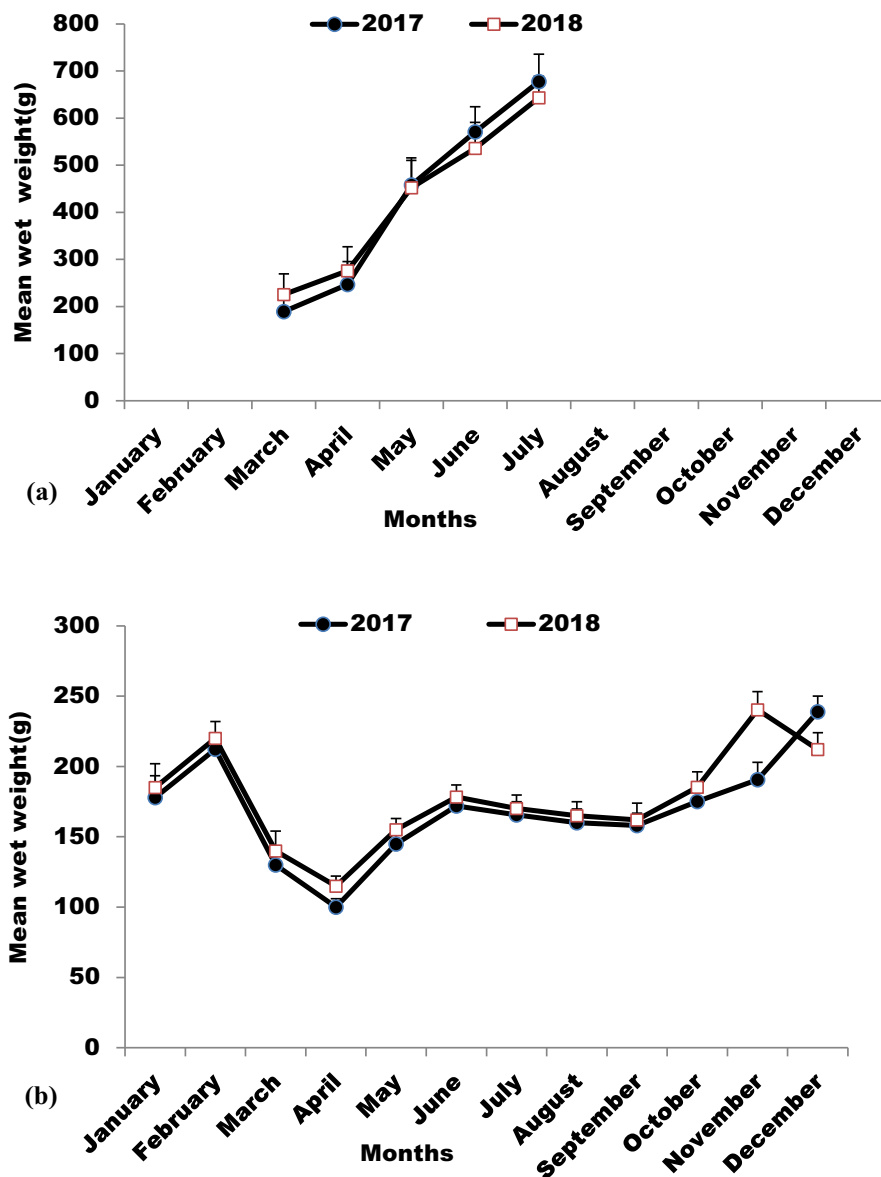


(K/year : 1.50) is similar to that of *Catostylus mosaicus* (1.50) reported by both Pitt and Kingsford (2003) and Palomares and Pauly (2009). Interestingly, however, it is lower than that noted for *Rhizostoma pulmo* from the coastal lagoon of Bages Sigeon, France (4.47; Leoni et al. 2021) or from Mar Menor lagoon, Spain (3.00–3.44; Fernandez-Alias et al. 2020). It should be noted, however, that neither *Catostylus* nor *Crambionella* get as large as *Rhizostoma pulmo* (Jarms and Morandini 2019) and that the coastal lagoons in question are shallow, have restricted access to the coast and are subject to anthropogenic enrichment. As a consequence, differences in growth rate are likely to

reflect local factors like food availability or temperature, both of which can influence growth (Fernandez-Alias et al. 2020).

Although *Chrysaora* spp is present throughout the year in the western Bay of Bengal, it appears to display pronounced seasonality in abundance that must be linked in some way to recruitment during summer (when individual sizes are lowest). That said, the simultaneous presence of a wide range of size classes for much of the year could be interpreted to reflect a prolonged release of ephyrae. However, we should be cautious in our interpretation of the data thus given that *Chrysaora* spp. may comprise more than one

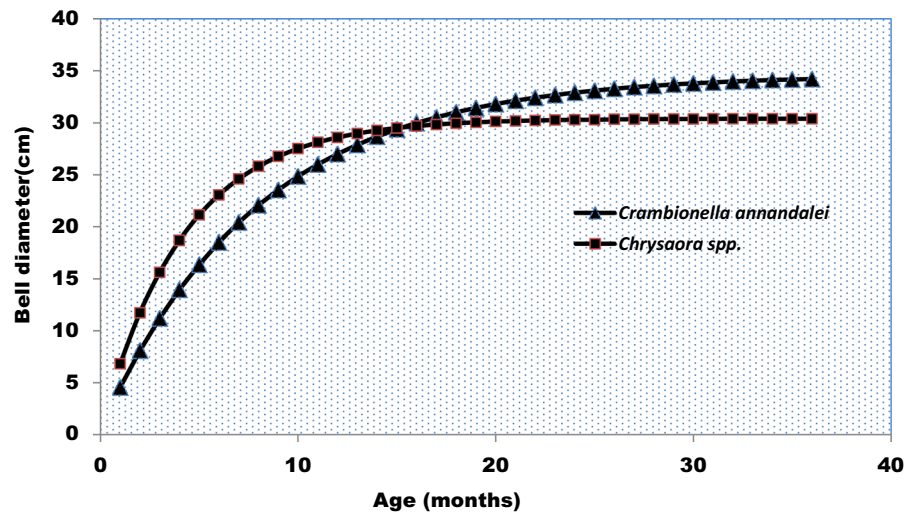
Fig. 5 Monthly variation of mean wet weight (g) (with errors bars—SE) of **a** *C. annandalei* and **b** *Chrysaora* spp. landed by gill net for the year 2017 and 2018



species, each of which could have its own, species-specific strobilation periods and there is no reason to suppose that these would be synchronized. It is not uncommon for a population to comprise a wide array of size classes over the few months of its temporal persistence (e.g. Houghton et al. 2007), but the persistent presence of jellyfish of a wide variety of size classes throughout the year is unusual. Interestingly, this observation has also been noted for *Chrysaora fulgida* off Namibia (Skrypzeck and Gibbons 2021). In the latter case, strobilation may vary latitudinally and can be spread across a five-month

window, but it is likely that the dynamic mixing of medusa into favourable and unfavourable water (from an individual growth perspective) may also contribute to the mix of size classes (Gibbons et al. in press). The growth rates of *Chrysaora* spp. reported here ($K/\text{year} = 2.80$) are relatively high, but fall within the range reported by Palomares and Pauly (2009) for *Chrysaora fulgida* (= *hysoscella*) off Namibia, and are not too different to those of *Aurelia* sp. from across the world ($0.45\text{--}3.83 \text{ year}^{-1}$) or of *Cyanea* sp. (2.30 year^{-1}) from the Niantic River estuary, USA (Palomares and Pauly 2009).

Fig. 6 Fitted growth curve of VBGF for **a** *C. annandalei* and **b** *Chrysaora* spp.



In the absence of concurrently collected data about the environment (temperature, salinity, plankton etc.), attempts to explain the patterns observed for either *C. annandalei* or *Chrysaora* spp. are effectively speculative. However, the fact that similar patterns in abundance and growth were observed in both years for both taxa, provides strong evidence of an inter-annual cohesion in the ecology of both populations and individuals and stresses the likely influence of monsoons. The differences between the taxa are intriguing, and although they may reflect differences in the distribution of polyps and/or the interactions between ephyrae and young medusae and prevailing oceanography, they deserve further scrutiny. Not least because one of the species recorded here represents an exploitable resource (*C. annandalei*), while the other does not. Regardless, we believe that the data presented here provide a useful baseline for future work in a poorly known region of the world, in addition to generating rare field-based values of growth.

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Authors' contribution PRB had contributed to conceptualization, methodology, data analysis, interpretation, and original draft preparation. JMA was involved in collections of field data. SG took part in review and editing, and funding acquisition. RS participated in supervision and correction of manuscript.

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Data availability Here we provided image (JPEG) of studied species as supplementary materials.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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