



POPULATION STRUCTURE AND BIOLOGICAL CHARACTERISTICS OF
SIRIELLA GRACILIS (MYSIDA) FROM THE EXCLUSIVE
ECONOMIC ZONE OF INDIA

BY

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ABSTRACT

The abundance, population structure and other biological aspects of *Siriella gracilis* were evaluated based on zooplankton collections in the Exclusive Economic Zone of India (The Arabian Sea, Bay of Bengal and the Andaman Sea) as part of a multidisciplinary project Marine Research on Living Resources Assessment programme. *S. gracilis* exhibit a wide range of variations in its population dynamics in the study area and their population density over the entire study area ranged from 0 to 29 250 ind. per 1000 m³. The highest abundance was in the Arabian Sea (70.1% of the total sampled population) followed by the Andaman Sea (22.7%) and the Bay of Bengal (5.2%). Temperature and salinity appeared to have little influence on the general distribution of *S. gracilis* in the study area. The number of egg/embryo carried by females exhibited a positive correlation with female size and the maximum brood size was 11. The egg diameter ranged from 0.32 to 0.46 mm and was independent of female size. Even though no significant body length difference was found between spent female and breeding females ($p > 0.05$), wet mass of spent females and breeding females was significantly different ($p < 0.0001$).

ABSTRACT

The abundance, population structure and other biological aspects of *Siriella gracilis* were evaluated based on zooplankton collections in the Exclusive Economic Zone of India (The Arabian Sea, Bay of Bengal and the Andaman Sea) as part of a multidisciplinary project Marine Research on Living Resources Assessment programme. *S. gracilis* exhibit a wide range of variations in its population dynamics in the study area and their population density over the entire study area ranged from 0 to 29 250 ind. per 1000 m³. The highest abundance was in the Arabian Sea (70.1% of the total sampled population) followed by the Andaman Sea (22.7%) and the Bay of Bengal (5.2%). Temperature and salinity appeared to have little influence on the general distribution of *S. gracilis* in the study area. The number of egg/embryo carried by females exhibited a positive correlation with female size and the maximum brood size was 11. The egg diameter ranged from 0.32 to 0.46 mm and was independent of female size. Even though no significant body length difference was found between spent female and breeding females ($p > 0.05$), wet mass of spent females and breeding females was significantly different ($p < 0.0001$).

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INTRODUCTION

Mysids are one of the major crustacean components of macro-zooplankton, occupying a wide variety of aquatic environments. In general, mysids are omnivores, feeding on detritus, zooplankton and phytoplankton, and thus form a link between microbial producers and secondary consumers (Webb, 1973). The significance of mysids in the ecosystem as energy converter at different trophic levels has been greatly underestimated. Mysids are a substantial dietary component of many invertebrates, such as cuttlefish, cephalopods and decapods shrimps (Aronson, 1989; Hanamura & Matsuoka, 2003; Huang, 2004), and are also prey for many larger predators, such as various fishes (Thiel, 1996; Hostens & Mees, 1999; Viharluto, 2001), birds and seals (Mauchline, 1980), thus playing a part in energy transfer to higher trophic levels. Many ecological and biological studies have been conducted on coastal mysids (e.g. Greenwood et al., 1985; Wooldridge, 1986; Mees et al., 1994; Vinas et al., 2005; Yamada et al., 2007; Biju & Panampunnayil, 2009, 2010; Biju et al., 2010; Sudo et al., 2011). Mysids are rich and diverse in the exclusive economic zone of India, and their taxonomy is reasonably known (Biju & Panampunnayil, 2011). However, a substantial gap exists on information regarding the ecology and biology of mysids in this area. A great understanding of the abundance and biology of mysids is necessary to implement the knowledge about the ecological role of these organisms in oceanic water. *Siriella gracilis* Dana, 1852 is one of the most abundant species and has been recorded from tropical and subtropical waters of the Indian and Pacific Oceans (Pillai, 1973). At present, there is no available information on the biology and ecology of this species. Considering the ecological importance of mysids, the present study was initiated to elucidate the population structure, abundance and biological characteristic of *Siriella gracilis* collected from the exclusive economic zone (EEZ) of India.

MATERIALS AND METHODS

Study area

The Exclusive Economic Zone (EEZ) of India is the northern part of Indian Ocean and spans an area of 2.02 million km². This zone includes the Arabian Sea, Bay of Bengal and the Andaman Sea. This area has unique physical settings and dynamic biochemistry, with intense seasonality due to the influence of the monsoon, coastal upwelling and presence of an oxygen minimum zone. The Bay of Bengal and the Andaman Sea are very complex basins, in which the interplay of frequent cyclonic depression, high precipitation, high sea surface temperature, low surface salinity and density stratification occurs (Pankajakshan et al., 2002;

Vinayachandran et al., 2002; Jayu & Prasannakumar, 2006). The Bay of Bengal and the Andaman Sea are traditionally considered to having poorer biological productivity compared to the Arabian Sea. They receive large quantities of fresh water from Hinterland Rivers, making their upper layer less saline. Although the riverine flux may bring nutrients, it is thought to be lost to the deep waters of its narrow shelf (Qasim, 1977; Senguptha et al., 1977). Prasannakumar et al. (2002) reported that the open ocean upwelling, wind-driven mixing and lateral advection makes the open ocean waters of the central Arabian Sea more productive.

Sampling procedure and data analysis

The materials for the present study are based on samples collected in the Arabian Sea, Bay of Bengal and the Andaman Sea (fig. 1) during different cruises of the research vessel, FORV "Sagar Sampada" as part of a multidisciplinary project entitled "Marine Research on Living Resources (MRLR) Assessment Programme" funded by the Ministry of Earth Science, Government of India, from 2002-2006. In this study, we used different seasonal data collected from the same stations during different years. Seasons are divided into the inter-monsoon (IM, March-May), summer or south-west monsoon (SWM, June-September), and the winter or north-east monsoon (NEM, October-February). Sampling locations were categorised into inshore (depth < 200 m) and offshore (depth > 200 m) areas. The collection

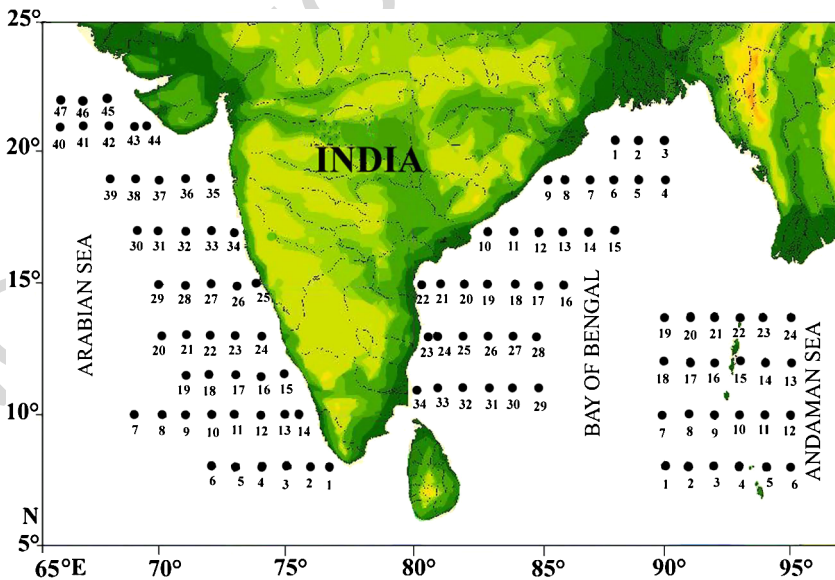


Fig. 1. Location of sampling stations in the EEZ of India. This figure is published in colour in the online edition of this journal, which can be accessed via <http://booksandjournals.brillonline.com/content/15685403>.

TABLE I
Station details and average population density (ind. per 1000 m³) of *Siriella gracilis* in the EEZ of India during different seasons

Area	Latitude (°N)	Longitude (°E)	Season and collection date	Density of <i>Siriella gracilis</i> (percentage composition)
Arabian Sea	8-22° (transects: 8°, 10°, 11°30', 13°, 15°, 17°, 19°, 21° and 22°)	66-77	IMS, 19 March-18 April 2004	2034 ± 4077 (62.9)
			SWM, 27 June-24 July 2005	268 ± 556 (8.3)
			NEM, 29 November-28 December 2006	930 ± 4515 (28.8)
			IMS, 21 March-17 April 2005	41 ± 102 (17.1)
Bay of Bengal	11-20°30' (transects: 11°, 13°, 15°, 17°, 19° and 20°30')	80-90	SWM, 10 July-4 August 2003	2 ± 5 (0.8)
			NEM, 11 November-6 December 2002	197 ± 418 (82.1)
			IMS, 28 March-16 April 2003	393 ± 1319 (38.6)
Andaman Sea	8-13°45' (transects: 8°, 10°, 12° and 13°45')	90-95	SWM, 10 June-30 July 2004	473 ± 1093 (46.5)
			NEM, 23 December 2003-14 January 2004	152 ± 419 (14.9)

IMS, inter-monsoon; SWM, south-west monsoon; NEM, north-east monsoon.

contains both day and night samplings. Details of the sampling areas are given in table I.

Surface mesozooplankton samples were collected from 105 stations using a Bongo net (BN, Hydrobios, mesh size 0.2 mm; filtering cone length 250 cm; ring diameter 60 cm) fitted with a calibrated flow meter. The net was hauled for 10 min at the surface at a ship speed of 2 knots. Plankton samples were fixed in 5% buffered formaldehyde-seawater solution and preserved prior to subsequent analysis. The abundance of *S. gracilis* was calculated based on the volume of water filtered through the net, filtering rate was calculated by adopting the calibration formula provided with the flowmeter. A Sea-Bird electronic CTD (SBE 911 Plus, U.S.A.) was used to obtain the surface temperature and salinity values. Salinity values were corrected using values obtained from the Autosal (Guildline Model 8400A) and the values are represented in psu (practical salinity unit).

In the laboratory, mysids were sorted from other zooplankton. All *S. gracilis* were counted and subjected to detailed analysis. Total body length (distance

1 between the anterior margin of the carapace and the apex of the telson, excluding
2 apical spines) was measured using a binocular microscope fitted with a micrometer
3 eyepiece. If the sample contained less than 15 individuals, all the mysids were
4 measured for body length, when exceeding this number, up to 15 specimens
5 were measured. After mysids were sexed and measured, they were categorised
6 into six developmental stages based on the following criteria as described by
7 Biju & Panampunnayil (2010): juveniles (J), immature males (IM), mature males
8 (MM), immature females (IF), spent females (SF) and ovigerous females (carrying
9 egg/embryo) or breeding females (BF). Ovigerous females were classified into
10 three categories corresponding to the developmental stages of eggs/embryos
11 carried in their brood pouches, i.e., females with spherical egg-like embryos
12 (stage I) (referred to as “egg” in this paper), females with eyeless embryos
13 (stage II) and females with eyed embryos (stage III). The developmental stages
14 of eggs/embryos were classified according to Hanamura et al. (2008): spherical
15 egg-like embryos (E_1); eyeless embryos (E_2); and eyed embryos (E_3). The oblong
16 or polygonal egg diameter was measured along the longest axis to the nearest
17 0.01 mm under a dissecting microscope. In the same way stage E_2 and E_3 embryos
18 were measured along the distance between the anterior ends of the eye (ventral
19 side) to the posterior end of the uropod when straightened. For wet mass (WM)
20 measurement, preserved specimens were rinsed briefly in distilled water and
21 blotted on a filter paper, then weighed with a balance (Mettler Toledo, JB 1603-
22 C/FACT).

23 Multiple regression analysis (SPSS-10) was employed to assess the predictabil-
24 ity of population density on the physico-chemical variables.

25 The model used for the purpose was:

$$Y = b_0 + b_1x_1 + b_2x_2,$$

26 where Y is population density, x_1 sea surface salinity and x_2 sea surface tempera-
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32 RESULTS

33 Hydrography

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35 Surface temperature and salinity of the Arabian Sea, Bay of Bengal and
36 the Andaman Sea are given in tables II-IV. The surface water temperature in
37 the Arabian Sea varied from 26.6 to 31.7°C and maximum seasonal average
38 temperature was during SWM ($30.6 \pm 0.5^\circ\text{C}$) followed by NEM ($28.7 \pm 0.8^\circ\text{C}$)
39 and IMS ($29.0 \pm 0.7^\circ\text{C}$). In the Bay of Bengal surface temperature ranges from
40 25.8 to 30.0°C. During SWM and NEM, the Bay of Bengal showed similar average

TABLE II
Population density (ind. per 1000 m³) of *Siriella gracilis* and environmental parameters in the Arabian Sea during different seasons

Station no.	Latitude (°N)	Longitude (°E)	IMS (2004)			SWM (2005)			NEM (2006)		
			<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity
1	8	76°30'	4923*	29.8	34.2	-*	29.9	35.0	-	29.3	35.2
2	8	76	2219*	29.7	34.2	-	30.2	35.2	-	29.3	34.9
3	8	75	-	30.2	34.4	162	30.7	35.1	-	29.1	35.6
4	8	74	16375*	30.0	34.3	-*	30.3	34.2	-*	29.0	36.0
5	8	73	-	29.9	34.2	740*	30.5	34.7	-*	28.9	36.6
6	8	72	12072*	30.1	34.3	1124*	30.4	34.7	-	28.2	36.3
7	10	69	N	N	N	99	28.7	36.9	-	29.3	35.2
8	10	70	3480*	29.8	34.7	-	30.7	35.4	-*	29.3	34.9
9	10	71	-	29.3	35.3	1515*	30.8	35.1	-*	29.3	34.9
10	10	72	-	29.8	34.8	-	30.5	34.8	-	29.1	35.6
11	10	73	-	29.9	34.8	-	30.5	34.9	-	29.0	36.0
12	10	74	16949*	30.2	34.0	2446*	30.4	35.1	-	28.9	36.6
13	10	75	6331*	30.3	33.2	-	30.1	35.1	-	28.2	36.3
14	10	75°30'	-*	30.4	33.6	-	30.2	35.4	-*	28.4	36.3
15	11°30'	75	N	N	N	248	30.1	35.7	-*	29.3	35.2
16	11°30'	74	-	30.3	34.0	754*	30.4	35.4	-*	29.3	34.9
17	11°30'	73	N	N	N	-*	30.3	35.7	-	29.1	35.6
18	11°30'	72	800*	30.1	34.7	1608*	30.3	35.4	-	29.0	36.0
19	11°30'	71	-*	29.6	35.3	-	30.1	35.8	-*	28.9	36.6
20	13	70	1397	29.1	35.4	-*	30.5	35.8	-*	28.2	36.3
21	13	71	6751	30.0	34.6	634*	30.5	35.5	-*	28.4	36.3
22	13	72	-	30.3	34.2	-	30.3	35.9	N	N	N
23	13	73	2500*	30.2	34.1	1558*	30.0	35.7	-*	29.3	35.2
24	13	74	662*	30.1	34.0	-*	30.0	35.9	-*	29.3	34.9
25	15	74	2876	30.2	35.7	-	30.4	36.2	-*	29.3	35.2
26	15	73	-*	29.9	35.3	-	30.8	36.2	-	29.3	34.9

POPULATION STRUCTURE AND BIOLOGY OF *SIRIELLA GRACILIS*

TABLE II
(Continued)

Station no.	Latitude (°N)	Longitude (°E)	IMS (2004)			SWM (2005)			NEM (2006)		
			<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity
27	15	72	-	29.7	35.0	-	30.7	35.9	-*	29.1	35.6
28	15	71	2924*	29.4	35.0	-	30.7	35.8	5670	29.0	36.0
29	15	70	-*	29.0	35.6	N	N	N	-*	28.9	36.6
30	17	69	-	29.1	36.0	-*	31.7	36.9	-	28.2	36.3
31	17	70	4591	29.7	35.1	-	31.4	36.8	-*	28.4	36.3
32	17	71	-	29.9	35.0	621	31.2	36.5	6933*	29.2	36.3
33	17	72	-*	29.5	35.1	-	30.9	36.3	-*	28.8	35.5
34	17	73	4656*	29.4	35.2	-*	30.9	35.7	-*	28.8	34.7
35	19	72	-	28.4	35.0	-	30.6	36.4	-	29.4	36.1
36	19	71	-	28.9	35.9	-*	30.6	36.3	-	29.2	36.5
37	19	70	-	28.9	35.0	-*	31.1	36.8	-*	27.6	35.7
38	19	69	-*	28.5	35.1	550*	31.4	37.0	-	27.9	35.8
39	19	68	-*	28.4	35.2	-*	31.1	36.9	-	27.3	36.6
40	21	66	-*	28.9	35.9	-	31.5	37.0	29250*	26.6	36.8
41	21	67	-	28.5	35.1	-	31.1	36.8	-	28.3	35.8
42	21	68	-	28.4	35.0	-	30.5	36.3	-*	26.7	36.5
43	21	69	-	28.9	36.0	-*	31.4	37.1	-	29.0	36.5
44	21	69°45'	-*	28.5	35.1	-*	31.1	36.8	-	26.6	35.8
45	22	68	-	28.9	35.0	N	N	N	N	N	N
46	22	67	-	28.5	35.1	-	31.4	37.0	-*	29.2	36.5
47	22	66	-	28.9	35.0	-	30.5	36.4	-*	27.6	35.7

N, no collection; -, absent; *, night collections.

TABLE III
Population density (ind. per 1000 m³) of *Sirriella gracilis* and environmental parameters in the Bay of Bengal during different seasons

Station no.	Latitude (°N)	Longitude (°E)	IMS (2005)			SWM (2003)			NEM (2002)		
			<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity
1	20°30'	88	-	26.1	30.6	N	N	14*	27.2	30.5	
2	20°30'	89	-	26.6	29.7	-	29.8	-	28.2	32.4	
3	20°30'	90	10*	25.8	30.0	-	29.6	-	28.3	31.9	
4	19	90	-	26.4	30.6	-*	28.7	-	27.9	31.1	
5	19	89	-	26.4	30.9	-	28.5	12*	28.0	32.1	
6	19	88	-*	27.0	31.3	-	28.6	-	28.0	32.1	
7	19	87	-*	27.1	32.5	-	28.7	7	28.2	30.3	
8	19	86	26	27.7	32.8	-*	28.7	-	27.5	28.1	
9	19	85°30'	24*	27.3	32.4	-*	28.4	-*	27.9	24.1	
10	17	83	136*	27.7	32.0	-*	29.0	-*	28.1	30.3	
11	17	84	242*	28.0	32.9	-	26.0	-*	28.1	29.6	
12	17	85	-	27.3	32.2	-*	28.5	-	27.7	29.0	
13	17	86	-	27.4	31.1	-*	28.2	-*	27.9	31.4	
14	17	87	113*	27.6	32.2	18*	28.8	-	28.9	33.3	
15	17	88	-*	27.4	31.3	-*	28.5	N	N	N	
16	15	86	8*	28.6	33.3	-	28.9	123*	29.5	33.4	
17	15	85	119*	27.9	33.1	-	28.8	-	29.3	32.2	
18	15	84	523*	28.3	32.1	-	28.7	-	29.4	33.3	
19	15	83	19	28.6	33.8	-	28.8	-*	27.0	31.9	

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POPULATION STRUCTURE AND BIOLOGY OF *SIRIELLA GRACILIS*

TABLE III
(Continued)

Station no.	Latitude (°N)	Longitude (°E)	IMS (2005)			SWM (2003)			NEM (2002)		
			<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity
20	15	82	-*	28.6	33.2	-	28.9	33.4	38*	26.8	32.1
21	15	81	-*	27.9	33.3	15*	28.5	33.9	-	28.9	34.4
22	15	85°30'	-*	28.2	33.7	17	27.0	34.3	1005	29.3	32.2
23	13	85°45'	-*	28.7	33.9	-	27.9	34.2	-	29.4	33.9
24	13	81	-*	28.3	33.4	-*	29.1	33.5	1013*	29.7	33.8
25	13	82	-	28.1	33.1	-	29.0	33.3	-	29.4	33.7
26	13	83	35	28.4	33.3	-*	28.8	33.7	963*	29.5	33.7
27	13	84	-*	28.5	34.0	-	28.9	33.9	-*	29.3	33.7
28	13	85	N	N	N	-*	28.9	33.4	-	29.3	34.0
29	11	85	-*	28.3	33.3	N	N	N	N	N	N
30	11	84	-*	28.4	33.2	-*	28.9	33.4	1464	30.0	33.5
31	11	83	-*	28.6	33.7	-	29.1	33.2	250*	29.8	33.9
32	11	82	-	28.7	33.7	-	29.2	33.8	-	28.4	33.5
33	11	81	33	29.1	33.8	-	29.5	33.9	1114*	29.5	33.7
34	11	80	52*	29.0	33.6	-	27.4	34.4	-	28.9	33.9

N, no collection; -, absent; *, night collections.

TABLE IV
Population density (ind. per 1000 m³) of *Siriella gracilis* and environmental parameters in the Andaman Sea during different seasons

Station no.	Latitude (°N)	Longitude (°E)	IMS (2003)			SWM (2004)			NEM (2004)		
			<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity	<i>S. gracilis</i> density	Temperature (°C)	Salinity
1	8	90	6085*	30.0	34.3	-*	28.9	32.2	-	28.6	33.4
2	8	91	-*	30.0	33.9	-	28.9	32.9	-*	28.5	33.8
3	8	92	-	29.7	34.0	-*	28.6	32.6	-	28.6	33.4
4	8	93	-*	30.2	33.6	-*	28.3	32.3	-*	28.2	33.6
5	8	94	-	29.8	33.0	-	28.9	32.2	-	28.5	33.0
6	8	95	-	30.0	32.8	370*	28.9	32.9	-*	28.4	32.2
7	10	95	N	N	N	810*	28.6	32.6	1850*	28.2	32.5
8	10	94	-	29.5	32.0	-*	28.4	32.9	-	28.3	32.5
9	10	93	-	29.8	33.6	-	28.6	32.6	-*	28.2	32.7
10	10	92	996*	29.6	33.0	76	28.8	32.6	-	28.1	33.2
11	10	91	-*	30.1	32.6	-	28.7	32.5	66*	28.2	32.8
12	10	90	1950*	29.4	33.4	-*	28.7	32.5	-	28.5	33.7
13	12	90	-	30.1	32.6	-*	27.2	33.2	-*	27.8	33.1
14	12	91	-	30.8	32.4	-	28.7	32.5	-	28.0	33.6
15	12	92	-	29.5	32.1	-	27.2	33.2	-*	28.1	33.1
16	12	93	-*	29.7	32.9	1960*	28.9	32.5	-	27.7	32.9
17	12	94	-*	29.7	32.9	2474*	28.5	32.4	181	27.8	32.8
18	12	95	-*	28.9	32.4	N	N	N	896*	28.1	32.7
19	13°45'	95	-	29.7	32.9	4510*	28.6	32.5	92*	28.2	29.6
20	13°45'	94	-	29.6	32.8	-	28.5	32.7	-	28.6	30.9
21	13°45'	93	-	28.9	32.5	75	28.9	32.2	-	27.8	32.3
22	13°45'	92	-*	29.0	32.4	556*	29.4	31.9	-*	27.8	32.9
23	13°45'	91	-	29.1	32.5	-*	29.4	31.9	-	27.8	32.7
24	13°45'	90	-	28.9	32.4	37*	29.4	33.4	560*	27.8	33.0

N, no collection; -, absent; *, night collections.

values (28.6°C). The maximum average surface temperature in the Andaman Sea was during IMS (29.7 ± 0.5°C) and minimum during NEM (28.2 ± 0.3°C).

In the Arabian Sea, surface salinity ranged from 33.2 to 36.9 and maximum average salinity was during SWM (35.9 ± 0.8) and minimum during IMS (35.0 ± 0.6). The Surface salinity in the Bay of Bengal varied from 24.1 to 34.4 and maximum average salinity was during SWM (32.7). In the Andaman Sea salinity ranged from 29.6 to 34.3 and maximum average surface salinity was during IMS (32.9 ± 0.6) and minimum during SWM (32.6 ± 0.4).

Abundance and population structure

A total of 1775 individuals of *S. gracilis* were collected from 105 stations in the EEZ of India. Abundance over the entire study area ranged from 0 to 29 250 ind. per 1000 m³; the highest abundance was observed in the Arabian Sea at a temperature and salinity of 28.3°C and 36.8, respectively (table II). The highest abundance of *S. gracilis* was in the Arabian Sea (72.1% of the total sampled population) with an average abundance of 961 ± 3544 ind. per 1000 m³ and collections comprised 23.3% mature males, 10.6% immature males, 5.7% spent females, 25.7% breeding females, 15.5% immature females and 19.2% juveniles (fig. 2). In the Arabian Sea, there was a clear variation in population densities of *S. gracilis* collected during different seasons (table I). The highest abundance was during IMS (62.9% of the total population of the Arabian Sea) and minimum during IMS (8.3%). Population density of this species was much higher in the offshore region (71.2%) than nearshore area. Average abundance of *S. gracilis* in

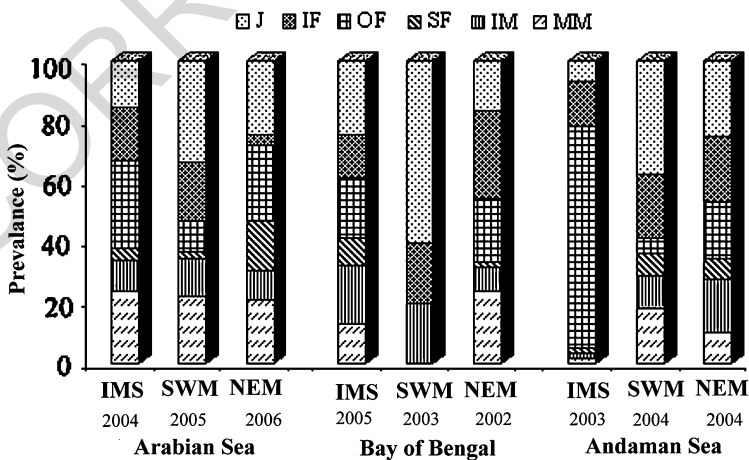


Fig. 2. Composition of the population of *Siriella gracilis* by age groups in the EEZ of India. J, juveniles; IF, immature female; SF, spent females; OF, ovigerous female; IM, immature males; MM, mature males.

TABLE V

Average population density (ind. per 1000 m³) of *Siriella gracilis* in the offshore and nearshore regions

Area	Season	Offshore	Nearshore
Arabian Sea	IMS (2004)	2183 ± 4457	1457 ± 2106
	SWM (2005)	328 ± 608	28 ± 83
	NEM (2006)	1163 ± 5034	–
Bay of Bengal	IMS (2005)	38 ± 108	34 ± 47
	SWM (2003)	5 ± 4	4 ± 6
	NEM (2002)	212 ± 435	127 ± 255
Andaman Sea	IMS (2003)	380 ± 1521	332 ± 572
	SWM (20004)	741 ± 1200	678 ± 788
	NEM (2004)	153 ± 475	–

–, absent.

the offshore and nearshore areas in the Arabian Sea are given in table V. The mean sex ratio (female/male) in the Arabian Sea was 1.38 and this ratio was significantly different ($\chi^2 = 37.23$, $df = 2$, $p < 0.01$). During the study period male individuals constituted 42.0% in the Arabian Sea.

Only 5.2% of the total sampled *S. gracilis* were present in the Bay of Bengal with an average abundance of 93 ± 354 ind. per 1000 m³ and collections comprised 16.7% mature males, 15.2% immature males, 6.2% spent females, 20.0% breeding females, 19.0% immature females and 22.9% juveniles (fig. 2). In the Bay of Bengal maximum abundance was during NEM (81.8% of the total population of the Bay of Bengal) and minimum during (SWM) (table I). In this area, population density of *S. gracilis* showed not much variation between offshore (50.9%) and nearshore waters (49.1%). Average seasonal population densities of *S. gracilis* in the offshore and nearshore areas are given in table V. the sex ratio of this area is higher (mean = 1.42, $\chi^2 = 8.51$, $df = 2$, $p < 0.05$).

The Andaman Sea contained 22.7% of the total sampled *S. gracilis*, with an average density of 317 ± 984 ind. per 1000 m³ and was composed of 15.6% mature males, 10.9% immature males, 6.9% spent females, 13.7% breeding females, 20.1% immature females and 32.6% juveniles (fig. 2). The highest abundance of *S. gracilis* in the Andaman Sea was during SWM (46.4% of the total population), followed by IM and NEM (table I). The offshore region of the Andaman Sea contributed 56% of the total population and the nearshore region 44%. The average density of *S. gracilis* in the offshore and nearshore regions of this subarea are given in table V. The mean sex ratio of mysids in the Andaman Sea was 1.39, and the male individuals constituted 39.4% of the total: female predominance was statistically significant ($\chi^2 = 28.15$, $df = 2$, $p < 0.01$).

Relation with environmental factors

Siriella gracilis is present in the EEZ of India throughout the year and tolerates wide ranges of temperature (25.8-31.4°C) and salinity (29.6-37). The fitted multiple regression model for the data was found to be $Y = -7588.325 + 173.254x_1 + 92.694x_2$. Statistical analysis reveals that temperature and salinity have little influence on the distribution of *S. gracilis*.

Breeding females and broods

In the Arabian Sea ovigerous females constituted 25.7% of the sampled population, of which stage I constituted 36.4%, stage II 39.1% and stage III 24.4% of the total gravid females sampled (fig. 3). The Bay of Bengal contributed 20.0% of total ovigerous females collected in this area, of which stage I constituted 66.7%, stage II 19.1% and stage III 14.3% of the total breeding females sampled (fig. 3). The Andaman Sea contributed 12.3% of the total breeding females sampled in this area, of which stage I constituted 54.4%, stage II 19.0% and stage III 26.6% of the total ovigerous females recorded (fig. 3). The relationship between salinity and the abundance of breeding females of *S. gracilis* was positively significant ($R^2 = 0.822$, fig. 4) but there was no significant correlation between temperature and the abundance of breeding females ($R^2 = 0.086$).

Breeding females occurred in a size range from 4.2 mm to 5.8 mm (table VI). No significant difference was observed in body length of ovigerous females from the Arabian Sea, Bay of Bengal and the Andaman Sea ($p > 0.05$). The mean length of gravid females successively increased as the stage progressed (table V). The

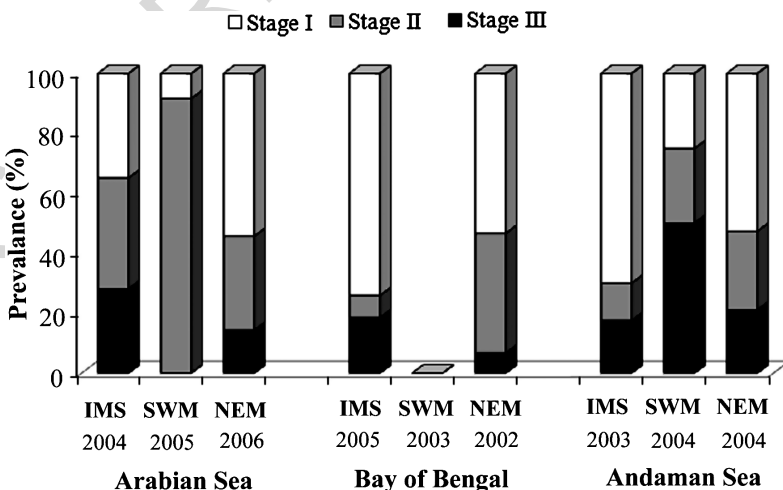


Fig. 3. Difference in the percentage occurrence of breeding females of *Siriella gracilis* in the EEZ of India.

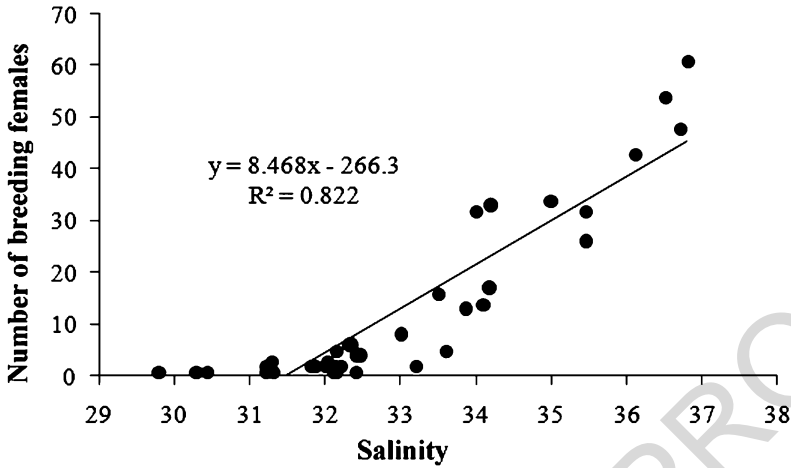


Fig. 4. Relationship between salinity and breeding females of *Siriella gracilis*.

Kruskal Wallis test showed significant size difference among the three group pooled data ($\chi^2 = 11.4$, $df = 2$, $p < 0.05$), in the same way wet mass of E_1 - E_3 embryos were also significant ($\chi^2 = 16.2$, $df = 2$, $p < 0.05$). The egg is oblong or polygonal in shape; body length and wet mass of different embryos (E_1 - E_3) are given in table VII.

There was no significant correlation between egg size and female body length ($p > 0.05$) while brood number (BN) was closely correlated with female body length (BL) for the entire study area ($BN = 4.71BL - 16.71$, $R^2 = 0.89$, $n = 213$) (fig. 5). A similar relationship was found for each subarea:

Arabian Sea; $BN = 3.365BL - 8.465$, $R^2 = 0.91$, $n = 60$;

Bay of Bengal; $BN = 3.376BL - 9.840$, $R^2 = 0.89$, $n = 78$;

Andaman Sea; $BN = 4.390BL - 15.11$, $R^2 = 0.91$, $n = 75$.

There is no significant difference statistically between three regressions.

The minimum brood size of *S. gracilis* in the EEZ of India was 4 (stage I embryo) from a 4.2 mm female, and the maximum brood size was 11 (stage II and stage III larvae for females of 5.6 and 5.8 mm, respectively).

The weight of eggs carried by a female was approximately 15% of female weight; this relationship between wet weight of stage I embryos (EM) and eggs removed females (BM) could be expressed in the following the best-fit equation:

$$EM = 0.448 \log BM + 0.4007, \quad R^2 = 0.82, \quad n = 30 \quad (\text{fig. 6}).$$

Body size and development

The total length of the smallest free-swimming individual of *S. gracilis* was 1.5 mm. The largest male observed in this study was 7.2 mm during IMS in the

POPULATION STRUCTURE AND BIOLOGY OF *SIRIELLA GRACILIS*

TABLE VI
Variation in body length (mm) of the various age groups and eggs of *Siriella gracilis*

Area	Season	MM	IM	SF			BF			IF	J	Eggs (E ₁)
				Stage I	Stage II	Stage III	Stage I	Stage II	Stage III			
Arabian Sea	IMS	5.7-7.0	3.4-5.2	4.9-5.6	4.2-5.1	4.7-5.2	4.8-5.2	3.2-4.8	2.2-3.3	0.38-0.42		
	SWM	5.8-6.9	3.6-5.7	5.2-5.7	4.4-5.2	5.1-5.2	-	3.9-4.3	1.7-3.8	-		
	NEM	5.6-6.8	3.8-4.6	5.4-5.8	5.2-5.3	5.3-5.5	4.4-5.8	3.6-5.2	2.2-3.5	0.42-0.46		
Bay of Bengal	IMS	5.5-7.0	3.8-5.4	5.2-5.6	4.8-5.1	5.1-5.4	5.1-5.5	3.4-5.0	2.5-3.8	0.32-0.40		
	SWM	-	4.0-5.2	-	-	-	-	3.8-4.8	1.5-3.5	-		
Andaman Sea	NEM	6.0-6.8	3.9-4.8	4.6-5.7	4.8-4.9	4.7-5.0	5.2-5.3	3.2-4.9	3.0-3.4	0.38-0.42		
	IMS	5.7-7.2	3.3-5.1	5.1-5.7	4.7-5.5	5.2-5.6	4.8-5.6	3.6-4.8	2.2-3.7	0.37-0.41		
	SWM	5.5-7.0	3.7-5.6	5.0-5.6	5.2-5.5	5.1-5.6	5.2-5.5	3.6-5.2	3.1-3.5	0.35-0.38		
	NEM	5.8-6.9	4.5-5.4	5.0-5.7	4.8-5.4	5.0-5.3	4.9-5.5	4.4-4.8	1.5-2.2	0.40-0.45		

-, absent.

TABLE VII

Siriella gracilis: average size ± S.D. in body length and wet weight, size range of different life cycles categories

Life stage	BL (mm)		Wet weight (mg)		n
	Range	Mean ± S.D.	Range	Mean ± S.D.	
E1 (Eggs)	0.32-0.46	0.38 ± 0.05	0.08-0.16	0.14 ± 0.04	15
E2 (Eyeless larvae)	0.48-1.00	0.75 ± 0.16	0.19-0.32	0.27 ± 0.27	26
E3 (Eyed larvae)	0.90-1.50	1.30 ± 0.20	0.20-0.43	0.33 ± 0.10	24
Juveniles	1.5-3.8	2.2 ± 0.6	0.5-1.2	0.7 ± 0.2	58
Immature males	3.3-5.7	4.2 ± 0.7	1.3-1.8	1.6 ± 0.2	36
Immature females	3.0-5.2	3.9 ± 0.6	1.1-1.7	1.4 ± 0.2	52
Mature males	5.5-7.2	6.3 ± 0.6	1.7-2.5	1.9 ± 0.4	48
Stage I females	4.2-5.5	4.9 ± 0.4	1.3-3.0	2.0 ± 0.5	30
Stage II females	4.6-5.6	5.1 ± 0.3	1.4-3.2	2.4 ± 0.6	23
Stage III females	4.7-5.8	5.2 ± 0.3	1.6-3.3	2.6 ± 0.6	25
Spent females	4.6-5.8	5.4 ± 0.4	1.4-3.0	2.4 ± 0.4	30

n, number of observations.

Andaman Sea, while the largest female observed was 5.8 mm in the Arabian Sea during NEM (table VI). In some male and female individuals measuring 5.7 mm and 5.2 mm, respectively, secondary sexual characters were not yet visible, while in some male and female measuring 5.5 and 4.2 mm respectively, secondary sexual characteristic were noticed already (table VI). Fully mature individuals varied in size from about 5.5-7.2 mm and 4.2-5.8 mm in males and females, respectively. Embryos (all stages) range in size from 0.32 to 1.50 mm, with an overlap between neighboring stages (table VII).

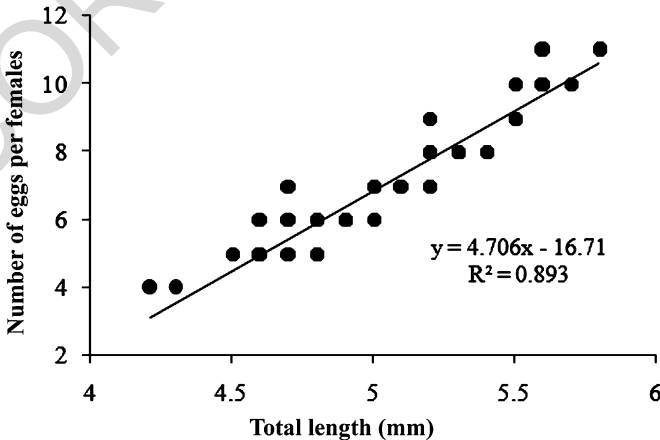


Fig. 5. Relationship between the brood numbers per females and maternal size of *Siriella gracilis*.

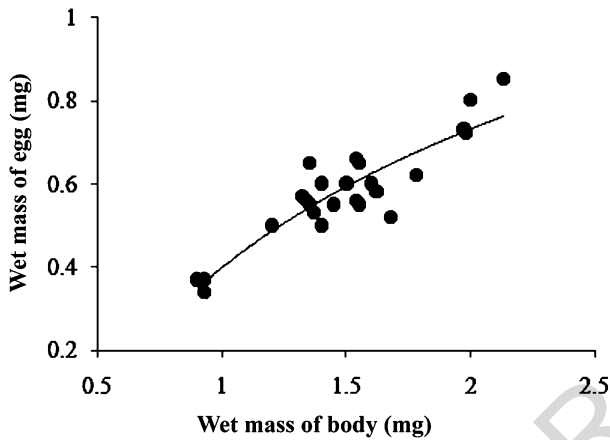


Fig. 6. Relationship between the body mass of females and the total weight of egg-like embryo of *Siriella gracilis*.

No significance body length difference was found between spent females and breeding females (stage I-III females pooled) ($t = 1.721$, $df = 48$, $p > 0.05$), while wet mass of breeding females was significantly higher than that of spent females due to the presence of eggs or embryos ($t = 5.178$, $df = 52$, $p < 0.0001$). The length of stage III females and spent females not significantly different ($t = 1.522$, $df = 48$, $p > 0.05$) while their wet mass was significantly different ($t = 5.550$, $df = 48$, $p < 0.003$). A similar relationship was found for stage II females and spent females. A significant difference was observed in body length ($t = 4.616$, $df = 52$, $p < 0.0001$) and wet mass ($t = 5.321$, $df = 52$, $p < 0.0001$) of stage I females and spent females.

DISCUSSION

The information supplied in this paper is part of a large study of the exclusive economic zone (EEZ) of India. *Siriella gracilis* is a widely distributed mysid in the Indian and Pacific Oceans. Biju & Panapunnayil (2011) reported that this species is one of the dominant species in the EEZ of India. As many other species of mysids, the population density of *S. gracilis* in the EEZ showed wide range of fluctuation (0-29 250 ind. per 1000 m³) in sampling. A comparatively large abundance of *S. gracilis* was observed in the Arabian Sea (72.1% of the total population), while the Bay of Bengal had the least abundance in the EEZ; only 5.2% of the total sampled population was present in this area. This difference in the abundance of *S. gracilis* in the study area may be related with the production of the respective areas. Compared to that of the Bay of Bengal and the Andaman Sea, the high abundance of mysids in the Arabian Sea is considered to be supported by frequent

1 coastal upwelling events throughout the year, which lead to high production in 1
2 most seasons (Prasannakumar et al., 2002). In the EEZ, the minimum abundance of 2
3 *S. gracilis* was observed in the Bay of Bengal during summer monsoon, might also 3
4 be related to less production. Prasannakumar et al. (2002) reported that although 4
5 river run-off brings high nutrients in the Bay of Bengal, heavier cloud cover during 5
6 the summer monsoon (SWM) might reduce the production. *Siriella gracilis* is 6
7 truly an oceanic species (Pillai, 1973), which may be a reason for the relatively 7
8 high abundance of this species in the offshore regions compared to the nearshore 8
9 area. Even though the population density of *S. gracilis* is comparatively high in the 9
10 offshore regions when compared to the nearshore regions, the Bay of Bengal and 10
11 the Andaman Sea do not show much variation between these two areas, because, 11
12 in general, the Bay of Bengal and the Andaman Sea have steep slopes on all sides 12
13 and, hence, oceanic conditions prevail, even in nearshore regions. 13

14 Statistical analysis shows that temperature and salinity have little influence on 14
15 the general distribution of *S. gracilis* in EEZ. Earlier reports reveal that these 15
16 parameters do not seem to be the main factor regulating of mysid distribution, 16
17 which seems more susceptible to other factors, such as food availability, substrate 17
18 type, predation and water depth (McKenny, 1994; Baldo et al., 2001). In the present 18
19 study *S. gracilis* showed a different pattern of variation in abundance with respect 19
20 to area. In the Arabian Sea high abundance of *S. gracilis* is recorded during IMS 20
21 (avg. 2034 ind. per 1000 m³), while in the Bay of Bengal and the Andaman 21
22 Sea high abundance was observed during NEM and SWM, respectively. In fact, 22
23 variations in abundance may not be related to seasonal variations in hydrodynamics 23
24 parameters, but also result from difficulty of sampling mobile organisms with 24
25 aggregated behaviour (Mauchline, 1980; Allen, 1984). Differential movements of 25
26 a size group (Morgan & Threlkeld, 1982) or migrations caused by water currents 26
27 (Johansson, 1992) may also affect size structure and catch rate of mysids. Calil & 27
28 Borzone (2008) reported that samples with a high number of replicates would be 28
29 necessary to effectively determine the pattern of variation in abundance during the 29
30 year. 30

31 Even though no strict correlation was observed between salinity and the general 31
32 distribution of mysids, abundance of breeding females significantly correlated with 32
33 salinity. Comparatively less abundance of gravid females was observed in the Bay 33
34 of Bengal; this may be related to the lower salinity of the surface water there. The 34
35 decrease in the number of gravid females in lower salinity surface areas may be due 35
36 to the migration of females from lower salinity to high salinity areas (deeper layers) 36
37 for the selection of the optimal salinity for the embryonic development. Generally, 37
38 ovigerous females seem to have less osmotic regulation in their marsupial fluid 38
39 than in their haemolymph (McLusky & Heard, 1971); therefore, females avoid low 39
40 salinity. The effect of salinity on breeding females has been widely documented for 40

1 other mysids (Greenwood et al., 1989; McKenny, 1994; McKenney & Celestial, 1
2 1995; Verslycke et al., 2003). 2

3 Breeding females and juveniles were observed during most of the sampling 3
4 period. An increase in the reproductive potential of a population is related to 4
5 an accelerated ontogenetic development that results in a fast maturation of the 5
6 individuals, allowing the production of many generations per year. In tropical 6
7 waters many workers have reported the continuous reproduction in mysids (e.g. 7
8 Goodbody, 1965; Biju & Panumpunnayil, 2009, 2010; Biju et al., 2009; Hanamura 8
9 et al., 2009). At subtropical latitude (25°S) ovigerous females of *Metamysidopsis* 9
10 *elongate atlantica* (Bacescu, 1968) and *Brasilomysis castroi* Bacescu, 1968 were 10
11 observed during all seasons of the year, although the existence of successive 11
12 generations was not clearly identified (Almeida Prado, 1974). Due to continuous 12
13 breeding, determining the number of generations becomes more complex (Mees 13
14 et al., 1994; Dalgado, 1997), because generations overlap and can rarely be 14
15 distinguished in field data; only additional laboratory observations on growth rate 15
16 and brood production will help to determine the number of generations and life 16
17 span of individuals (Mauchline, 1980). 17

18 The number of eggs/embryos carried by females ranged from 4 to 11. The 18
19 average body length of breeding females increased with the progress of larval 19
20 development. A similar size increase in breeding females has been reported in 20
21 various species of mysids and has been explained as inter-moult growth causing the 21
22 stretching of the abdomen (Fenton, 1994). Gorokhova & Hansson (2000) reported 22
23 that approximately 3% inter moult growth in length was observed in gravid females 23
24 of *Mysis mixta* Lilljeborg, 1852 during the brooding period. Even though marsupial 24
25 content (eggs) is present in the stage I females, their wet mass lower than that of 25
26 spent females (table VII). This suggests that spent females overcome the weight 26
27 loss due to the loss of marsupial content through inter moult growth. Unfortunately, 27
28 in the present study, the somatic growth of the abdomen was not measured. 28

29 The results of the present study on the distribution and biological characteristic 29
30 of *S. gracilis* will be useful in designing detailed research on other epipelagic 30
31 mysids/zooplankton. 31

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