Marine Biology (2000) 136: 561–571

S. Kidwai · S. Amjad

Zooplankton: pre-southwest and northeast monsoons of 1993 to 1994, from the North Arabian Sea

Received: 27 February 1998 / Accepted: 8 October 1999

Abstract Zooplankton samples from the North Arabian Sea Environment and Ecosystem Research (NASEER) cruises were analyzed to determine the basic taxonomic composition, biomass (standing stock) and the total and copepod numeric abundance; these characteristics are discussed with reference to the different monsoon periods. Cruises carried out during March 1993 and May 1994, categorized as pre-southwest monsoon periods, and a cruise in December 1994, categorized as a northeast monsoon period, are discussed in detail. The biomass of January 1992 versus August 1992 and August 1992 versus March 1993 differed significantly ($F = 6.44$, $P \leq 0.05$). Ranges of highest and lowest biomass from each cruise are also given. Distinct "high" and "low" production areas of statistically significant difference ($F = 12.67$, $P \leq 0.05$) were observed. The "high" and "low" production areas were mobile and followed the surface wind circulation patterns (wind reversal pattern) during the northeast and southwest monsoon periods. Overall zooplankton showed a patchy distribution. The overall zooplankton abundance and total copepod counts differed significantly between the Cruises 3 versus 4 and 4 versus 5 ($F = 15.67$, $P \leq 0.05$ and $F = 34.39$, $P \leq 0.05$, respectively). There was no significant difference ($P \geq 0.05$) in biomass, between eutrophic and oligotrophic stations, suggesting no difference between near shore and offshore waters. Thirty-eight taxonomic groups were identified from the samples, with copepods being the most dominant group, followed by chaetognaths and siphonophores. Copepods constitute an average of 52.50 to 74.93% of the total zooplankton count and reach maxima of 92.14% of the total zooplankton count at the outset of the southwest monsoon (March 1993) and 91.39% at the outset of the active northeast monsoon (December 1994).

Communicated by O. Kinne, Oldendorf/Luhe

S. Kidwai (✉) · S. Amjad
National Institute of Oceanography,
ST 47, Block 1, Clifton,
Karachi 75600, Pakistan

Introduction

The Arabian Sea is located in the extreme northwest of the Indian Ocean. It is semi-enclosed, with land masses on three sides: Pakistan in the north, the Arabian Peninsula in the west and India in the east. Water influxes and exchanges take place with the Persian Gulf and the Gulf of Aden, from the northwest, and with equatorial waters. The area lies within the boundaries of the monsoonal regime and is influenced by the biannual monsoonal cycle. The southwest monsoon (or the summer monsoon) begins in June and lasts until September. The northeast monsoon (or the winter monsoon) starts around November and lasts up to February. Monsoons play a vital role in determining the various physical and chemical features of the area, which vary from summer to winter. The uniqueness of the Arabian Sea in comparison to the other oceans is the seasonal reversal of atmospheric and oceanic surface circulation (Fig. 1). The southwest monsoon winds are stronger than those of the northeast monsoon, and the coastal currents tend to be anti-clockwise during northeast, and clockwise prior to and during much of the southwest monsoon season (Wyrtiki 1971; Banse 1984; Slater and Kroopnick 1984; Williams 1984; Amjad et al. 1995; Baars et al. 1995). Other features such as mixed layer depths and stability ratios during the two monsoons are briefly discussed (Ahmed et al. 1995). All these special features of the area have an impact on the overall productivity and biological richness of the region.

Studies of zooplankton in the Arabian Sea date back to 1857–1859 (Rao 1973). Several later research surveys have also been conducted in the area [IIOE (1960 to 1965), R.V. "Dr. Fridtjof Nansen" (1977), INDEX (1979), R.V. "Meteor" (1987)], leading to the publication of atlases and papers (e.g. IOBC 1968a, b; Prasad 1968; Wyrtiki 1971). Earlier works on zooplankton have

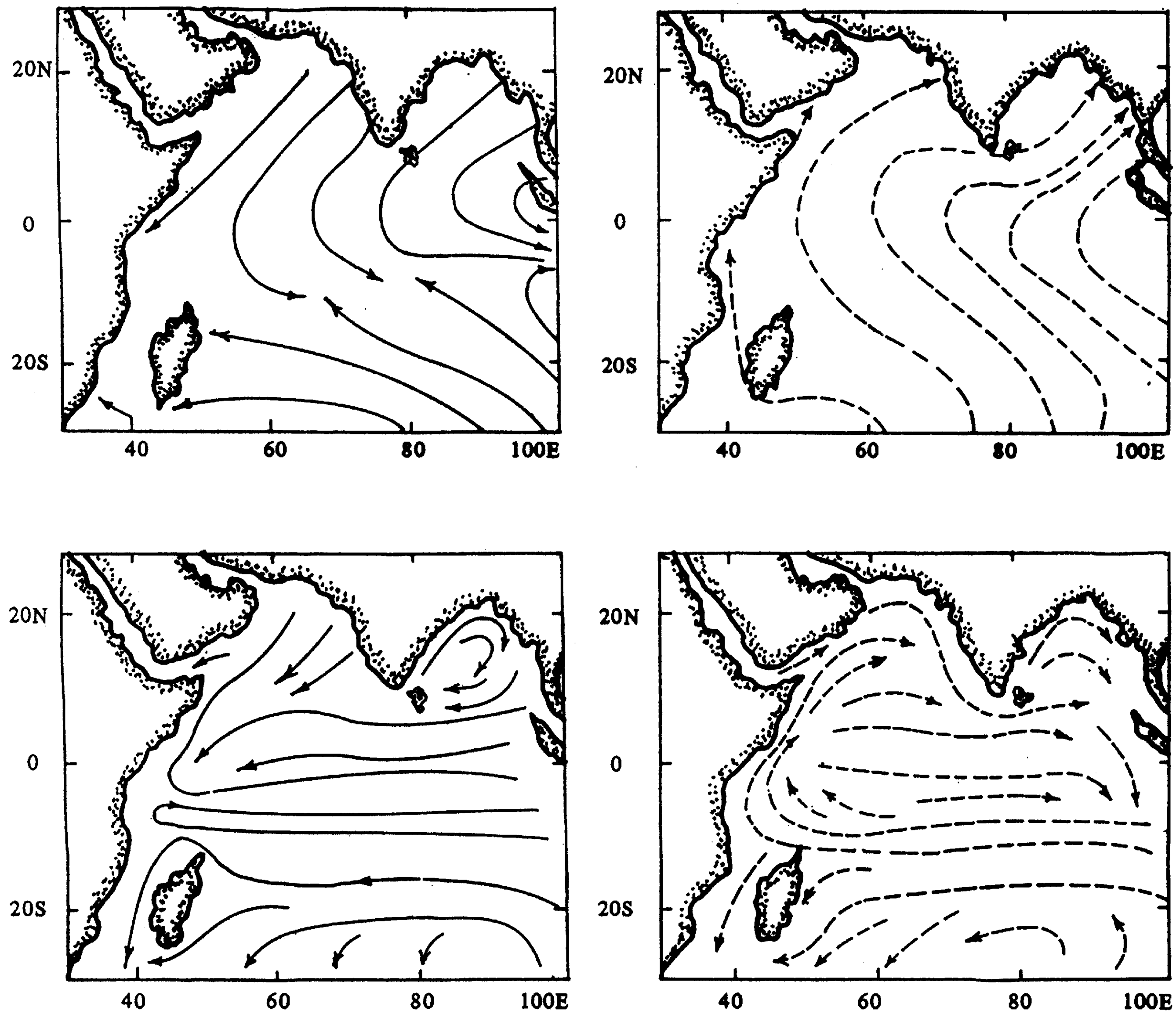


Fig. 1 Seasonal circulation patterns for the northern Indian Ocean. *Upper panels* show surface winds (after Hastenrath and Lamb 1980); *lower panels* show surface currents (after Pickard 1963) (*continuous lines* northeast monsoon; *dashed lines* southwest monsoon). The figures were reproduced from Slater and Kroopnick (1984)

been of a taxonomic nature, providing information on the major zooplankton groups/species, their distribution and abundance, however little information is available on the abundance of zooplankton species from the Arabian Sea (Peterson 1991). Zooplankton biomass from the extreme North Arabian Sea (Pakistan) has been discussed briefly in earlier works (Haq et al. 1973; Ali-Khan 1976), but there are gaps in the information that need to be addressed.

The present study was part of the NASEER (North Arabian Environmental and Ecosystem Research) project, a collaboration between Pakistan and the United States' Office of Naval Research, and was aimed at examining the basic composition, abundance and behavioral trends of zooplankton in relation to oceanographic changes during different annual monsoon periods. Preliminary information on zooplankton from NASEER Cruises 1 and 2 (N1 and N2) have previously been discussed (Amjad et al. 1995); the present paper provides an overview as well as focusing on the data obtained from Cruises 3, 4 and 5 (N3, N4 and N5).

Materials and methods

The present study includes samples taken during the five NASEER cruises. The zooplankton samples from the first two cruises, carried out during January 1992 (northeast monsoon, NE) and August 1992 (southwest monsoon, SW) have been discussed in some detail in an earlier publication (Amjad et al. 1995). The last three cruises of March 1993, May 1994 (pre-SW) and December 1994 (NE) are discussed in detail in the present paper.

The biomass (standing stock) of zooplankton was calculated for all stations. These data were only differentiated according to day and night samples when used for studies related to diel migration pattern (Kidwai et al. 1997; Kidwai and Amjad in preparation).

The NASEER cruise track covered 1500 nautical miles, between 20–25°N and 59–67°E (Fig. 2). There were 18 biological sampling stations along the track, of which five (Stn. 8, 27, 33, 45, 57) were 24 h repeat stations, where a 6 h sampling routine was followed in order to study day and night differences in the biomass, behavior and species composition.

The zooplankton sampling was carried out by using Bongo nets with frame diameters of 60 cm and mesh sizes of 335 μm (N1 to N3) and 150 μm (N4 and N5). A digital flowmeter (HYDROBIOS, 0.3 m rev^{-1}) was mounted at the mouth of the net to measure the water flow entering the nets. The nets were towed in a circular path, at the speed of 2 to 3 knots, for 10 min, to obtain surface to subsurface samples (0 to 5 m). The samples obtained were washed in seawater and stored in 10% neutral formalin in plastic jars. Qualitative and quantitative analyses were carried out on shore at the National Institute of Oceanography laboratory. Biomass (standing stock) of zooplankton was determined by the settlement method (Steedman 1976). Three samples of 10 ml were qualitatively (taxonomic groups) analyzed and their numeric abundances were determined. Biomass was calculated on the order of milliliters per cubic meter × 100, and abundance was calculated per square meter × 10 (Amjad et al. 1995).

In order to investigate the difference between the eutrophic and oligotrophic stations, on the basis of their proximity to the continental shelves of Pakistan and Oman, Stns. 4, 8, 45, 60 and 62 were assumed to be eutrophic stations. While Stns. 12, 15, 18, 21, 24, 27, 30, 33, 36, 37, 39, 41, 42, 49, 53 and 57 were assumed oligotrophic, being the furthest away from the Pakistani or the Omani shelf area.

All calculations for abundance were performed on the means of three sub-samples. ANOVA using SPSS for Windows (Version 6.0 Inco, Chicago) was performed, to determine statistical significance between the zooplankton standing stocks from all five cruises (N1 to N5). Differences between eutrophic and oligotrophic stations were also calculated. The total zooplankton and copepod numeric abundances are discussed for N3, N4 and N5 (pre-SW and NE monsoon).

Results and discussion

Zooplankton composition

The composition of major taxonomic groups and the presence or absence of groups in the samples has been summarized in Table 1. Thirty-eight different classifications belonging to 23 major taxonomic groups were identified.

Total numeric abundances of 12 of the major taxonomic groups identified within the samples are given in Fig. 3. Copepods were the most abundant group in N3 to N5, with a maximum mean abundance appearing in N5 of 73 633 m^{-2} × 10, forming nearly 74.93% of the total zooplankton population. The copepod population was uniformly distributed. The numbers ranged from as low as about 7.44% at Stn. 8D and 53 (N3) to 92.14% at Stn. 8C (N3); this difference cannot be attributed entirely to diurnal migration, but presumably reflects

Fig. 2 North Arabian Sea Environment and Ecosystem Research (NASEER) cruise track (*all circles* biological stations; *closed circles* 24 h repeat stations)

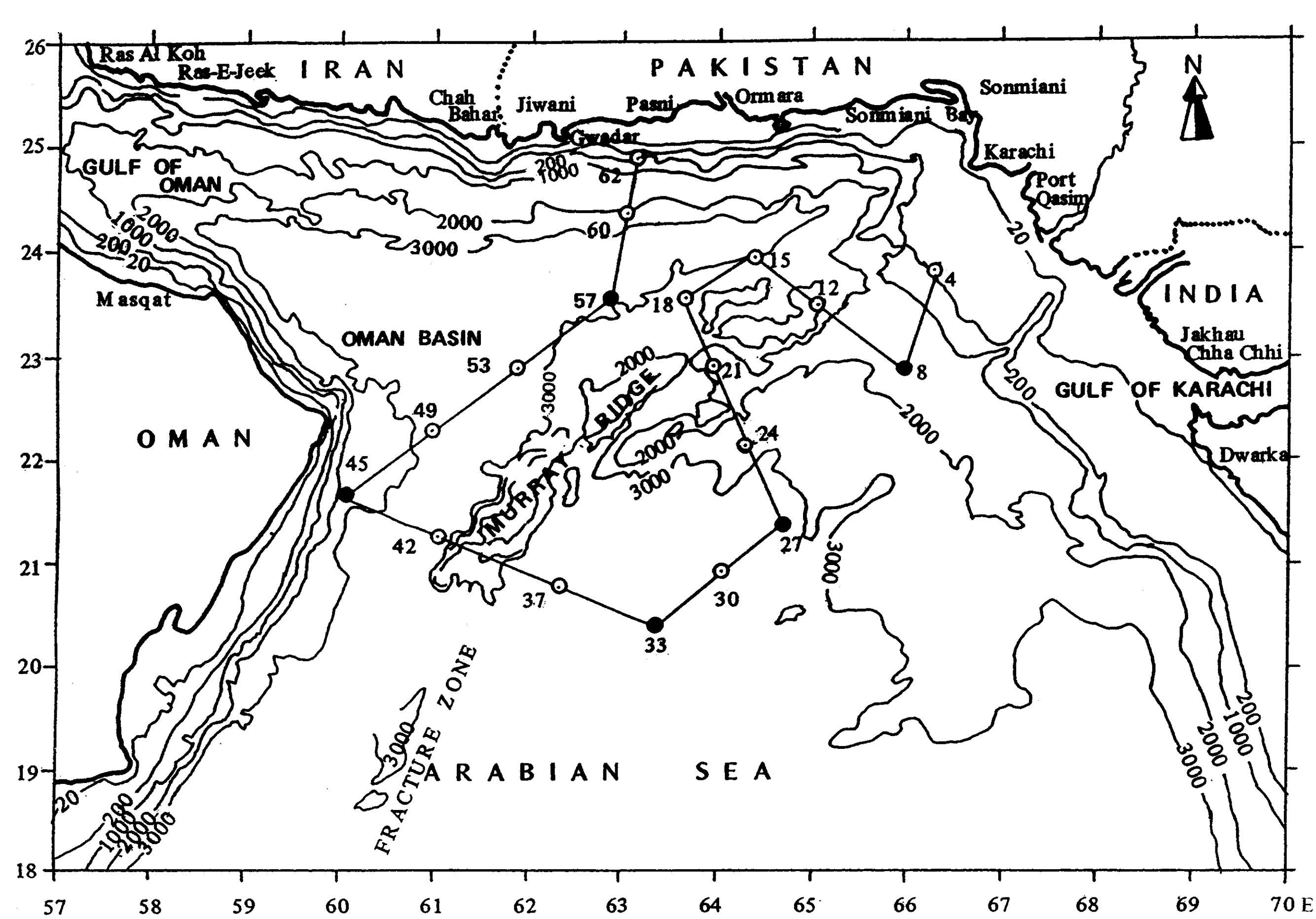


Table 1 Appearance of different groups in NASEER Cruises 3, 4 and 5 (+, present; –, absent)

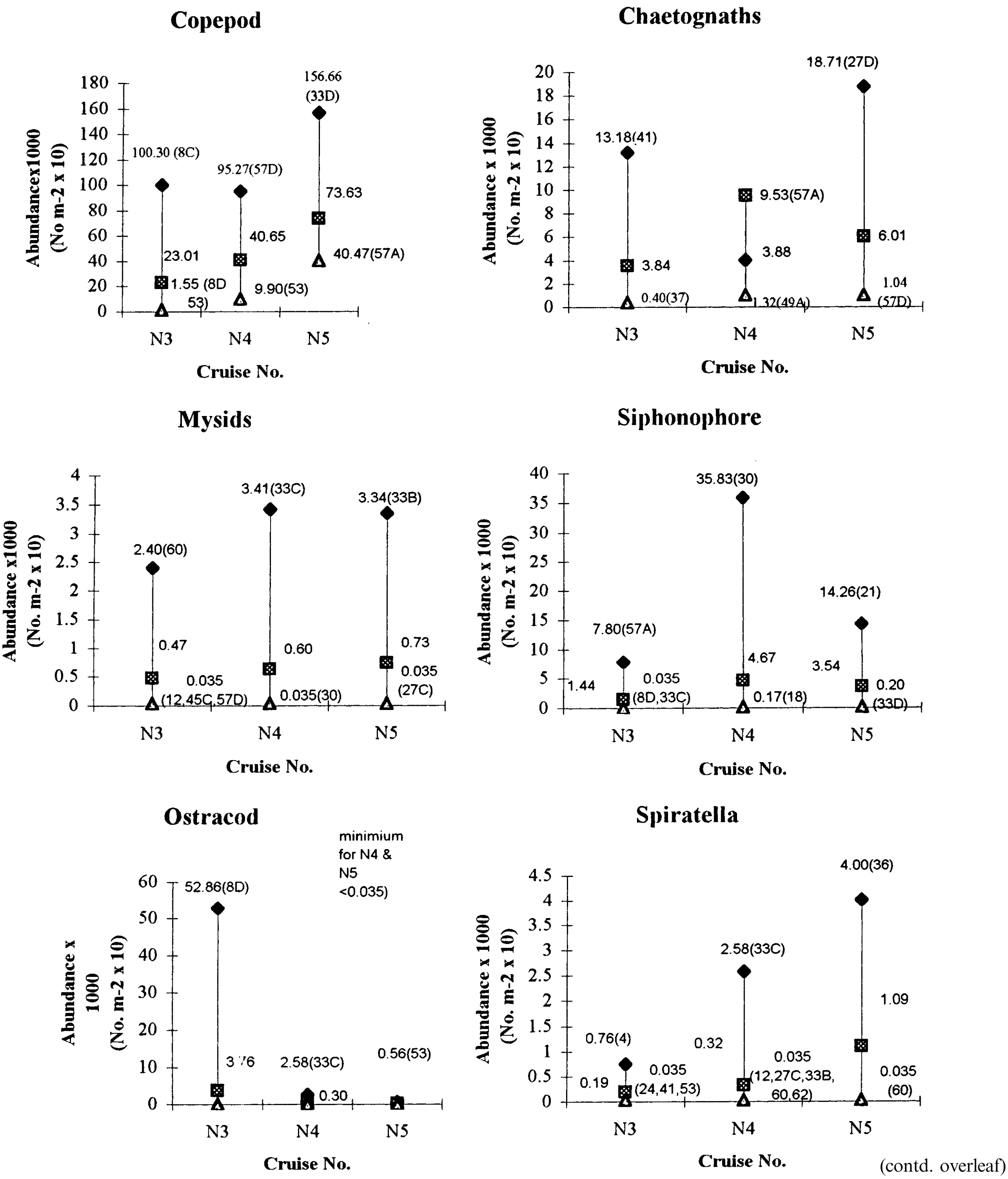
Taxonomic groups	NASEER 3	NASEER 4	NASEER 5
Crustacean copepods			
Calanoid	+	+	+
Cyclopoid	+	+	+
Harpecticoid	+	+	+
Copepod naupliar stage	+	+	+
Branchiopods			
Ostracod	+	+	+
Cladocera	–	+	+
Amphipods	+	+	+
Mysidacea			
Mysid	+	+	+
Mysid (juveniles)	+	+	+
Euphausids	+	+	+
Decapods			
Lucifer	+	+	+
Crustacean larval forms			
Cirripedia (cypris: barnacle larvae)	+	+	+
Decapoda			
Phyllosoma stage	+	–	+
Anomuran larvae	+	–	–
Brachyuran larvae	+	+	+
Somatopoda			
Mantis shrimp (alima)	+	+	+
Crustacean zoea	–	+	+
Euphausid (furcilia)	+	+	+
Egg mass	+	+	+
Chaetognaths	+	+	+
Coelenterates			
Siphonophore	+	+	+
Siphonophore larvae	+	+	+
Ctenophore	+	+	–
Medusae	+	+	+
Gastropods			
Janthina	+	+	+
Gastropod larvae	+	+	–
Pteropods			
Spiratella	+	+	+
Cephalopod larvae	+	+	+
Bivalvia larvae	+	+	+
Doliolids	+	+	+
Salps	+	+	+
Formaniferans			
Globigerina	+	+	+
Radiolaria	–	+	+
Acantheria	+	+	+
Appendicularia	+	+	+
Polychaete larvae	+	+	+
Echinoderm larvae	+	+	+
Fish egg/larvae	+	+	+

the involvement of other factors as well (Kidwai and Amjad in preparation). Similar trends were observed for N4 and N5. For N4, the minimum percentage of copepods in relation to total zooplankton number was (22.69%) at Stn. 53 and the maximum percentage (88.55%) at Stn. 57. For N5, the minimum percentage (22.16%) was at Stn. 57 and the maximum (91.39%) was reported at Stn. 33.

Earlier studies such as Haq et al. (1973) have estimated that copepods comprise the bulk of the zooplankton population, forming 63 to 90% of the average number of total zooplankton. Copepods were among the most dominant groups off India (Madhupratap et al. 1992; Stephan et al. 1992). The copepod *Calanus carinatus*, which is used as a biological tracer for cold, upwelled water, formed 61% of the total zooplankton population in the Arabian Sea, off Somalia (2 to 12°N) during SW monsoons from 1964 to 1979 (Smith 1982, 1984; Stephans et al. 1992; Baars et al. 1995). Paulinose et al. (1992) have estimated that copepods comprise 77% of the general zooplankton community. Madhupratap et al. (1992) have estimated this proportion to range between 15 and 20%. Copepods generally account for 40 to 90% of the total zooplankton count between 15 and 20°N (Achuthankutty et al. 1992). This figure is estimated as 64% in the NE Arabian Sea during November and December (NE monsoon) (Krishnakumari and Achuthankutty 1989). Tirmizi and Nayeem (1992) have calculated the proportion of copepods in the total zooplankton samples to range between 70 and 90%, for January 1977 (NE monsoon). Other areas of the Indian Ocean also have high percentages of copepods, with figures reaching up to 80% (Mwaluma 1995).

It is interesting to note that although the copepod population is generally the most dominant during both the pre-SW and NE monsoons, maximum numbers have been reported only during the NE monsoon. Chaetognaths and siphonophores are numerically the next most abundant groups, with similar trends reported in Haq et al. (1973).

Exceptionally high values of ostracods were found at Stn. 8 (90.13%) during N3. Buskey (1995) has discussed ostracod abundance during N3 in the context of bioluminescence, and reported dense ostracod concentrations at the surface. It is interesting to note that complementary to the ostracod high (90.13%) was a copepod low (7.44%), at the same station (Stn. 8) and time (N3). This suggests that the exceptional high of one group corresponds with the exceptional low of another group. Other studies also report these high and low trends (Qureshi 1997). Paulinose and Aravindakshan (1977) report that bioluminescent ostracods form the bulk of the nocturnal zooplankton population. However, these elevations in numbers are short lived and therefore do not account for the general productivity of the area (Haq et al. 1973; Paulinose and Aravindakshan 1977; Qasim 1977). Salps and siphonophores, like the ostracods, have also been reported to form large blooms and contribute signifi-



(contd. overleaf)

Fig. 3 Total numeric abundance of major taxonomic groups, during NASEER cruises (*N3*, *N4*, *N5*) (◇, maximum; □, mean; △, minimum; *numbers in parentheses* station numbers at which the value was recorded)

cantly to the overall zooplanktonic bulk (Haq et al. 1973; Ali-Khan 1976). The exact causes of such blooms are not known, nevertheless, nutrients are considered to have a major influence (Madhupratap et al. 1992). Another aspect to consider is the predator–prey effect on such a bloom, especially since carnivorous plankton, such as chaetognaths, can be so numerically abundant in areas rich in zooplankton (Qasim 1977).

Biomass (standing stock)

The variance in biomass of N1 versus N2 and N2 versus N3 was found to be statistically different ($F = 6.44$, $P \leq 0.05$). For N1 and N2, the highest biomass was observed at Stn. 57, and the lowest values were

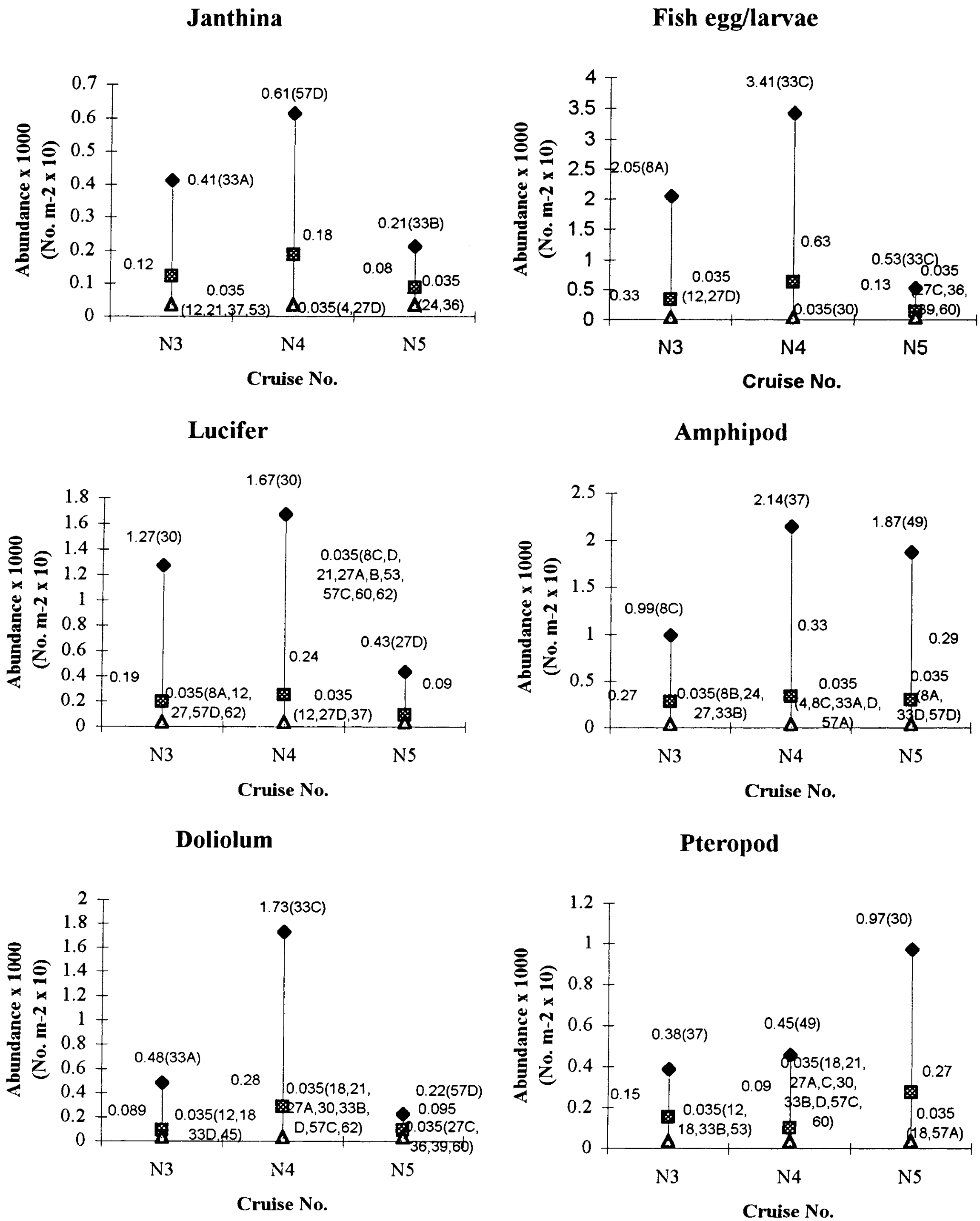


Fig. 3 (contd.)

estimated at Stn. 24 and Stn. 8, respectively. For N3, the highest biomass was observed at Stn. 41 (between Stns. 37 and 42) and the lowest at Stn. 8; for cruises N4 and N5, the highest biomass was observed at Stn. 18 and the lowest at Stn. 27.

Clearly, no fixed "high" or "low" productive areas exist (Figs. 4 to 8). Observations suggest that these areas are variable but that shifts follow a particular pattern. In January 1992:NE (Fig. 4), the highest biomass was estimated at Stn. 57. This high was found in an anti-clockwise direction at Stn. 41 in March 1993:pre-SW (Fig. 6), it was found further in the same direction (Stn. 18) in May 1994:pre-SW (Fig. 7). The direction reversed to clockwise during the summer and in August 1992:SW the high was found again at Stn. 57 (Fig. 5); in December 1994:NE the high was again anti-clockwise to Stn. 18 (Fig. 8). The surface wind reversal follows the anti-clockwise direction in the northeast

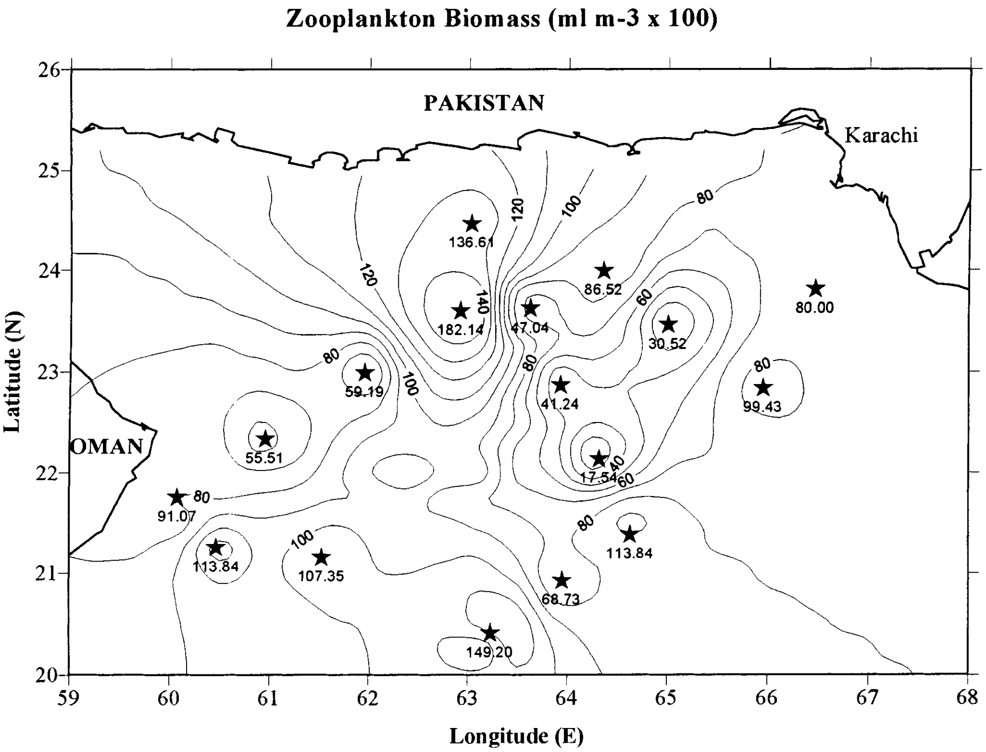


Fig. 4 Zooplankton standing stock (biomass) distribution and density, during the NASEER Cruise 1, January 1992 (NE monsoon period). Stars indicate the station positions and numerals below stars indicate the standing stock. For the 24 h stations, the contours were generated considering all four observations at a position; however, the value shown on the contour is the maximum abundance observed at the station

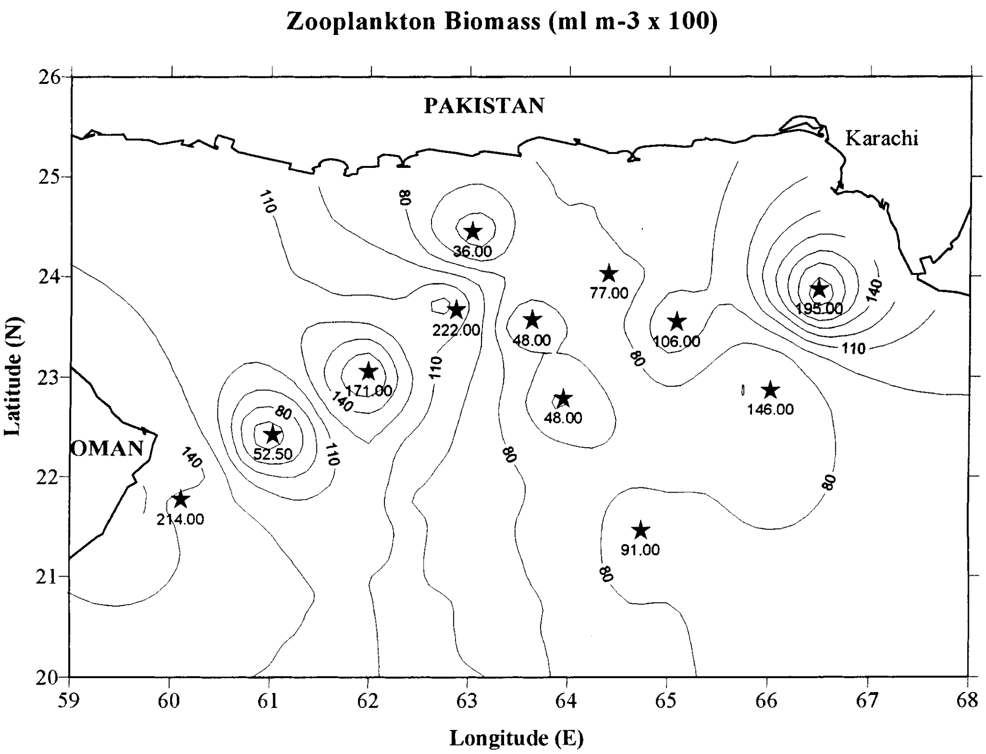


Fig. 5 Zooplankton standing stock (biomass) distribution and density, during the NASEER Cruise 2, August 1992 (SW monsoon period). Stars indicate the station positions and numerals below stars indicate the standing stock. For the 24 h stations, the contours were generated considering all four observations at a position; however, the value shown on the contour is the maximum abundance observed at the station

and the clockwise direction in the southwest (Fig. 1) (Banse 1984; Slater and Kroopnick 1984; Baars et al. 1995). Observations suggest that the surface zooplankton distribution is influenced by the surface wind circulation pattern. Earlier studies have also suggested seasonal changes in winds leading to changes in the location of productive regions (Nakagome 1959a, b). Models show that monsoon wind strength is a fundamental forcing factor, and since the cycle of productivity is driven by the ocean's response to monsoonal winds large and regular seasonal oscillations are exhibited (Smith 1995).

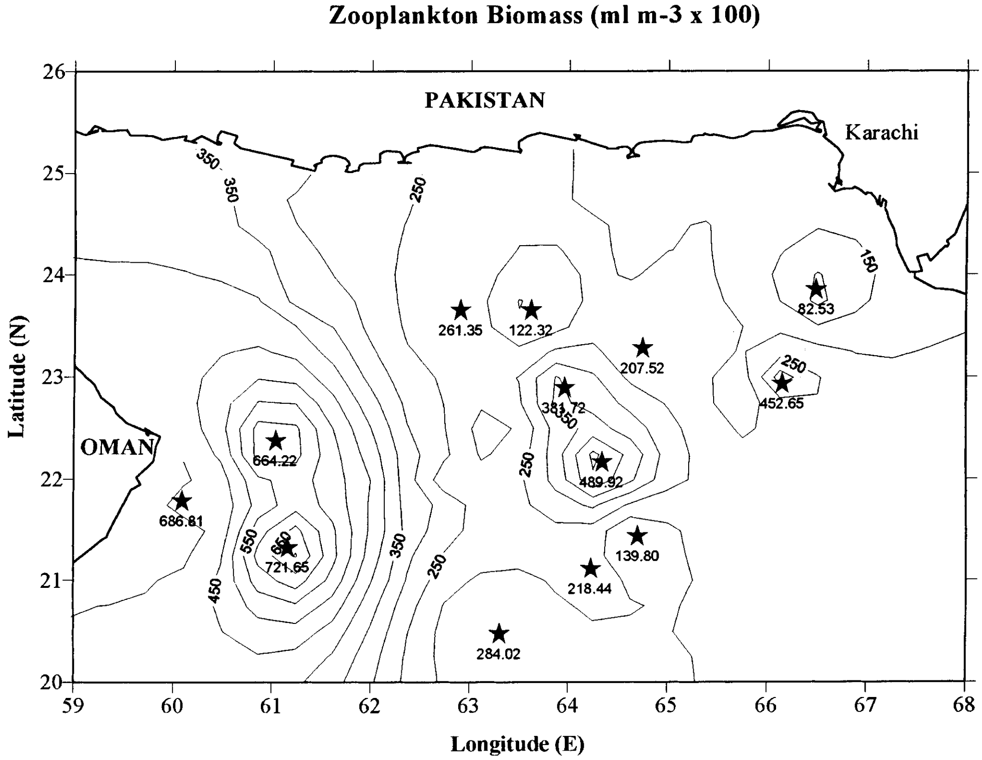


Fig. 6 Zooplankton standing stock (biomass) distribution and density, during the NASEER Cruise 3, March 1993 (pre-SW monsoon period). Stars indicate the station positions and numerals below stars indicate the standing stock. For the 24 h stations, the contours were generated considering all four observations at a position; however, the value shown on the contour is the maximum abundance observed at the station

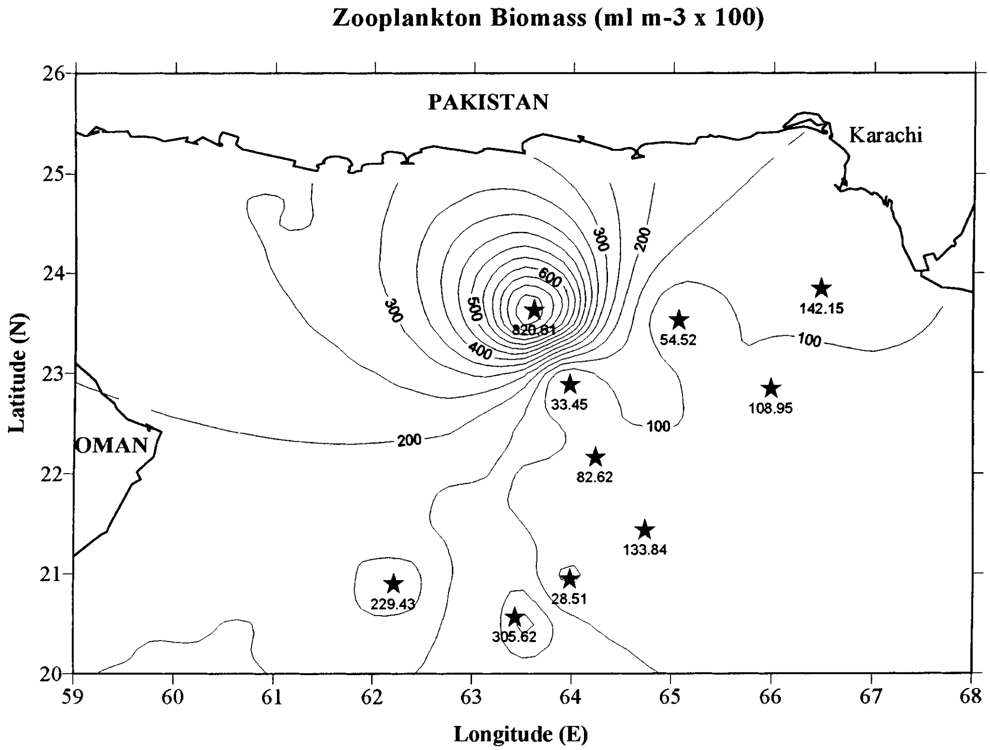


Fig. 7 Zooplankton standing stock (biomass) distribution and density, during the NASEER Cruise 4, May 1994 (pre-SW monsoon period). Stars indicate the station positions and numerals below stars indicate the standing stock. For the 24 h stations, the contours were generated considering all four observations at a position; however, the value shown on the contour is the maximum abundance observed at the station

Differences between the high and low productivity areas suggest that the zooplankton standing stock is not evenly distributed. Even though the highs and lows tend to vary in location and are seasonally dependent (observations from present study) (Figs. 4 to 8). The difference between the most and least productive station was found to be significant ($F = 12.67$, $P \leq 0.05$). Zooplankton distribution in this area is characterized by a patchy distribution with high density pockets (Mathew et al. 1990; Goswami et al. 1992).

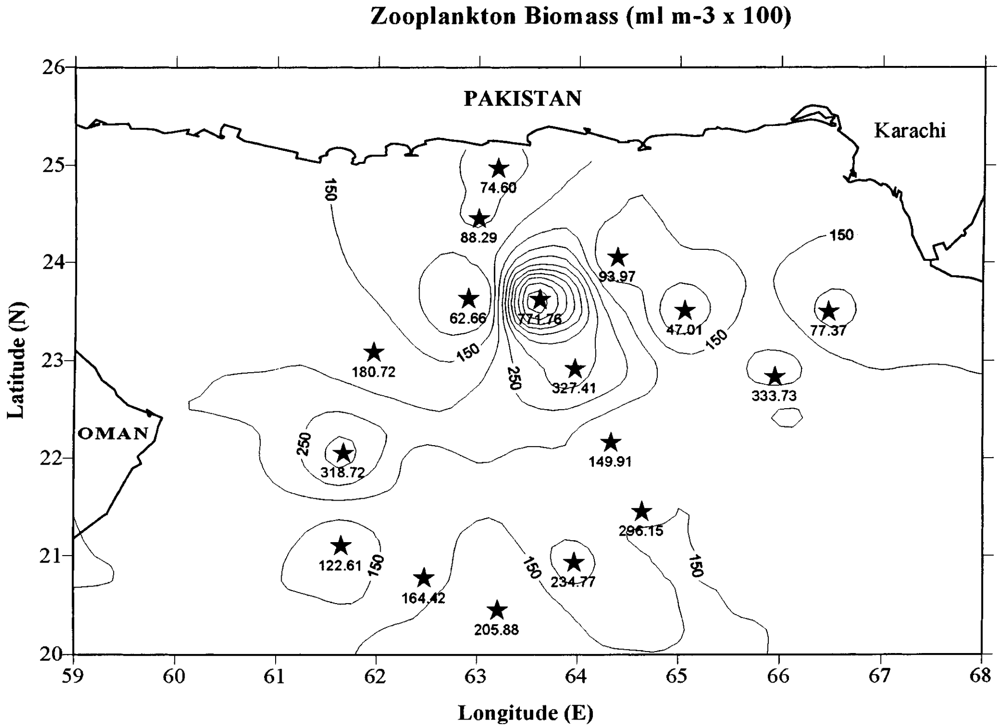


Fig. 8 Zooplankton standing stock (biomass) distribution and density, during the NASEER Cruise 5, December 1994 (NE monsoon period). Stars indicate the station positions and numerals below stars indicate the standing stock. For the 24 h stations, the contours were generated considering all four observations at a position; however, the value shown on the contour is the maximum abundance observed at the station

No significant difference was noted ($P \geq 0.05$) between the eutrophic and oligotrophic groups. A variety of related observations has been reported from earlier studies from the Arabian Sea. Distinct differences in the standing stock for eutrophic and oligotrophic areas were computed between the North and Central Indian Ocean (Baars et al. 1995; Smith 1995). Higher concentrations of zooplankton appear in the shelf area than in the open water, however the trend was not as distinct in some sections of the shelf area (Grobov 1968; Tyuleva 1974; Banse 1984). There were differences between eutrophic and oligotrophic regions (Achuthankutty et al. 1992), with coastal areas being more productive than the oceanic region (Krishnakumari and Achuthankutty 1989). Zooplankton concentrations may be greater some distance from shore (for water depths less than 40 m depth) (Goswami et al. 1992). Results based on the samples collected during the R.V. "Dr. Fridtjof Nansen" (1977), from coastal and non-coastal waters of the the Arabian Sea, also did not show differences in the abundance of zooplankton between coastal, slope and open waters (Tirmizi and Nayeem 1992).

Studies on overall biomass suggest that zooplankton biomass remains stable throughout the year (Peterson 1991; Smith 1995). Mean standing stocks have been calculated for several areas of the Indian Ocean, and the Arabian Sea has been defined as the most productive area of the Indian Ocean (Bogorov and Vinogradov 1961).

According to the present study, the mean standing stocks were approximated at 89.17 ml $m^{-3} \times 100$ (n = 30, 17.54 to 182.14), 96.92 ml $m^{-3} \times 100$ (n = 21, 34.13 to 222.0), 277.83 ml $m^{-3} \times 100$ (n = 24, 68.60 to 721.64), 145.85 ml $m^{-3} \times 100$ (n = 17, 16.52 to 820.60) and 178.57 ml $m^{-3} \times 100$ (n = 30, 29.74 to 771.76), for cruises N1 to N5, respectively.

The zooplankton biomass in the northern and northwestern Arabian Sea is four to ten times higher than the rest of the Arabian Sea, ranging from 0.01 to 2.80 ml m^{-3} (Paulinose and Aravindakshan 1977), and the highest values are found in the coastal waters of India, Pakistan, Oman and Yemen (Qasim 1982). According to plankton atlases of the IIOE (IOBC 1968a, b), the mean standing stock of the Indian Ocean is estimated at 12.5 ml m^{-2}, the mean value for the North Arabian Sea was 50 ml m^{-2}, and the mean value for the coastal Arabian Sea was estimated at 62 ml m^{-2}. Bogorov et al. (1969) and Qasim (1982) estimated the zooplankton biomass to range between 101–200 mg m^{-3} (wet mass) and 51–100 mg m^{-3} south of 20°N. Prasad (1969) reports the highest biomass values between 10–25°N and 50–60°E (54.7 ml m^{-2}, up to 200 m). Tyulena (1974) confirms that for the area north of 20°N, biomass ranges between 50–100 mg m^{-3}, for the upper 100 m, from January to June, and 200–300 mg m^{-3} from April to May (Qasim 1977). A similar trend was reported by Paulinose and Aravindakshan (1977). Biomass from the shelf and off the coast of Pakistan from four different cruises ranges between 10 and 405 ml m^{-2} (mean 53 ml m^{-2}). The high biomass value has been attributed to the salp and medusa swarms (Ali-Khan 1976).

The present study suggests that the overall mean biomass of the area changes from northeast to southwest. Higher values were noted with the onset of the SW monsoon and considerable lowering is witnessed as it enters into the full-fledged monsoon period. Significant differences were seen between N1 (89.17 ml $m^{-3} \times 100$) and N3 (277.8 ml $m^{-3} \times 100$) and between N3 and N2

(96.92 ml $m^{-3} \times 100$); hence differences from January to March and March to August were observed. Other studies have demonstrated trends, in which the zooplankton biomass was elevated during the SW monsoon (Madhupratap et al. 1990). While no significant difference was reported between the monsoons (Madhupratap et al. 1992; Baars et al.1995).

Total numeric abundance of zooplankton between N3, N4 and N5 demonstrates a significant difference ($F = 15.78$, $P \leq 0.05$). The present study covers taxonomic groups only, of which copepods form a large proportion in the numeric abundance; therefore copepods follow the same trend as the overall abundance and vary from the two pre-SW monsoons (1993 and 1994) to the NE monsoon (1994) ($F = 34.39$, $P \leq 0.05$).

Studies of the epipelagic zooplankton community off Somalia exhibit significant change in the species composition from one monsoon to another. The biomass is dominated by meso-macro planktonic grazers (copepods); the numbers are reduced in the subsurface layer during the NE monsoon and distinctly rise in areas of upwelling off Somalia (Smith 1995). Studies conducted within the upwelling and outside the upwelling regions along the Somalian coast, 5 to 10°N, show no significant difference in total numbers of organisms between monsoons (Smith 1982). This could be caused by the productivity being so high that the zooplankton population is more-or-less evenly distributed.

The North Arabian Sea has a distinctive oceanography; the present study establishes that the trend for the zooplankton population in this region is similar to that found in other areas of the Indian Ocean. The pattern noted between the surface wind circulation patterns and the zooplankton distribution needs further investigation. Analysis of the samples, with emphasis on specific taxonomic groups, could also be useful for understanding trophodynamics in the context of the oceanography of the region.

Acknowledgements Financial assistance to NASEER was provided by the US Office of Naval Research, under Grant N00014-86-G-0230, Pak-US Cooperation Program in Oceanography of the Arabian Sea. The authors acknowledge the efforts of all participating scientists of the NIO, in the NASEER cruises; Mr. J. Baquar, Mr. A. Rehman, Mr. A. D. Shah, Mr. M. E. Khan and Mr. M. A. Hashmi, of the Biology Section, for the plankton sampling and Mr. S. M. Tabrez, of the Computer Section, for his help with the contour generation. The first author would especially like to thank Mr. R. Snyder, Aquatic Science Division, Agriculture and Food Science Centre, Belfast, N. Ireland, for his support and suggestions and the two referees for their useful suggestions which helped in the overall improvement of the manuscript.

References

Achuthankutty ST, Nair SRS, Nair VR, Padmavati G, Madhupratap M (1992) Micro distribution of zooplankton in the neustonic realm of the eastern Arabian Sea during southwest monsoon. In: Desai BN (ed) Oceanography of the Indian Ocean. IBH, New Delhi, pp 177–189

Ahmed SI, Khan N, Saleem M, Ali A (1995) Changes in biomass and size fractionated primary productivity in the northern Arabian Sea in response to winter and summer monsoons. In: Thompson MF, Tirmizi NM (eds) The Arabian Sea living marine resources and the environment. Vanguard Books Ltd., Lahore, Pakistan, pp 479–495

Ali-Khan J (1976) Distribution and abundance of fish larvae off the coast of West Pakistan. Mar Biol 37: 305–324

Amjad S, Khan ME, Hashmi MA, Shah AD, Ali-Khan TM (1995) Impact of monsoon reversal on zooplankton abundance and composition in the northwestern Arabian Sea. In: Thompson MF, Tirmizi NM (eds) The Arabian Sea living marine resources and the environment. Vanguard Books Ltd., Lahore, Pakistan, pp 497–508

Baars MA, Schalk PH, Velduis MJW (1995) Seasonal fluctuations in plankton biomass and productivity in ecosystems of the Somali current, Gulf of Aden, and southern Red Sea. In: Okemwa E, Ntiba MJ, Sherman K (eds) Status and future of the large marine ecosystems of the Indian Ocean. A report of the international symposium and workshop. IUCN, Gland, Switzerland, p 211

Banse K (1984) Overview of the hydrography and associated biological phenomenon in the Arabian Sea, off Pakistan. In: Haq BU, Milliman J (eds) Marine geology and oceanography of Arabian Sea and the coastal Pakistan. VNR/SAE Co., New York, pp 271–303

Bogorov VG, Vinogradov ME, Vornina NM, Kanaena IP, Suetova IA (1969) Zooplankton biomass in the ocean surface layer. Dokl Akad Nauk SSSR for Lang Edn 182: 235–237

Bogorov VG, Vinogradov ME (1961) Some characteristics of the plankton biomass distribution in the surface waters of the Indian Ocean in the winter of 1959/60. No. 9. Okeanol Issled Xrazdel programmy 'MGG', Nauk, SSSR, pp 66–71

Buskey EJ (1995) Bioluminescence and growth rates of heterotrophic dinoflagellates on varying algal diets: implication for studies of bioluminescence in the Arabian Sea. In: Thompson MF, Tirmizi NM (eds) The Arabian Sea living marine resources and the environment. Vanguard Books Ltd., Lahore, Pakistan, pp 149–159

Goswami SC, Saparia JS, Bhargava RMS (1992) Zooplankton standing stock assessment and fishery resources in the Indian Seas. In: Desai BN (ed) Oceanography of the Indian Ocean. IBH, New Delhi, pp 217–225

Grobov AG (1968) Quantitative distribution of zooplankton within the 1–100 m layer in the north-western part of the Indian Ocean. Trudy vses Inst Zashch Ras 64: 260–270 (in Russian)

Haq SM, Ali-Khan J, Chughtai S (1973) The distribution of abundance of zooplankton along the coast of Pakistan during post monsoon and pre monsoon periods. In: Zeitzschel B (ed) The biology of the Indian Ocean. Springer-Verlag, New York, pp 257–272

Hastenrath S, Lamb PJ (1980) On the heat budget of hydrosphere and atmosphere in the Indian Ocean. Int J Oceanol Limnol 1: 46–54

IOBC (Indian Ocean Biological Centre) (1968a) Plankton atlas, international Indian Ocean expedition, 1,1,18. NIO/CSIR, New Delhi

IOBC (Indian Ocean Biological Centre) (1968b) Plankton atlas, international Indian Ocean expedition, 1,2,9. NIO/CSIR, New Delhi

Kidwai S, Amjad S, Khan ME (1997) Interannual variability of zooplankton biomass and abundance in the North Arabian Sea The Oceanographic Society 5th Scientific Meeting "Ocean Interfaces", April 1–4, 1997. Seattle, Washington (Abstract ML-40)

Krishnakumari L, Achuthankutty CT (1989) Standing stock and biochemical composition of zooplankton in the northeastern Arabian Sea. Indian J mar Sci 18 (2): 103–105

Madhupratap M, Haridas P, Ramiah N, Achuthankutty CT (1992) Zooplankton of the southwest coast of India, abundance, composition, temporal and spatial variability in 1987. In: Desai BN (ed) Oceanography of the Indian Ocean. IBH, New Delhi, pp 99–112

Madhupratap M, Nair S, Haridas P, Padmavati G (1990) Response of zooplankton to physical changes in the environment, coastal upwelling along the central west coast of India. J cstl Res 6: 413–426

Mathews KJ, Naomi TS, Antony G, Vincent D, Anilkumar R, Soloman K (1990) Studies on zooplankton biomass and secondary and tertiary production of the EEZ of India. In: Mathews KJ (ed) Proc. 1st workshop on scientific results of FORV Sagar Sampada, 5–7 June 1989. CMFRI, Cochin, India, pp 59–69

Mwaluma J (1995) Zooplankton species distribution and abundance during the monsoons off the Kenyan coast, 1992. In: Heip CHR, Hemminga MA, de Bei MJM (eds) Monsoons and coastal ecosystems in Kenya. National Museum of Natural History, Leiden, pp 113–115

Nakagome J (1959a) Annual and monthly variation of fishing conditions and distribution of yellowfin tuna in the Arabian Sea. Bull Jap Soc scient Fish 25: p 6

Nakagome J (1959b) Annual and monthly variation of fishing conditions and distribution of black marlin (*Makaira mozora*) in the Arabian Sea. Bull Jap Soc scient Fish 25: p 6

Paulinose VT, Aravindakshan PN (1977) Zooplankton biomass abundance and distribution in the north and northwestern Indian Ocean. In: Proc. symp. on warm water zooplankton. NIO, Goa, India, pp 132–136

Paulinose VT, Gopalakrishnan KC, Nair KKC, Aravindakshan PN (1992) Stratification of zooplankton in the northwestern Indian Ocean. In: Desai BN (ed) Oceanography of the Indian Ocean. IBH, New Delhi, pp 113–120

Peterson WT (1991) Zooplankton and nekton in the Arabian Sea. US JGOFS: Arabian Sea Process, US JGOFS Planning Report No. 13, WHOI, Woods Hole, Massachusetts

Pickard GL (1963) Descriptive physical and oceanography. Pergamon Press, Oxford

Prasad RR (1968) Maps on the total zooplankton biomass in the Arabian Sea and the Bay of Bengal. IIOE plankton atlas. Vol.1, Fase 1. Indian Ocean Biology Centre, NIO CSIR, New Delhi

Prasad RR (1969) Zooplankton biomass in the Arabian Sea and the Bay of Bengal with a discussion on the fisheries of the regions. Proc natn Inst Sci India (Ser B) 35: 399–437

Qasim SZ (1977) Biological productivity of the Indian Ocean. Indian J mar Sci 6: 122–137

Qasim SZ (1982) Oceanography of the northern Arabian Sea. Deep-Sea Res 29 (9A): 1041–1068

Qureshi NA (1997) Distribution, abundance and diversity of meso zooplankton in the northern Gulf of Mexico. In: Proc. 17th Pakistan Congress of Zoology 5–7 April 1997. Karachi University, Karachi (abstract)

Rao TSS (1973) Zooplankton studies in the Indian Ocean. In: Zeitzschel B (ed) The biology of the Indian Ocean. Springer-Verlag, New York, pp 243–255

Slater RD, Kroopnick P (1984) Controls on dissolved oxygen distribution and organic carbon deposition in the Arabian Sea. In: Haq BU, Milliman J (eds) Marine geology and oceanography of Arabian Sea and the coastal Pakistan. VNR/SAE, New York, pp 305–313

Smith SL (1982) The Northwest Indian Ocean during the monsoons of 1979: distribution, abundance and feeding of zooplankton. Deep-Sea Res 29 (11A): 1331–1353

Smith SL (1984) Biological indications of active upwelling in the northwestern Indian Ocean in 1964 and 1979, and a comparison with Peru and northwest Africa. Deep-Sea Res 31: 951–967

Smith SL (1995) The Arabian Sea: mesoplankton response to seasonal climate in tropical ocean. ICES J mar Sci 52: 427–438

Steedman HF (ed) (1976) Zooplankton fixation and preservations. Monograph on oceanographic methodology. UNESCO Press, Paris

Stephan R, Saraladevi K, Meenakshikunjamna P, Gopalakrishnan T, Saraswathy M (1992) Calanoid copepods of the international Indian Ocean Expedition collection. In: Desai BN (ed) Oceanography of the Indian Ocean. IBH, New Delhi, pp 143–156

Tirmizi NM, Nayeem I (1992) Zooplankton in the northern Arabian Sea. Pakist J Zool 24 (3): 267–268

Tyuleva LS (1974) Seasonal occurrence of productive zones off the west coast of India. Oceanology 13: 268–273 (translation from Okeanologiia 13, 1973)

Williams F (1984) Environmental studies in support of fisheries development and management programs in Pakistan. In: Haq BU, Milliman J (eds) Marine geology and oceanography of Arabian Sea and the coastal Pakistan. VNR/SAE, New York, pp 263–269

Wyrtiki K (1971) Oceanographic atlas of the international Indian Ocean Expedition. National Science Foundation, Washington, DC