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Occurrence and temporal variation in the size-frequency distribution of 2 bloom-forming jellyfishes, *Catostylus perezi* (L. Agassiz, 1862) and *Rhizostoma pulmo* (Cuvier, 1800), in the Indus Delta along the coast of Sindh, Pakistan

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Abstract: Blooms of jellyfishes were studied at 3 sites, namely Bhanbore, Mirpur Sakro, and Keti Bunder. The sampling was carried out from April 2005 to March 2006. Only 2 species of jellyfish, *Catostylus perezi* and *Rhizostoma pulmo*, were found in samples. *C. perezi* was present at all 3 sampling sites, whereas *R. pulmo* was found only at Keti Bunder. Specimens of *C. perezi* appeared in the subsurface waters for a period of 6–8 months during April to August 2006 and February to March 2006. The smallest specimens of *C. perezi* appeared in January, and a gradual increase in size was observed in the population until August. The smallest specimens of *R. pulmo* were found in February, and their largest specimens occurred in July. The numeric abundance of medusae in zooplankton was also studied. They were more abundant at Mirpur Sakro, with a peak in December and January, while at Keti Bunder their highest number was noted in May. Their number at Bhanbore was comparatively lower than at the other 2 sites. No significant difference in physical oceanographic factors such as salinity, pH, dissolved oxygen, and suspended load of the sampling site was found, except for water temperature.

Key words: Northern Arabian Sea, medusae, blooms

1. Introduction

Recently, it has been established that populations of jellyfishes are increasing globally, and their blooms are encountered in coastal ecosystems and seas all over the world (Purcell et al., 2007; Brotz et al., 2012; Purcell, 2012). Rapid increase in abundance of blooms is a natural part of the life cycle of many species of jellyfishes. These blooms usually occur annually, in spring, with larger blooms occurring perhaps every 10–12 years (Queruel et al., 1996), every 20–30 years (Burnett, 1996; Codon et al., 2013), or at intervals of greater than 30 years (Martin et al., 1997). Large blooms have been reported more often and in greater densities throughout the world's oceans recently, and often such outbreaks are associated with global environmental changes (Arai, 2001; Brierley et al., 2001; Graham et al., 2001; Mills, 2001; Purcell, 2005; Xian et al., 2005; Purcell et al., 2007; Uye, 2008; Richardson et al., 2009; Zhang et al., 2009). In recent decades, extensive commercial fishing has depleted fish stocks, removing the highest trophic levels (predatory fishes) throughout the world's oceans (Pauly et al., 1998). It is a well-known fact that jellyfish typically feed on the same kind of prey as many adult or larval fishes do; therefore, it is possible that energy that previously went into the production of fishes may be switched over to the production of pelagic cnidarians or ctenophores (Mills, 1995). The introduction of nonindigenous species of jellyfishes into coastal ecosystems has also resulted in the population explosion of such species (Mills, 2001).

In the last decade, in the northern Arabian Sea along the coast of Pakistan, the blooms of *Catostylus perezi* and *Rhizostoma pulmo* in major creeks of the Indus Delta have adversely affected the local fisheries and threatened local fish stocks (Paryar, 2003). The fishermen of the Karachi area are greatly affected by these sudden blooms of jellyfishes, as they are creating socioeconomic problems by damaging nets and increasing the cost of fishing (Paryar, 2003; Muhammad and Sultana, 2008; Tahera and Kazmi, 2008). Owing to the effect of jellyfish blooms on the local fisheries, the present study was undertaken to provide information about the occurrence and temporal variation in size-frequency of 2 important jellyfishes from the Indus deltaic areas.

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2. Materials and methods

2.1. Sample collection and preservation

The sampling of *C. perezi* and *R. pulmo* was carried out during the period from April 2005 to March 2006 from commercial fishing boats operating at Bhanbore, Mirpur Sakro, and Keti Bunder in the Indus Delta (Figure 1). The jellyfishes were collected from the surface water with the locally used Katra (mesh size: 3.75–7.5 mm), gill (mesh size: 38–89 mm) and Bhoola nets (mesh size: 120–150 mm), respectively, from Bhanbore, Mirpur Sakro, and Keti Bunder. However, occasional sampling was also carried out with the help of dip nets operated by the local fishing trawlers. In total, 1102 specimens of *Catostylus perezi* were collected from all 3 study sites, while *Rhizostoma pulmo* was only found at Keti Bunder; 141 specimens of that species were studied. The identification of jellyfish species was based on characters of these species described by Kramp (1961) and Gul and Morandini (2013).

2.2. Collection of medusae in zooplankton samples

Monthly sampling of zooplankton was carried out for a period of 1 year (April 2005 to March 2006) at Bhanbore, Mirpur Sakro, and Keti Bunder, with a boat towing the Bongo net horizontally in subsurface water for 5 min. The mesh size of the net used for sampling was 300 µm. The samples, when brought on board, were immediately fixed in formalin and were transferred to the laboratory for further study. Three subsamples of 10 mL were analyzed for identification and numeric abundance of medusae. The identification of medusae was made from Wickstead (1962), Newell and Newell (1963), and Santhanam and Srinivasan (1994). The abundance was expressed as individuals per 10 m^2 and was calculated by the formula described by Amjad et al. (1995).

2.3. Measurements

In order to study the size frequency of the 2 bloom-forming species of jellyfishes, the bell diameter (BD) was measured each month to the nearest 0.01 mm. For the measurement

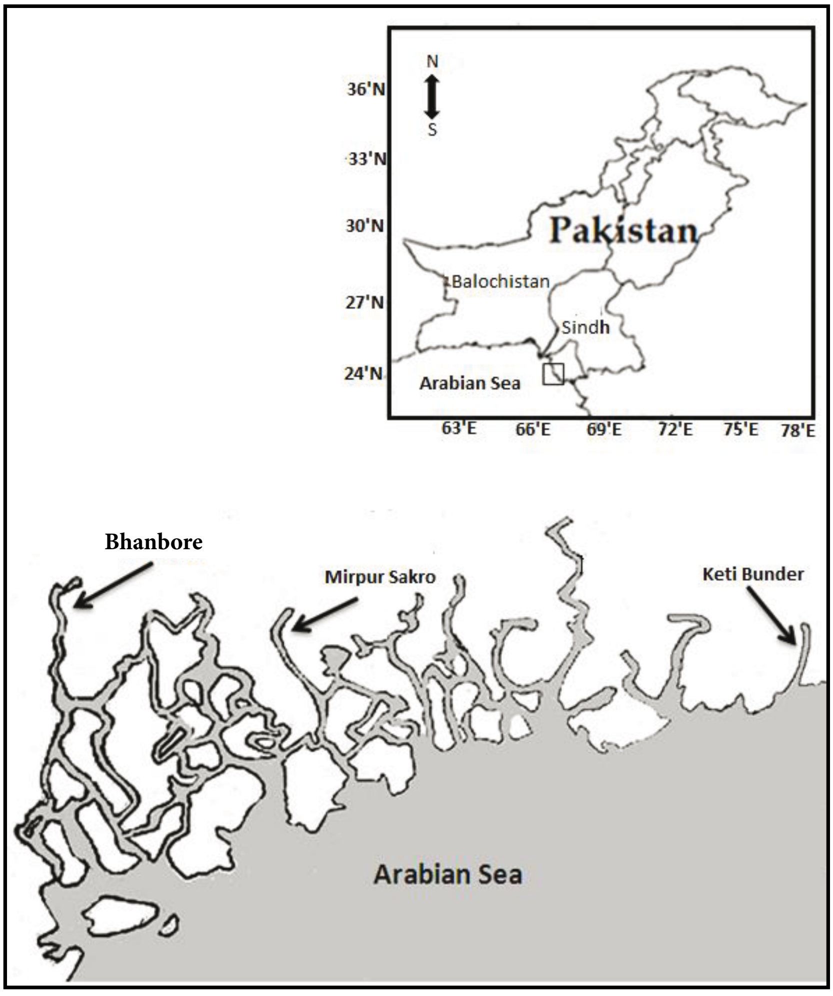

Figure 1. Map showing 3 sampling sites: Bhanbore, Mirpur Sakro, and Keti Bunder.

of BD, the medusae were expanded to their fullest length immediately after being taken out of the water in order to avoid contraction of the bell due to dehydration.

2.4. General oceanographic parameters

Sea surface water temperature, air temperature, salinity, and pH were noted at the time of sampling at each location. For the estimation of dissolved oxygen, the water samples were collected in glass stoppered bottles and immediately fixed by adding KI and $KMnO_4$ onboard. The samples were later analyzed using the Winkler procedure described by Strickland and Parsons (1972). Air and water temperatures were recorded by thermometer, and salinity by handheld refractometer (Atago, S/Mill-E). Suspended load in seawater was measured by following FAO (1975) protocol.

2.5. Statistical analysis

One-way analysis of variance (ANOVA) was performed to test the mean differences in physical parameters in different months.

3. Results

3.1. General oceanographic parameters

The mean salinity at Bhanbore, Mirpur Sakro, and Keti Bunder was 37.83 ± 6.34‰, 33.75 ± 6.97‰, and 34.83 ± 6.90‰, respectively. As shown in Figure 2, the salinity at Bhanbore was 22‰ in September, while it declined to 25‰ from July to September at Mirpur Sakro, and 15‰ in August at Keti Bunder. However, the variation in salinity at the 3 sites was not significant (ANOVA, F = 1.8; $P \geq 0.05$).

No significant difference in pH (ANOVA, F = 1.36; $P \geq 0.05$) was observed among the 3 sampling sites in the study period (Figure 2). The mean pH at all 3 sites was in the range of 7.90 ± 0.10 to 7.96 ± 0.07.

The seawater temperature was significantly different at the 3 sampling sites (ANOVA, F = 3.60; $P \leq 0.05$). At Bhanbore, the mean water temperature was 27.17 ± 3.24 °C, and the lowest temperature (22 °C) was recorded in April (Figure 2). The temperature at Mirpur Sakro

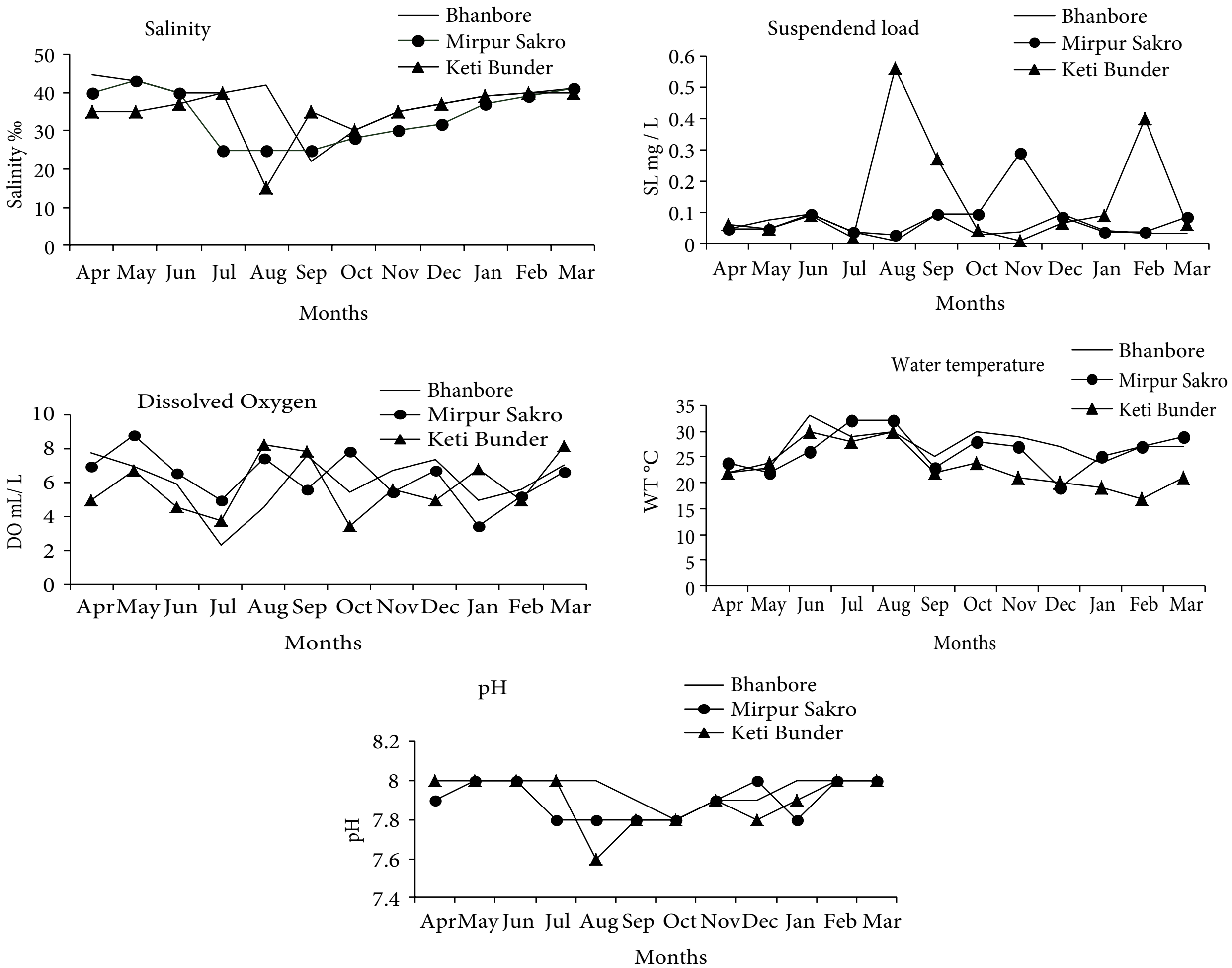

Figure 2. Salinity, pH, water temperature (WT), dissolved oxygen (DO), and the suspended load (SL) in the surface waters of sampling sites.

remained at 26.17 ± 3.90 °C, and the lowest temperature (19 °C) was noted in December. At Keti Bunder, the mean water temperature was 23 ± 4.21 °C.

The comparison of monthly dissolved oxygen (DO) concentration at Bhanbore, Mirpur Sakro, and Keti Bunder showed no statistically significant difference (ANOVA, $F = 0.28$; $P \geq 0.05$). The mean DO concentrations at Bhanbore, Mirpur Sakro, and Keti Bunder were 5.98 ± 1.57, 6.27 ± 1.46, and 5.79 ± 1.68 mL L^{-1}, respectively. Relatively low DO concentrations were observed during July to October at all 3 sites, and also in January at Mirpur Sakro (Figure 2).

The seasonal variation in suspended load (SL) at the 3 sites is shown in Figure 2. At Bhanbore, the mean SL was 0.05 ± 0.03 mg L^{-1}, and at Mirpur Sakro it was 0.08 ± 0.07 mg L^{-1}, whereas at Keti Bunder it was 0.14 ± 0.17 mg L^{-1}. No significant difference in SL (ANOVA, $F = 2.15$; $P \geq 0.05$) was recorded at the 3 sites.

3.2. Temporal variation in size-frequency distribution

3.2.1. *Catostylus perezi*

The mean BD of *C. perezi* was 140.5 ± 73.1 (N = 369), 204.6 ± 81.2 (N = 580), and 133.4 ± 60.4 (N = 157), respectively at Bhanbore, Mirpur Sakro, and Keti Bunder (Table). One-way analysis of variance of mean sizes in different months showed significant variation in BD during the sampling period at Bhanbore ($F = 384.83$; $P < 0.05$), Mirpur Sakro ($F = 39.79$; $P < 0.05$), and Keti Bunder ($F = 59.97$; $P < 0.05$).

At Bhanbore in April, the BD of jellyfishes was 50–199 mm. The highest percentage (41%) was that of jellyfishes of 50–99 mm in size. Only 19% of jellyfishes were of 10–49 mm BD. The mean BD in this month was 76.4 ± 28.6 mm. In May, only intermediate-sized specimens (100–249 mm) were present in the sample, of which 95% of specimens were of <199 BD; the remaining 5% were of 200–249 mm in size. The mean BD in this month was 147.4 ± 27.9 mm. The medusae procured in June showed a wide size range. However, the population mainly belonged to the size classes of 200–249 and 250–299 mm BD. The largest (300–349 mm) specimens were also found during this month, but they accounted for only 5.5% of the population. The mean BD in June was 229.90 ± 36.0 mm. No jellyfish was found in the July to December period at this site; they reappeared in January, but 96% of the specimens of the total sample procured were of the smallest size (10–49 mm). The mean BD in this month was 23.00 ± 6.9 mm, while the remaining 4% were of 100–149 mm BD. In February, specimens of 50–99 mm in size with a mean BD of 81.4 ± 24.7 mm were most abundant, amounting to 75% of the sample. The size class of 100 to 149 mm was represented by 15% of the individuals, and the remaining 10% belonged to the size class of 150–199 mm. In March the specimens' BD was 50–249 mm, and jellyfishes of 150–199 mm in size constituted 58.3% of the total sample. The average BD in this month was 179.6 ± 22.0 mm (Table; Figure 3).

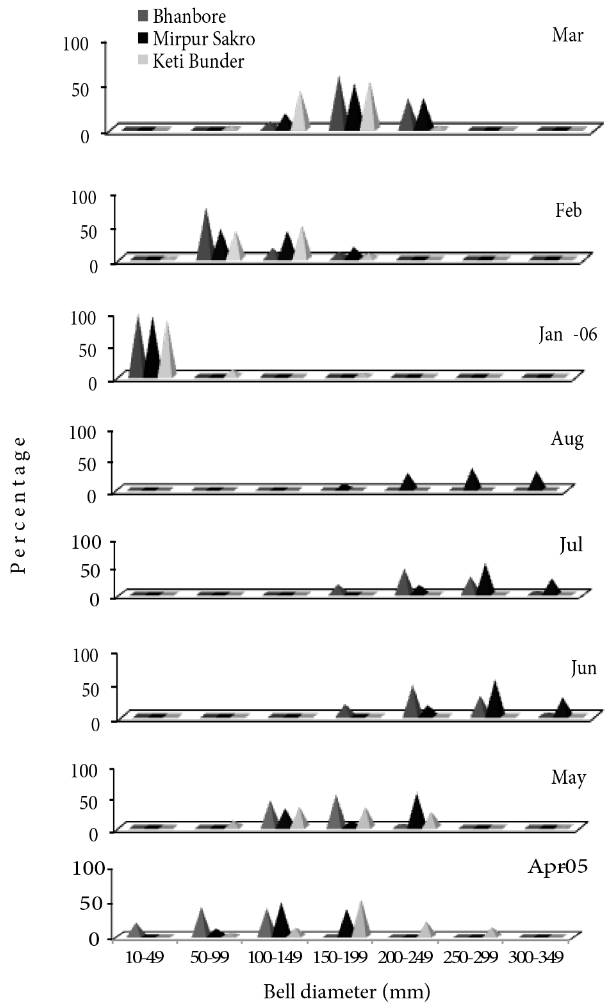

Figure 3. Temporal variation in size distribution in 3 populations of *C. perezi*.

At Mirpur Sakro in April, nearly half of the specimens (48%) belonged to the size class of 100–149 mm, followed by the size class of 150–199 mm BD (amounting to 38% of the sample). The largest specimens were not found during this month. The mean BD in this month was 126 ± 33.3 mm. In May, intermediate-sized groups predominated and the highest percentage (55) was of size class 200–249 mm, followed by 100–149 mm (30%). The specimens with >250 mm BD constituted only 4% of the population. The smallest specimens were also found in this month, but in very low numbers (1%). The mean BD in May was 186.7 ± 45.5 mm. During June, *C. perezi* of <150 mm BD were not found, and the larger jellyfishes dominated the population. The highest percentage (54.5%) was jellyfishes of 250–299 mm BD, followed by specimens of 300–349 mm in size, which amounted to 27.3%; the remaining were of 150–

Table. Monthly variation in bell diameter (mean ± SD) of *C. perezi* and *R. pulmo* from 3 sites during the sampling period. N: sample size, SD: standard deviation.

	Catostylus perezi						*Rhizostoma pulmo*	
	Bhanbore		Mirpur Sakro		Keti Bunder		Keti Bunder	
Months	N	Mean ± SD (mm)	N	Mean ± SD (mm)	N	Mean ± SD (mm)	N	Mean ± SD (mm)
Apr-05	100	76.4 ± 28.6	100	126.6 ± 33.3	25	184.0 ± 42.3	75	632.3 ± 177.4
May	100	147.4 ± 27.9	100	186.7 ± 45.5	38	160.1 ± 47.6	25	466.5 ± 159.1
Jun	99	229.9 ± 36.0	100	274.1 ± 35.3				
Jul			100	260.6 ± 45.8	19	157.9 ± 48.9	6	497.2 ± 92.4
Aug			99	260.3 ± 45.9				
Sep								
Oct								
Nov								
Dec								
Jan-06	25	23.0 ± 6.9	26	26.7 ± 9.1	20	28.8 ± 10.4		
Feb	20	81.4 ± 24.7	30	102.8 ± 30.4	25	99.2 ± 24.4	15	202.7 ± 38.0
Mar	25	179.6 ± 22.0	25	172 ± 32.8	30	142.1 ± 29.6	20	298.4 ± 124.1
Total	369	140.5 ± 73.1	580	204.6 ± 81.2	157	133.4 ± 60.4	141	400.2 ± 316.1

249 mm in size. In this month, mean BD was 274.1 ± 35.3 mm. In July, although specimens ranging from 100 to 349 mm in size were present, individuals of 200–349 mm dominated the population. The highest percentage (34%) was of specimens of 250–299 mm, followed by the size class of 300–349 mm, which constituted 32% of the sample procured, and the mean BD was 260.3 ± 45.9 mm. In August, specimens representing 200–349 mm BD were found. The highest percentage (34.3%) was of jellyfishes with 250–299 mm BD. However, medusae with <50 mm BD also reappeared in this month (1.0%). The mean BD was 260.3 ± 45.9 mm. No specimens of *C. perezi* were found from September to December at this sampling site. In January, jellyfishes started to reappear; the smallest (10–49 mm) individuals predominated (92.3%) in the population, and the mean BD was 26.7 ± 9.1 mm. In February, medusae measuring 50–99 mm BD were most abundant (43.3%), followed by those measuring 100–149 mm (40%). In March, the smallest jellyfishes completely disappeared in the samples and intermediate-sized specimens were predominant in the population. The highest percentage (50%) was of individuals of 150–199 mm in size, followed by 200–249 mm (33.3%). The mean BD in March was 172.0 ± 32.8 mm (Table; Figure 3).

During *C. perezi* sampling at Keti Bunder, in April 52% of the jellyfishes belonged to the size class of 150–199 mm BD, and the mean BD in this month was 184.0 ± 42.3 mm. In May, larger individuals were present in the sample and were represented by equal numbers of individuals (32%) in the size classes of 100–149 mm and 150–199 mm BD. The mean BD was 160.1 ± 47.6 mm. In July, the smallest individuals (10–49 mm) appeared in the sample, but in very small numbers (5.3%). The jellyfishes of 150–199 BD dominated the population, amounting to 36.8% of the sample procured, followed by jellyfishes of 200–249 mm BD (26.3%). The mean BD was 157.9 ± 48.9 mm. No specimen of this species was found during the August to December period. In January jellyfishes reappeared in the subsurface waters, and 85% of them were of 10–49 mm BD; the mean BD in this month was 28.8 ± 10.5 mm. In February the BD increased to 99.2 ± 24.4 mm, and the highest percentage (48%) was of specimens of 100–149 mm BD, while specimens of 50–99 mm BD constituted 40% of the sample. In March, 51.7% jellyfishes belonged to the size class of 150–199 mm BD, followed by 100–149 mm (41.4%), and the mean BD in this month was 142.1 ± 29.6 mm (Table; Figure 3).

3.2.2. *Rhizostoma pulmo*

Rhizostoma pulmo was found at Keti Bunder only, and it appeared in surface waters during April, May, and July 2005 and February and March 2006 (Table; Figure 4). In April the mean BD was 632.3 ± 177.4 mm, and medusae of 410–600 mm BD made up 48% of the population. Individuals of <600 mm were abundant in May and July. No specimen was found in the August to January period. In February, the smallest specimens, belonging to the size class of 110–200 mm, were abundant and constituted 60% of the sample. The mean BD was 202.7 ± 38.0 mm in this month, but the size increased to 298.4 ± 124.1 mm in March, when medusae of 210–400 mm constituted 85% of the sample (Table; Figure 4).

3.3. Medusae collected in zooplankton nets

In the present study, an attempt was made to study medusae collected in the zooplankton samples. At Bhanbore, the numeric abundance of medusae ranged between 5310 m^{-2} in May and 6790 m^{-2} individuals in March. At Mirpur Sakro, the numeric abundance of medusae was 116,330 m^{-2} in the total zooplankton sample. Two instances of peak abundance, 34,300 m^{-2} and 33,090 m^{-2}, were observed in December and January, respectively. At Keti Bunder, medusae were found in May, September, November, January, and March. Their highest number (17,390 m^{-2}) was noted in May and lowest in November (3730 m^{-2}) (Figure 5).

4. Discussion

In the present study, the blooms of 2 species of jellyfishes, namely *C. perezi* and *R. pulmo* of Rhizostomeae, were observed. *Catostylus perezi* occurred at all 3 sites, while *R. pulmo* was found only at Keti Bunder. Earlier, the occurrence of *C. mosaicus* (which is now identified as *C. perezi*) and *R. pulmo* along the Sindh coast had also been reported by Tahera and Kazmi (2008) and Muhammad and Sultana (2008). The blooms of jellyfish *C. perezi* were evident at all 3 sites during the January to August period, while those of *R. pulmo* were seen during February to July at Keti Bunder only. It was reported in earlier studies that the life cycle of jellyfishes is seasonal and they can form large aggregates, appearing and disappearing with great annual regularity (Pitt, 2000). Similarly, *C. mosaicus* is also an estuarine species and reported to aggregate within 1 km offshore on the eastern coast of Australia; furthermore, 10% of jellyfish species so far known have a maximum depth range of 25 m and they aggregate in estuaries and bays in groups of thousands of individuals (Kramp, 1965; Kingsford and Pitt, 1998).

In the present study, *C. perezi* was found in the surface waters for 6–8 months. At Bhanbore, this species was present during April to June and January to March; at Mirpur Sakro it was present in April to June, August, and the January to March period. However, at Keti Bunder, it was present throughout April, May, July, and January to March. The lifespan of the related *C. mosaicus* has been reported to exceed 10 months, but that can vary with location (Kingsford and Pitt, 1998). The disappearance of *C. perezi* in the months of June or July or August at the 3 sampling sites may be related to the fact that this period is characterized by the turbulent monsoon season, which is further aggravated during high spring tides, resulting in extremely rough conditions in the coastal waters of Pakistan. It has been reported that jellyfishes display vertical migration during periods of strong wind, heavy rain, strong currents, and intense sun, and they confine themselves to deeper layers in the water column, whereas in cooler conditions with less wind or fewer waves, they move to subsurface waters (Kingsford et al., 2000). The occurrence of *C. perezi* for a longer period (8 months) and in relatively greater numbers at Mirpur Sakro as compared to Bhanbore and Keti Bunder could be due to the topography of the sampling sites, as Mirpur Sakro is an enclosed estuary forming a channel providing a protected environment during the rough SW monsoon season. Similarly, Pitt and Kingsford (2000) reported from Australia that *C. mosaicus* occurs in greater abundance in inner estuaries and at sites close to the mouth of rivers. It was further stated that after gonad maturation and subsequent sexual reproduction, they die in winter due to low temperatures, or this is genetically determined, and their lifespan is usually less than 1 year (Uye, 2008).

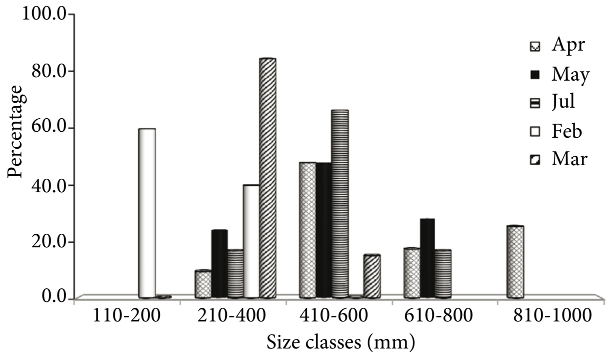

Figure 4. Temporal variation in size frequency distribution of *R. pulmo* at Keti Bunder during the study period.

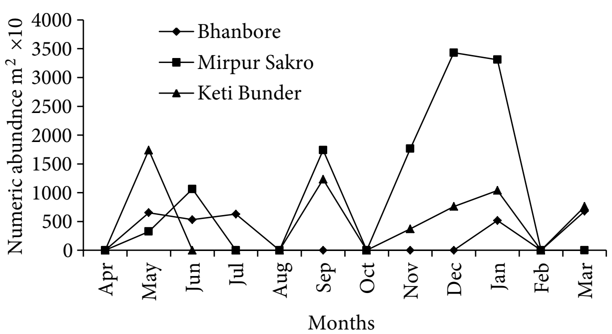

Figure 5. Temporal variation of jellyfish medusae in zooplankton samples.

The temporal variability in the size-frequency distribution of *C. perezi* at all 3 sites clearly showed that the smallest medusae of *C. perezi* appeared in the surface water in January; they gradually increased in size until August. After that, they completely disappeared from the surface water. However, the smallest medusae of *R. pulmo* appeared in February and the larger individuals were observed until July. In the zooplankton samples studied during the present study, medusae were present in the samples from September to January, with the exception of October, at Mirpur Sakro and Keti Bunder. This could be due to the fact that in the polypoid phase, due to strobilation, the jellyfish continuously release their larvae, but jellyfish greater than 10 mm in size do not come to the subsurface water before January. Earlier, it was reported that the recruitment of scyphomedusae in addition to strobilation of polyps depends on several factors, such as survival rates of ephyrae (Kikinger, 1992; Kingsford et al., 2000), availability of appropriate food (Olesen et al., 1996; Bamstedt et al., 1997; Purcell et al., 1999), light (Custance, 1964), and temperature (Loeb, 1972). Furthermore, the interaction of multiple factors such as temperature and salinity also plays an important role (Rippingale and Kelly, 1995; Purcell et al., 1999).

The variation in the BD of *C. perezi* at the 3 sites could be due to the different types of nets used by local fishermen from whom the samples were procured. The comparison of the physical parameters of the sampling sites revealed that there was no significant difference in the physical conditions among the collection sites except for the water temperature, which may be due to the difference in sampling time. The salinities at 2 collection sites, i.e., Bhanbore and Keti Bunder, ranged between 35‰ and 45‰ with the exception of a few months when salinities were low. However, at Mirpur Sakro the salinity remained between 25‰ and 32‰ from July to December 2005, while in the remaining months it was >32‰. The prevalence of 25‰–32‰ salinity during the 6-month period at Mirpur Sakro shows the influx of fresh water in the system, although estuaries or tidal creeks along the Sindh coast are characterized by high salinities as a result of reduction in rainfall and, consequently, reduction in the runoff from the Indus River into the sea (Ahmed and Rizvi, 1980; Rizvi et al., 1988). The increase in salinity can result in the introduction of fauna from hypersaline environments; therefore, fish and shellfish of the normal saline and brackish water could disappear from the creeks and backwaters (Ahmed, 1999). Therefore, the possibility of disappearance of predators of jellyfishes from these waters could not be ruled out, and this could be one of the reasons for their blooms in estuarine waters. This is the first report on the temporal variation of jellyfishes from the northern Arabian Sea. Further detailed study of ecological and physical factors is required to understand the pattern of jellyfish blooms in the coastal waters of Pakistan.

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