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Short-term impact of cyclone Yass on the copepod community of Muriganga estuary of India

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Abstract

Tropical cyclones (TCs) are discrete events that affect ecology of estuaries. On 26 May 2021, TC Yass (category-1) disrupted the Muriganga estuary (ME), West Bengal coast, India. Authors assessed short-term cyclone-mediated changes of the copepod community by sampling three stations on the ME before and after TC Yass. Copepod and water samples collected on November 2020, and January and April 2021 were assumed as pre-Yass samples. Post-Yass samples were collected between 4 and 22 June 2021 once in every 6 days. It was hypothesized that diversity, total abundance and dominance of the copepods of the ME were impacted by TC Yass. Post-Yass the ME turned polyhaline from its meso-haline characteristic. Post-Yass species richness was higher than the pre-Yass period. Pre-Yass *Bestiolina similis* was the most abundant species, and species such as *Paracalanus parvus* and *Acartiella tortaniformis* co-dominated the copepod community. Post-Yass, *Acartiella tortaniformis* was the most abundant species of the copepod community followed by *Oithona brevicornis* and *Paracalanus parvus*. Post-Yass, total abundance of cyclopoid copepods was higher than the pre-Yass. Spatial heterogeneity of the copepods, which was observed during the pre-Yass was lost in the post-Yass period. Those changes in composition and abundances may have cascading consequences for the ecology of the copepods in the ME. Such changes could be traced through a high frequency sampling (e.g., daily to weekly) starting within the first week of a TC impact followed by a medium (e.g., monthly interval) frequency sampling based on the intensity of a TC, resident time of water in an estuary and the complexity of its copepod community.

Keywords Diversity, Dominance, *Oithona*, Indian Sundarbans, Copepod monitoring

1 Introduction

Tropical cyclones (TCs) are discrete events that temporarily disrupts the lives and livelihoods of ecological communities of many coastal ecosystems including estuaries [19]. Lack of predictability of a TC track, immediate mobility of the scientific infrastructures and human resources following a TC are the barriers before cyclone research of estuaries unless regular institutional monitoring programs are in place [22–24, 27]. Furthermore,



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estuaries come with various shapes, sizes, hydrology, ecology, therefore, a monitoring plan has to be estuary type specific [31, 32].

Cyclone ecology research programs of river-estuaries are globally rare except a few that are running in estuaries of the United States and India [24]. Those programs have shown that the distance to the landfall site and the intensity of the floods associated with a TC causes the major disruptions of the plankton communities of a river-estuary, and the windspeed of a TC has less to do with the mechanical disruption of the structural components of a zooplankton community [24]. Among zooplankton copepods are often the majority so the changes in their community structure (e.g., composition, abundance, dominance hierarchy) have been monitored by estuarine scientists before-after a stochastic event e.g., TC, for evaluating the cascading consequences on the lower food web and such has been done in the estuaries of the United States, South Africa, Taiwan, and India [2, 3, 6, 22–24, 28].

The intensity of the TCs are increasing in the Bay of Bengal (BoB) [1, 16], therefore, evaluation of their impacts (e.g., immediate (a few days), short-term (a few weeks to a month), medium-term (a few months to a few seasons) and long-term (years to decades)) are becoming more essential than before. Considering that need, the 'Cyclone Ecology (CE)' research program was established by the authors in 2019 on the Muriganga estuary (ME) (see details in [22–24]). The CE research program uses the copepods as a model community for assessing the before-after impacts of a TC and/or successive TCs on the ME [22, 23] a, b, 2023).

The TC Yass (Category-1) landfall on 26 May 2021 near the Dhamra Port of the Balasore region, Odisha state of India with a maximum sustained wind speed of 130–140 km.h⁻¹ gusting up to 155 km.h⁻¹ [20]. On the same day, after its landfall it progressed towards the coastal regions of the West Bengal. The TC Yass passed the permanent sampling stations of the 'CE' program sites on the ME on 26 May 2021. In that time the BoB sea surface temperature dropped about 3 °C, salinity and density had raised by 1 PSU and ~2 kg/m³, respectively [30]. Indian Tide Table 2021 published by the order of the Surveyor General of India in 2020, showed that the astronomical high tide on 26 May 2021 of Sagar Island (close to the permanent sampling stations on the ME) reached as high as 5.71 m. The Yass has brought with it a high storm surge of 3.5 to 5 meters in the coasts of the Odisha and West Bengal and the tidal waves of height 1 to 2 m above the astronomical tide were observed [16, 30]. Further, during the Yass 1195 mm of rainfall occurred in short-time so a massive inundation occurred on the both sides of the ME [7, 20]. Floods following a cyclone generally exert considerable mechanical forcing to the copepod community of the ME [24]. The objective was to use the copepods as model community to understand the structural changes of the lower food web of the ME. Consequently, the copepod community of the ME were studied following a before-after sampling design to detect changes in consequence to TC Yass. It is, therefore, hypothesized that the copepod community structure (diversity, abundance, dominance) of the ME is significantly impacted by the TC Yass. The results may help in establishing a short-term monitoring program on copepods of a tropical river-estuary affected by a TC or successive TCs.

2 Material and methods

2.1 Study site

The ME is a part of the Indian Sundarbans and it generally remains mesohaline and slightly basic ($\text{pH} > 8$) except during monsoon months when it receives excessive rainfall (70% rainfall of annual average of 1600 mm) [18]. The study was conducted from the permanent sampling stations of the CE program (i.e., S1, S2 and S3). Those stations have been established in February 2019 on the ME as a part of the long-term monitoring of the CE research program (Fig. 1). Those permanent sampling stations follow a north–south direction on the ME. The S1 ($21^{\circ}44'53.8''\text{N}, 88^{\circ}12'46.2''\text{E}$) is toward the north, S3 is the southern most site ($21^{\circ}44'55.4''\text{N}, 88^{\circ}12'36.8''\text{E}$) and S2 ($21^{\circ}44'55.7''\text{N}, 88^{\circ}12'40.0''\text{E}$) stands at the middle almost equal distance from S1 and S2 (Fig. 1) [25].

2.2 Field sampling

On the occasions of the 21 November 2020, 29 January 2021 and 19 April 2021, copepod assemblages and water were sampled. Those samples were assumed as the samples of the pre-cyclone conditions. The inundation that followed the TC Yass (landfall: 26 May 2021) caused a massive damage to the infrastructure including roads to the Namkhana (adjacent to the ME) West Bengal, India. Further, mobilisation of scientific resources during the COVID-19 pandemic was difficult. Post-Yass, the copepod assemblages and water sampling were carried out on four occasions once in 6 days interval i.e., between 4 and 22 June 2021 after the TC Yass passed the ME. Those samples were assumed to represent the post-Yass condition. On sampling days, copepod assemblages ($> 200 \mu\text{m}$) were collected in triplicate from each sampling station by a $200 \mu\text{m}$ horizontal plankton net (diameter: 60 cm; length: 3 m) fitted with a mechanical flowmeter (HydroBios, Germany) towed for 3 min from a dinghy boat after sunset on high tide from sub-surface water depth between 0.3–0.5 m. Simultaneous to copepod sampling, salinity (PSU),

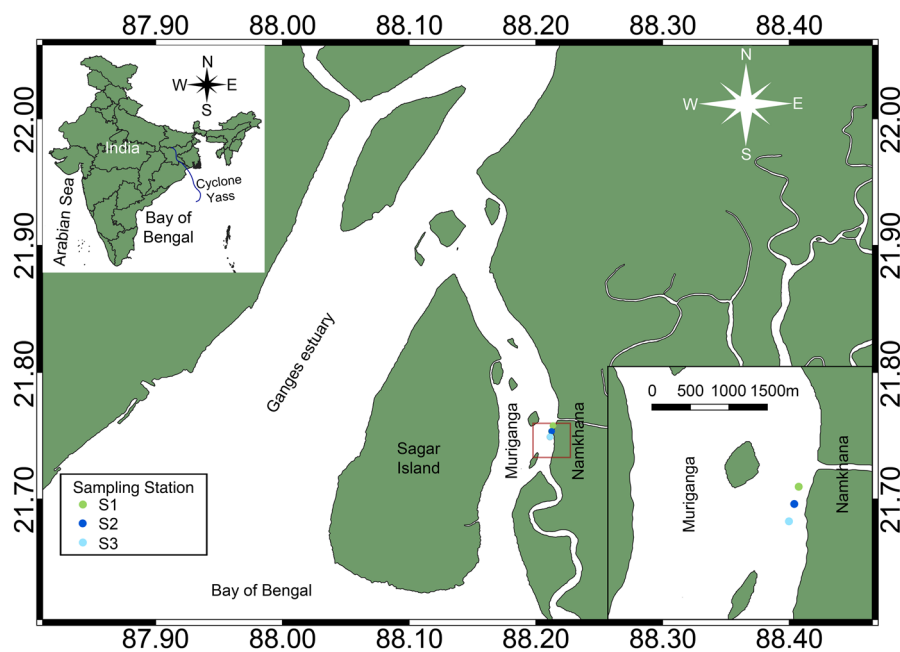


Fig. 1 Map of the sampling stations on the Muriganga estuary of India and the track of the tropical cyclone Yass (after [24])

water temperature (°C) and pH were recorded from the sub-surface (0.3–0.5 m depth) water by a multi-parameter probe (YSI-1030; USA).

2.3 Laboratory processes

Copepod assemblages were preserved in 4% formalin and brought to the laboratory for species level identification (at least 1% volume of all the replicates were analysed) by following the Kasturirangan [9] under the microscope (Bestscope-BS30T, China). Abundances (adults only, not sexed) of each copepod species were expressed as individual(s) per cubic metre (i.e., ind.m⁻³).

2.4 Statistical analysis

Abiotic data are presented in Table 1 for providing a reference of the hydrological condition of the ME before-after the TC Yass. The hypothesis that is currently under consideration never intended to draw any correlation between the abiotic variability and the copepod assemblages so any such analysis was avoided. Diversity indices were calculated by using the ‘vegan’ package version 2.6–10 using CRAN-R 4.4.3 [26]. Sampling station-specific total and relative abundances of the copepods were calculated and presented in Table 3, 4. For ordination analysis species abundance data were square root transformed. Non-metric Multidimensional Scaling (NMDS) analysis was conducted using the Bray–Curtis measure of dissimilarity and a dendrogram (Fig. 2) was drawn using PRIMER version 7 [4]. Permutational Multivariate Analysis of Variance (PERMANOVA) was conducted (i.e. Adonis test, permutations = 999, method = Bray–Curtis, package: ‘Vegan’ version 2.6–10) to test the variations of the copepod assemblages among the sampling sites. For the PERMANOVA an assumption of the homogeneity of the multi-variate dispersion was tested by conducting Analysis of Variance (ANOVA). Similarity percentage analysis (i.e. SIMPER) was conducted for assessing the similarity and dissimilarity of the copepod assemblages by using the package ‘Vegan’ version: 2.6–10 of the CRAN-R 4.4.3 [26]. All the statistical analysis was carried on CRAN-R 4.4.3. Level of significance was set at 95% and the values of t, p, Pseudo-F, F and DF were reported as test statistics.

3 Results

3.1 Abiotic variability

During the pre-Yass the salinity remained consistently ranged between 7.50 and 17.90 (Table 1). After the TC Yass the salinity of the ME remained consistently ranged 15.90 to 20.80 for a few weeks (Table 1). The pre- and post-Yass levels of the pH of the ME were

Table 1 Variability of the salinity (PSU), water temperature (°C) and pH of the sampling stations on the Muriganga estuary of India before and after the tropical cyclone Yass

Condition	Sampling Date	Salinity (PSU)			Water temperature (°C)			pH		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
Before tropical cyclone Yass	21.11.2020	7.50	7.65	7.70	26.90	26.80	26.80	7.50	7.48	7.54
	29.01.2021	12.20	12.50	12.70	21.40	21.40	21.50	6.83	7.69	7.63
	19.04.2021	17.50	17.90	17.60	29.40	30.30	29.80	8.13	8.30	8.30
After tropical cyclone Yass	04.06.2021	20.80	19.70	19.80	30.80	31.20	31.10	7.88	8.19	8.21
	10.06.2021	18.20	18.30	18.30	29.10	29.10	29.10	8.12	8.13	8.12
	16.06.2021	18.30	18.10	18.30	30.10	30.10	30.10	7.89	7.86	7.91
	22.06.2021	16.20	15.90	15.90	28.90	28.90	28.70	8.00	8.11	8.13

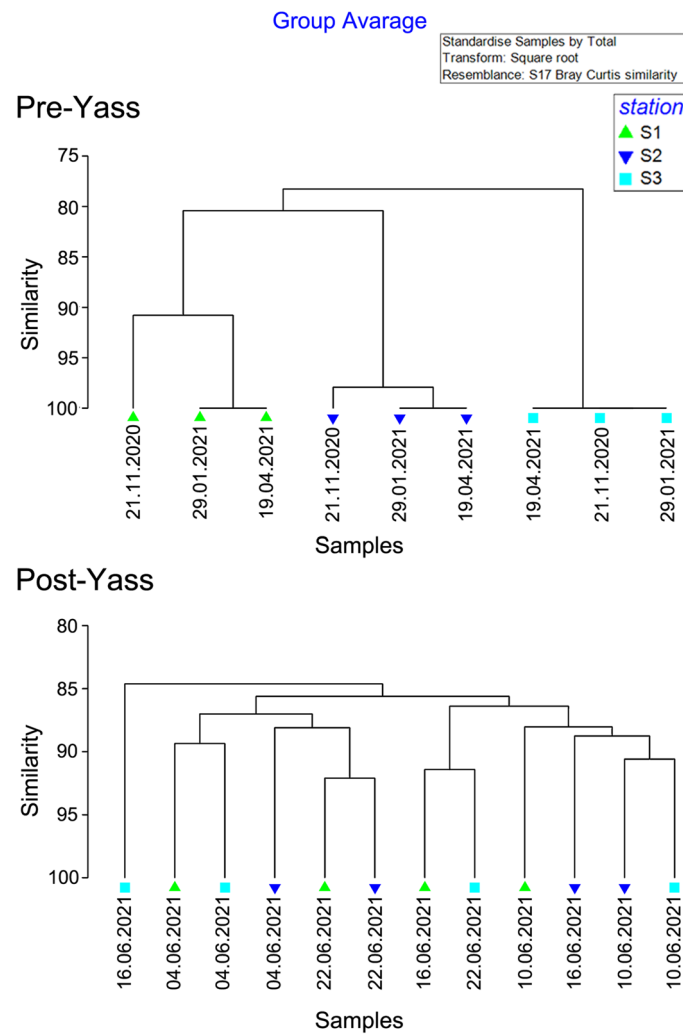


Fig. 2 Dendrogram for assessing the spatial variability of the copepod community sampled from the Muriganga estuary of the India before and after the tropical cyclone Yass

slightly alkaline (Table 1). The water temperature in the post-Yass period varied from 29.10 to 31.20 °C. During the pre-Yass period the water temperature varied from 21.40 to 30.30 °C (Table 1).

3.2 Copepod community before-after Yass

Before the TC Yass the species richness ranged 17 to 20 whereas after the TC Yass the species richness ranged 20 to 24 (Table 2). The Shannon-diversity during the pre-Yass condition ranged 2.37 to 2.61 but the range was 2.79 to 3.00 during the post-Yass period (Table 2). During the pre-Yass the Simpson and Pielou's indices ranged 0.87 to 0.90 and 0.82 to 0.87, respectively (Table 2). Post-Yass, those indices ranged 0.93 to 0.95 and 0.93 to 0.96, respectively (Table 2). Between November 2020 and April 2021 species such as the *Bestiolina similis*, *Paracalanus parvus* and *Acartiella tortaniformis* co-dominated the copepod community of the ME and among them *Bestiolina similis* was the most abundant species contributing up to 20.52% of the total abundance of the community (Table 3, 4). Species such as *Bestiolina similis*, *Paracalanus parvus*, *Acartiella tortaniformis* and *Acartia spinicauda* co-dominated the copepod community after the

Table 2 Variability of the diversity indices of the copepods sampled from the different sampling stations of the Muriganga estuary of India before and after the tropical cyclone Yass

Condition	Sampling Date	Species Richness			Shannon Index			Simpson Index			Pielou's Index		
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Before tropical cyclone Yass	21.11.2020	17	19	20	2.37	2.49	2.61	0.87	0.89	0.90	0.84	0.85	0.87
	29.01.2021	19	19	20	2.51	2.41	2.61	0.89	0.87	0.90	0.85	0.82	0.87
	19.04.2021	19	19	20	2.51	2.41	2.61	0.89	0.87	0.90	0.85	0.82	0.87
After tropical cyclone Yass	04.06.2021	20	20	20	2.79	2.85	2.80	0.93	0.93	0.93	0.93	0.95	0.93
	10.06.2021	21	22	23	2.88	2.97	3.00	0.94	0.94	0.94	0.95	0.95	0.96
	16.06.2021	22	22	20	2.98	2.91	2.89	0.94	0.94	0.94	0.96	0.94	0.96
	22.06.2021	22	22	24	2.97	2.90	3.05	0.94	0.94	0.95	0.96	0.94	0.96

TC Yass but their abundances declined from the pre-Yass period (Table 3, 4). Post-Yass *Acartiella tortaniformis* had the highest abundance in the copepod community and it was the dominant species in terms of its relative abundance too (Table 3, 4). After the TC Yass relative abundances of species such as *Canthocalanus pauper*, *Temora turbinata*, *Corycaeus crassiusculus* Dana and *Oithona* spp. were higher than the pre-Yass (Table 4). After the TC Yass, cyclopoid copepod *Oithona brevicornis* co-dominated the copepod community (Table 3, 4). Species such as the *Labidocera euchaeta* and *Oithona nana* were not present in the copepod assemblages which were sampled before the TC Yass but those species were present in the samples of the post-Yass period (Table 3, 4). Before the TC Yass, the copepods of the Paracalanidae (cumulative abundance 49 to 59%) family dominated the community followed by the Acartiidae (cumulative abundance 27–33%) and the Oithonidae (cumulative abundance 3–8%). After the Yass the contribution of the copepods of the Paracalanidae family in the total abundance of the community declined to 28 to 35% and the Acartiidae family declined to 17 to 29%. The contribution of the Oithonidae family raised to 13 to 19% of the total abundance of the copepod community in post-Yass. The NMDS, followed by the dendrogram (Fig. 2) and the PERMANOVA analysis before the TC Yass period revealed a significant sampling station-specific variability of the copepod assemblages (PERMANOVA: DF = 2, Pseudo-F = 17.66, $R^2 = 0.85$, $P = 0.005$; homogeneity of the multivariate dispersion test ANOVA: DF = 2, $F = 0.4$, $P = 0.95$). Those analysis carried on the post-Yass dataset suggested that the sampling station-specific variability of the copepod assemblages was not significant (PERMANOVA: DF = 2, Pseudo-F = 0.41, $R^2 = 0.08$, $P = 0.95$; homogeneity of multivariate dispersion test ANOVA: DF = 2, $F = 0.28$, $P = 0.76$) (Fig. 2). The SIMPER analysis suggested that the average similarity of the copepod assemblages before Yass was 37.04% (chiefly contributed by the species such as *B. similis* 18.94%, *P. parvus* 17.82% and *A. tortaniformis* 14.83% and *A. spinicauda* 10.35%) and the average dissimilarity was 66.21% (chiefly contributed by the species such as *A. tonsa* 10.84%, *O. similis* 9.34, *A. longicornis* 7.74% and *B. similis* 6.98%). After the TC Yass the average similarity within the copepod assemblages of the ME did rise to 77.09% (chiefly contributed by the species such as *A. tonsa* 10.7%, *O. similis* 9.43, *P. parvus* 8.56% and *A. longicornis* 8.13%).

4 Discussion

4.1 Habitat characteristics

Muriganga is a macro-tidal river-estuary where salinity varies widely with semi-diurnal tides, seasonal changes and stochastic events such as cyclones [18, 22, 23] a, b [24, 25]). The sampling stations on the ME are in closely proximity to sea but the estuary receives large influx of freshwater from its upstream (i.e., Ganges River locally known as the Hooghly River), therefore, at the time of ecosystem stability it maintains a mesohaline characteristic [18]. Shortly after the TC Yass, salt water intrusion from the adjacent BoB had turned the estuary from a mesohaline to a polyhaline one and that continued for weeks. After the TC Aila the ME did remain polyhaline for a considerable time [3, 15]. In contrast to the present results, the TC Fani, Bulbul and Amphan which successively disrupted the ME between May 2019 and May 2021 did not have such an impact on the salinity regime of the ME [22, 23]. The pH profile of the ME generally remains slightly alkaline throughout the year unless there is an excessive rain which lowers the pH specially in monsoon [18]. After the TC Yass, alkalinity of the ME remained high, which is

Table 3 Abundances (ind.m⁻³) of the copepod species sampled from the different sampling stations of the Muriganga estuary of India before and after the tropical cyclone Yass

Order	Species	Before cyclone Yass			After cyclone Yass		
		S1	S2	S3	S1	S2	S3
Calanoida	<i>Acartia sewelli</i>	1440	0	1560	7250	6033	6967
	<i>Acartia spinicauda</i>	10,080	11,183	10,920	15,083	16,133	15,783
	<i>Acartia tonsa</i>	0	2237	1560	6383	3433	7800
	<i>Acartia tropica</i>	0	0	4680	1700	2100	833
	<i>Acartiella tortaniformis</i>	14,400	17,893	14,040	23,983	24,033	21,217
	<i>Acrocalanus gibber</i>	3687	0	0	0	0	0
	<i>Acrocalanus gracilis</i>	3687	2237	6240	9417	9400	10,217
	<i>Acrocalanus longicornis</i>	1613	2237	1560	5550	6967	4917
	<i>Bestiolina similis</i>	18,087	24,507	14,040	17,567	16,200	17,917
	<i>Canthocalanus pauper</i>	1440	2237	1560	10,300	8000	8733
	<i>Labidocera acuta</i>	0	2237	0	0	0	1717
	<i>Labidocera euchaeta</i>	0	0	0	5117	3700	4550
	<i>Paracalanus aculeatus</i>	5127	2237	1560	6433	9000	7150
	<i>Paracalanus dubia</i>	807	6710	3120	1750	3067	1583
	<i>Paracalanus indicus</i>	2247	2237	1560	7733	8067	7200
	<i>Paracalanus parvus</i>	13,767	23,340	15,600	18,467	16,700	17,917
	<i>Parvocalanus crassirostris</i>	1440	2237	4680	6967	6767	4967
	<i>Pseudodiaptamus binghami</i>	1440	0	0	3800	2933	5017
	<i>Pseudodiaptamus serricaudatus</i>	2880	4473	3120	9367	11,733	15,517
	<i>Subeucalanus crassus</i>	0	0	1560	817	933	1717
<i>Subeucalanus subcrassus</i>	1440	2237	0	5550	5300	6267	
<i>Temora turbinata</i>	1440	2237	1560	11,167	10,400	12,533	
Cyclopoida	<i>Corycaeus danae</i>	1440	2237	1560	6000	10,900	9467
	<i>Oithona brevicornis</i>	2880	4473	6239	20,600	17,867	19,733
	<i>Oithona nana</i>	0	0	0	8533	5733	8733
	<i>Oithona similis</i>	0	2237	0	5550	4600	7100
	<i>Oncea venusta</i>	0	0	1560	0	0	0
Total abundance per site		89,342	119,423	98,279	215,084	209,999	225,552
Median abundance before-after Yass		98,279			215,084		

possibly related to the persistent high salinity. High alkaline condition of the ME was observed after the TC Phailin which caused sudden influx of salt near the mouth of the ME [5]. The water temperature of the ME generally follows the typical seasonal characteristics of a tropical river-estuary [18, 25]. Post-Yass the water temperature did not exhibit any drastic change. Any drastic change in the water temperature of the ME was also not observed even after the TC Fani, Bulbul and Amphan [22, 23]. Water temperature change was not drastic after the TC Domoina which impacted the lake St. Lucia and northern estuarine systems of the Natal, South Africa [6]. In contrast to the present results, a considerable decline in the water temperature of the ME was observed within a few days after the TC Aila [3].

4.2 Cyclone effects on the copepod community

Results suggested that in the short-term the copepod community of the ME underwent structural changes following the TC Yass. After TC Aila, Fani, Bulbul and Amphan there were significant declines in the copepod species richness in the ME [3, 22–24]. Species richness did not decline in the ME after the TC Yass passed through it. The total

Table 4 Relative abundances of the copepod species sampled from the different sampling stations of the Muriganga estuary of India before and after the tropical cyclone Yass

Order	Species	Before cyclone Yass			After cyclone Yass		
		S1	S2	S3	S1	S2	S3
Calanoida	<i>Acartia sewelli</i>	01.61	00.00	01.58	03.37	02.87	03.08
	<i>Acartia spinicauda</i>	11.28	09.36	11.11	07.01	07.68	06.99
	<i>Acartia tonsa</i>	00.00	01.87	01.58	02.97	01.63	03.46
	<i>Acartia tropica</i>	00.00	00.00	04.76	00.79	01.00	00.37
	<i>Acartiella tortaniformis</i>	16.11	14.98	14.28	11.15	11.44	09.41
	<i>Acrocalanus gibber</i>	04.13	00.00	00.00	00.00	00.00	00.00
	<i>Acrocalanus gracilis</i>	04.13	01.87	06.34	04.37	04.48	04.53
	<i>Acrocalanus longicornis</i>	01.80	01.87	01.58	02.58	03.32	02.18
	<i>Bestiolina similis</i>	20.24	20.52	14.28	08.17	07.71	07.94
	<i>Canthocalanus pauper</i>	01.61	01.87	01.58	04.79	03.81	03.87
	<i>Labidocera acuta</i>	00.00	01.87	00.00	00.00	00.00	00.76
	<i>Labidocera euchaeta</i>	00.00	00.00	00.00	02.38	01.76	02.02
	<i>Paracalanus aculeatus</i>	05.73	01.87	01.58	02.99	04.29	03.17
	<i>Paracalanus dubia</i>	00.90	05.61	03.74	00.81	01.46	00.70
	<i>Paracalanus indicus</i>	02.51	1.87	01.58	03.59	03.84	03.19
	<i>Paracalanus parvus</i>	15.40	19.50	15.87	08.58	08.00	07.94
	<i>Parvocalanus crassirostris</i>	01.61	01.87	04.76	03.24	03.22	02.20
	<i>Pseudodiaptamus binghami</i>	01.61	00.00	00.00	01.77	01.40	02.22
	<i>Pseudodiaptamus serricaudatus</i>	03.22	03.74	03.17	04.35	05.59	06.88
	<i>Subeucalanus crassus</i>	00.00	00.00	01.58	00.38	00.44	00.76
<i>Subeucalanus subcrassus</i>	01.61	01.87	00.00	02.58	02.52	02.78	
<i>Temora turbinata</i>	01.61	01.87	01.58	05.19	04.95	05.56	
Cyclopoida	<i>Corycaeus crassiusculus Dana</i>	01.61	01.87	01.58	02.79	05.19	04.19
	<i>Oithona brevicornis</i>	03.22	03.75	06.35	09.58	08.51	08.75
	<i>Oithona nana</i>	00.00	00.00	00.00	03.97	03.00	03.87
	<i>Oithona similis</i>	00.00	01.87	00.00	02.58	02.19	03.15
	<i>Oncaea venusta</i>	00.00	00.00	01.58	00.00	00.00	00.00

abundance of the copepod community declined in the ME after TC Aila, Fani, Bulbul and Amphan [3, 22, 23]. The TC Hudhud, caused decline in the abundances of many zooplankton populations in the Chilika Lagoon of India [28]. Decline in the overall abundance and in the abundances of the individual species were not uncommon for copepods in the estuaries of the India, South Africa and Taiwan after a TC [2, 3, 6, 12, 28]. The total abundance of the copepod community (i.e., pre-Yass: 307,044 ind.m⁻³ and post-Yass: 650,635 ind.m⁻³) and the individual abundances of many (not all) calanoid and cyclopoid species were higher after the TC Yass than they were before the Yass. The results, therefore, do contradict the previous works on the cyclones conducted in the ME and other estuaries in India and elsewhere. The results, however, shall be treated with some caution because of the asymmetry of the temporal replicates before-after Yass. TC Imboa caused extensive flood in the St. Lucia estuary of South Africa [13]. After that proportional densities of many estuarine resident species did not change but there were increases in the proportional densities of marine migrant species [13]. Present results also suggested the temporary inclusion of some marine migrant species as well as their higher individual abundances in the copepod community of the ME after TC Yass. The *L. euchaeta* is not a resident species of the ME rather it is a marine intrusion [21]. It is possible that after TC Yass the polyhaline nature of the ME assisted the species to thrive for a limited period. *Acartia tortaniformis* was the most abundant species of the ME after Yass, which contradicts the previous results. Bhattacharya et al. [3] found that after

TC Aila impacted the ME *B. similis* relative abundance went up from 48.10% to 58.75% (i.e., 122% increase). *Bestiolina similis* was the most abundant species of the community even after TC Fani, Bulbul and Amphan successively affected the ME between May 2019 to May 2020. After TC Aila (2009) and Hudhud (2014) affected Indian Sundarbans and Chilika Lagoon, abundances of the copepods of the order Cyclopoida were higher compared to the pre-cyclone conditions [3, 28]. Present results on cyclopoid copepods are somewhat consistent with the findings of the Bhattacharya et al. [3] and Srichandan et al. [28]. The higher number of the individuals of the Oithonidae family is mainly due to the increment of *O. brevicornis* abundance in the post-Yass samples. That was also observed in the ME after TC Aila affected the estuary [3]. After the TC Aila relative abundance of *O. brevicornis* went up from 0% to 10.5% (i.e., 1050% increase). The *Oithona* spp. are generally omnivores and mostly survive on organic debris, dinoflagellates, diatoms, and proto-zooplankton (Wang et al. 2017). The sudden increment of the Oithonidae family in the post- Yass samples could be attributed to the increased organic debris in the water which is common after a TC as found by Bhattacharya et al. [3] after the TC Aila in the Indian Sundarbans and Srichandan et al. [28] after the TC Hudhud in the Chilika Lagoon of India. The NMDS and SIMPER analysis suggested that the composition of the copepod community was spatially more homogeneous during the post-Yass period than pre-Yass. A short-term homogenization of the spatial niche of the copepod community was also observed after the TC Amphan affected the ME in May 2020 [24]. It is possible that the TC Yass had mechanically impacted the spatial niche of the copepods because of the massive flood which followed the TC Yass.

4.3 Monitoring estuarine copepods following a cyclone

Ecological researches on the Indian estuaries in the context of a TC or successive TCs are relatively new as their roots could be traced only in last two decades [3, 8, 10, 11, 15, 17]. India has no institutional mechanism in place for regular monitoring of any of its estuaries for ecological research, therefore, any assessment of cyclone-mediated ecological changes for any taxon and community even its most rudimentary forms is difficult [21–24]. Some academic researches on the water quality, plankton (both phytoplankton and zooplankton) and fish of the Indian Sundarbans and Chilika lagoon were conducted in the last two decades for providing perspectives of the cyclone-mediated disruptions but they do not follow a continuity of hypothesis, universal methods and best practises, therefore, drawing conclusions on sampling frequency are difficult from those researches [24].

[22–24] while tracking the impacts of the TC Fani, BulBul and Amphan in the ME had reiterated the need of before-after assessment and unavailability of pre-cyclone databases for the Indian estuaries. Present results suggested a rapid recolonization response of the copepod community within a few days to a few weeks following a TC in the ME. That indicates bi-weekly, monthly and seasonal sampling frequencies might be too coarse to record short-term ecological changes of estuarine copepods after a TC event [22–24, 29]. For a river-estuary such as the ME, it is recommended that sampling occurs within the first week following a cyclone and continued daily or weekly interval for at least a few weeks or a few months. The extent of sampling timelines shall consider the antecedent conditions of the estuary, distance of study site from the landfall site [11], and residence time of the water of a specific estuary because that exerts mechanical

disruption [24, 29]. If the resident time is short, one may avoid resample the copepod community originally impacted by a TC as suggested by the Topor [29]. Lagrangian floats could be deployed to record real-time changes of the copepod community when a cyclone is passing through an estuary unless the float is overthrown by the cyclone [29]. Establishment and success of cyclone ecology research for the Indian estuaries are going to be synonymous with institutionalise regular monitoring of the Indian estuaries. The authors, therefore, recommend that the United Nation Ocean Decade (2020–2030) could be taken as a baseline for establishing such research programs for Indian estuaries.

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Author contributions

Sourav Paul: Conceptualization, Methodology, Formal analysis and investigation, writing original draft, writing—review and editing, Funding acquisition **, ** Resources, Supervision; **Samya Karan:** Methodology; writing—review and editing. **Bhaskar Deb Bhattacharya:** Methodology, writing—review and editing.

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Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Sourav Paul declares they are an Editorial Board Member of *Discover Ecology* and confirms that they were not involved in the handling or decision-making of their own submission.

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