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Diversity rhythm in pontellid copepods (Pontellidae: Copepoda) from the Covelong coast pre- and post-COVID-19 lockdown, Bay of Bengal

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Abstract: Copepods act as indicators of the aquatic ecosystem since they rapidly respond to changes in nutrient content of the environment. Plankton samples were collected for two years from the Covelong coast, India (January to December 2019 and January to December 2021). The diversity patterns of pontellid copepods before and after the COVID-19 lockdown were analyzed. Physicochemical parameters like temperature, salinity, pH, dissolved oxygen, calcium, magnesium, nitrite, phosphate, and ammonia level for both years were measured to compare and contrast the coastal health before and after the lockdown. Six species of pontellid copepods were reported before the lockdown period and 10 species were reported after the lockdown. Physicochemical parameters like ammonia, nitrite, and phosphate levels were reduced after the lockdown. Temperature and nitrite showed a considerable negative correlation with pontellid copepods (–0.749 and –0.782), whereas dissolved oxygen showed a high positive correlation (0.732). Regression analysis was carried out to emphasize the relationship between pontellid copepods with the environment. The regression (R^2) coefficient with temperature, nitrite, and dissolved oxygen were 0.571, 0.682, and 0.636, respectively. However, high species diversity was observed in February during both pre- and postlockdown periods. Redundancy analysis was used to visualize the relationship between the pontellid copepods and physicochemical parameters. The density of pontellid copepods and the level of physicochemical parameters greatly fluctuated throughout the entire study period and showed variation in density and diversity.

Key words: Pontellidae, COVID lockdown, physicochemical parameter, Covelong coast, diversity

1. Introduction

Marine water quality has a huge effect on aquatic ecosystems, especially in marine life. Many aquatic organisms went endangered due to the increased threshold level of pollutant in the water (Edward et al., 2021). The major causes of pollution in every aspect of the environment are population shifts from rural to urban environments, excessive industrial expansion, and overexploitation (Masood et al., 2016). The COVID-19 pandemic was one of the deadliest pandemics in history, affecting nearly the entire world (Fang et al., 2022). Several countries have implemented various forms of nationwide lockdowns to slow down the spread of the virus through human contacts. Meanwhile, about half of the world's population was under strict lockdown and normal life had been brought to a halt because of the pandemic (Pant et al., 2021). However, the lockdown helped to reduce anthropogenic activities, which improved the environment to some extent over the world and the polluted ecosystems in terms of water and natural habitats seems to be recovered (Corlett et al., 2020; Islam et al., 2021). Many studies have shown that the water quality in rivers and the ocean has significantly improved throughout the lockdown period (Shah, 2020; Chakraborty et al., 2021)

Calanoid copepods play an important role in the marine ecosystem as an energy carrier to higher trophic levels by consuming a significant amount of primary producers. They also serve a crucial role in the transport of organic matter to the deep ocean either through defecation or through their remnants after death or by daily vertical migration and the biological pump (Abo-Taleb et al., 2020; Sivakumar et al., 2021). Copepods of the family Pontellidae are usually large and show clear sexual dimorphism and their diverse shape and structure have attracted many scientists to study and review this group (Mulyadi, 2002; Othman and Toda, 2006; Abo-Taleb, 2019; Smith et al., 2019). They include 9 genera and more than 140 accepted species worldwide. The genus *Labidocera* is the most diverse, with 79 acknowledged

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species (Walter and Boxshall, 2021), most of which are found in temperate to tropical waters and can be used as bio-indicators of different water masses, inshore-offshore divisions, and biogeographical boundaries (Fleminger et al., 1982; Murniati and Mulyadi., 2018). Most *Labidocera* species can be found during both day and night in the neuston zone, which extends down to about 10–15 m depth (Fleminger and Moore, 1977). Genus *Calanoipia*, *Pontella*, and *Pontellopsis* consist of 20, 106, and 37, species respectively (Walter and Boxshall, 2021). *Pontellopsis* species are commonly found in temperate and tropical surface waters, and their taxonomy is still evolving due to their morphological complexity and incomplete descriptions (Suarez-Morales and Kozak, 2012). Generally, environmental conditions, biological interactions, and species-specific eco-physiological performances are some of the factors that affect the copepod diversity in the marine environment (Bode et al., 2018).

In India, 44 species of pontellid copepod belonging to 6 genera have been reported (Roy, 2018). Kasturirangan (1963) described 14 species of pontellid copepods in his manual. Seven species of pontellid have been reported from the offshore region of Tuticorin (Kavitha et al., 2018). In the present study, 11 species of pontellid copepods were observed from the Covelong (Kovalam) coast. Covelong is a fishing town in Chennai, located 40 km south of the city on the East Coast Road on the way to Mahabalipuram. However, there is a lack of literature on the diversity of pontellid copepods from Indian waters. The main aim of the present study was to compare the diversity and density of pontellid copepods along with the physicochemical parameters before and after the COVID-19 lockdown and to find out the important parameters that affect the diversity and distribution of pontellid copepods from the Covelong coast.

2. Materials and methods

2.1. Sampling site and sampling method

Samples were collected from Kovalam (Covelong, India) (12°47′13.2″ N, 80°15′1.44″ E), one of the longest sandy beaches on the Chennai coast, which is popular for tourism and fishing activity (Figure 1). To collect plankton samples, a standard zooplankton net made of Bolton silk with a mesh size of 150 micron was used. A monthly sample was collected for 2 years, in Jan–Dec 2019 and Jan–Dec 2021. Samples were collected five nautical miles away from the beach at a depth of 5 m by horizontally pulling the zooplankton net from the motor boat for 15 min during the early morning hours. Collected samples were immediately preserved in 5% formalin buffered with seawater and transported to the laboratory.

2.2. Identification and enumeration of pontellid copepods

Pontellid copepods were separated from the rest of the zooplankton sample. Under a high-magnification compound microscope, the adult samples were dissected and identified up to species level using standard

Figure 1. Site of collection—Covelong beach, Chennai.

taxonomic key characters (Kasturirangan, 1963; Boxshall and Halsey, 2004; Razouls et al., 2022). A Sedgwick-Rafter counting cell was used to count the number of pontellid copepod species. The zooplankton samples were well mixed and 1 mL (20-drops) of sample was extracted using a wide mouthed pipette and transferred to the counting chamber for counting and enumerating them as triplet values using the compound microscope. The mean values of three subsamples after enumeration were calculated. Number of zooplankton per cubic meter (m^{-3}) was also calculated following the method used by Perry (2010) and Sivakumar (2021).

$$Number of\ copepods\ per\ cubicmeter =$$

$$Average\ numbers\ in\ the\ drops \times \frac{Total\ drops\ in\ entire\ sample}{Volume}$$

where Volume = $\pi r^2 L$; Length (L) is derived from equation = Speed × Time.

Average number of animals per drop is calculated by:

$$Average\ numbers\ in\ the\ drops = \frac{Numbers\ of\ animals\ observed}{Number\ of\ drops\ analysed}$$

2.3. Analysis of physicochemical parameters

Physicochemical parameters such as temperature, salinity, pH, dissolved oxygen, calcium, magnesium, phosphate, nitrite, and ammonia were measured each month. Water temperature was measured using the standard mercuric thermometer; salinity was estimated using Mohr's method (Belcher et al., 1957). pH was measured using a standard pH meter and dissolved oxygen was estimated following a modified Winkler's method (Golterman, 1983). The calcium and magnesium level of seawater was estimated using a standard protocol by titrating to the distinct photometric endpoint with EDTA (Malmstadt and Hadjiioannou, 1959). Phosphate, nitrite, and ammonia level was measured following the standard procedure (Strickland and Parsons, 1972). The nitrate in the water was completely transformed to nitrite when a sample was passed through a column containing cadmium filings lightly coated with metallic copper. The nitrite (NO_2) level was then determined by producing a vividly colored azo dye and it was colorimetrically measured at 540 nm (Wood et al., 1967). The colorimetric approach was used to analyze inorganic phosphate (PO_4) in seawater by producing a highly colored blue Phosphomolybdate complex (Murphy and Riley, 1962). Ammonia was estimated by treating seawater in an alkaline citrate medium with sodium hypochlorite and phenol in the presence of the catalyzer sodium nitroprusside (Soloranzo, 1969).

2.4. Statistical analysis

All statistical analysis was carried out using PAST 4.09 (Hammer et al., 2001) and JASP 0.16 (Love et al., 2019). Pearson's Correlation Analysis was carried out to find out the positive and negative relationship between the copepods and the physicochemical parameters. Regression analysis was carried out between the total pontellid copepods from both stations and the physicochemical parameters to emphasize the relationship between different species and how much the surroundings influence the population of copepods. The regression coefficient (R^2) was calculated. Redundancy analysis (RDA) with 9 explanatory variables (physicochemical parameters) was constructed to visualize the relationship between the pontellid species and the environmental parameters. Shannon's (Spellerberg et al., 2003) diversity indices of pontellid copepods at different months were also calculated throughout the study period.

3. Results

Physicochemical parameters before the lockdown and after the lockdown showed considerable differences in each month. Mean temperature, nitrite, inorganic phosphate, and ammonia level was found to be higher before the lockdown period (30.3 ± 4.2 °C, 2.8 ± 0.6 mg L^{-1}, 1.4 ± 0.2 mg L^{-1}, 0.08 ± 0.02 mg L^{-1}), respectively, whereas mean salinity, magnesium, and dissolved oxygen was found to be lower before lockdown (32.9 ± 1.1 ppt, 1.05 ± 0.06 mg L^{-1}, 5.17 ± 0.75 mg L^{-1}), respectively. Figure 2 shows a comparison between various physicochemical parameters in different months. Figure 3 shows the relationship between the physicochemical parameters. A constant negative correlation coefficient was observed between temperature, pH, salinity, dissolved oxygen, and phosphate during both the prelockdown and postlockdown periods. Temperature relatively increases from April to June. Nitrite, phosphate, and ammonia levels were high during the postmonsoon season from both pre- and postlockdown times (Oct–Dec). Dissolved oxygen level was relatively low during May–August. pH, salinity, and calcium do not show much difference from both pre- and postlockdown time.

A total of 11 species of pontellid copepods were recorded in the entire study. Six species of pontellid copepods were recorded during prelockdown period, whereas 10 species were recorded during postlockdown period. *Labidocera aestiva* was found to be dominant among pontellid copepods during prelockdown period, whereas they were completely absent during the postlockdown period. Table 1 shows the monthly mean density of pontellid copepods throughout the pre- and postlockdown periods. *L. acuta*, *L. pavo*, *C. elliptica*, *P. danae*, and *P. scotti* were found during both the prelockdown and postlockdown periods. *L. minuta*, *L. bengalensis*, *C. aurivilli*, *C. minor*, and *P. herdmani* were some pontellid copepods observed only after

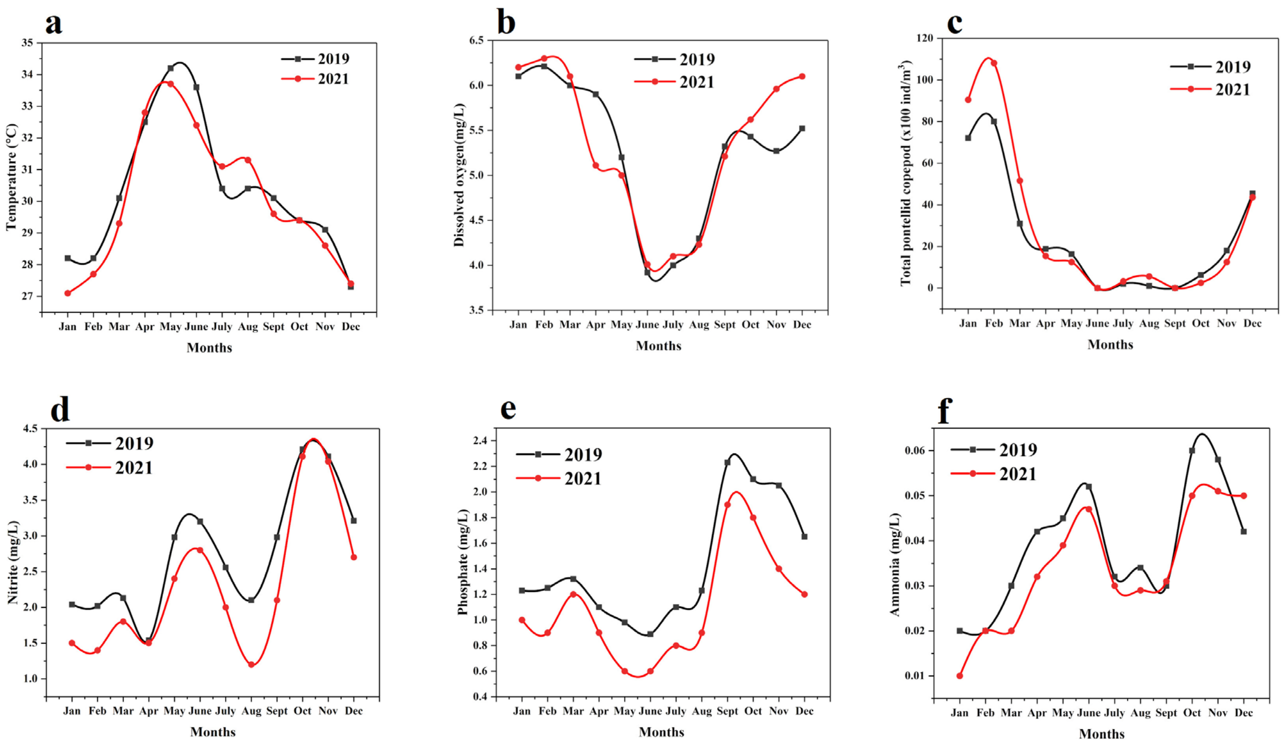

Figure 2. Comparison between physicochemical parameters observed during prelockdown and postlockdown period: (a) temperature, (b) dissolved oxygen, (c) total pontellid density, (d) nitrite, (e) phosphate, (f) ammonia.

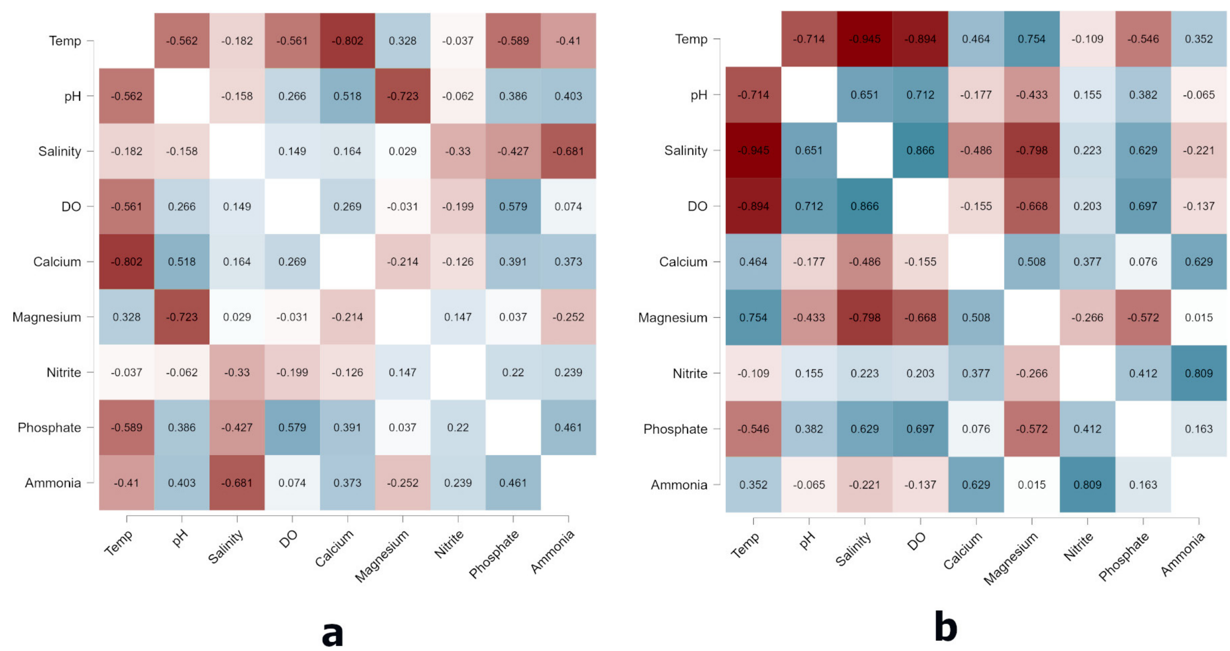

Figure 3. Correlation between physicochemical parameters in (a) prelockdown period and (b) postlockdown period (shades of brown indicate the coefficient towards –1 and shades of blue indicate the coefficients towards +1).

the lockdown period. Correlation between pontellid copepods and physicochemical parameters reveals that temperature and nitrite have a big negative impact on the population of pontellid copepods with a considerable negative coefficient compared to other parameters (–0.749 and –0.782). The relationship between temperature and nitrite in pontellid copepods was also expressed by linear regression analysis with regression (R^2) coefficients of 0.571 and 0.682, respectively. However, a strong positive correlation and regression coefficient were found between pontellid copepods and dissolved oxygen. Table 2 shows the correlation coefficients between several pontellid copepod species and physicochemical parameters.

Similarly, the regression coefficient between various pontellid copepod species and physicochemical parameters given in Table 3 and Figure 4 depicts the association between pontellid species and physicochemical parameters using redundancy analysis (RDA). RDA shows that pontellid copepods were negatively correlating with temperature from both study periods. High species diversity was observed between the months of Jan and March from both pre- and postlockdown periods with (4, 5, 4) and (6, 8, 5) species respectively. Between May and October, there was very limited species diversity, with only one species present at any given time. Table 4 shows the diversity indices of pontellid copepods before and after the lockdown. Shannon's diversity indices were found to be high during February from the pre- and postlockdown period.

Table 1. Mean density of Pontellid copepods throughout the months from pre- and postlockdown period.

Name of the pontellid copepod species	**Prelockdown (×100 ind. m^{-3}) (mean ± SD)**	**Postlockdown (×100 ind. m^{-3}) (mean ± SD)**
Labidocera aestiva (Wheeler, 1900)	11.8 ± 10.9	-
Labidocera acuta (Dana, 1849)	4.7 ± 6.9	5.2 ± 7.5
Labidocera pavo (Giesbrecht, 1889)	2.3 ± 4.1	3.2 ± 5.8
Labidocera minuta (Giesbrecht, 1889)	-	0.7 ± 1.9
Labidocera bengalensis (Krishnaswamy, 1952)	-	8.6 ± 8.2
Calanopia minor (Scott A., 1902)	-	2.05 ± 4.5
Calanopia aurivilli (Cleve, 1901)	-	1.9 ± 4.2
Calanopia elliptica (Dana, 1849)	6.4 ± 7.9	3.75 ± 5.6
Pontella danae (Giesbrecht, 1889)	0.25 ± 0.6	0.27 ± 0.71
Pontellopsis scotti (Sewell, 1932)	0.3 ± 0.8	0.5 ± 1.3
Pontellopsis herdmani (Thompson I.C. & Scott A., 1903)	-	0.84 ± 1.7
Total pontellidae	25.96 ± 27.72	27.26 ± 34.67

Table 2. The correlation coefficient of various calanoid copepod species with physico-chemical parameters.

Species	**Temperature**	**pH**	**Salinity**	**DO**	**Calcium**	**Magnesium**	**Nitrite**	**Phosphate**	**Ammonia**
L. aestiva	−0.413	0.236	−0.127	0.788	0.146	0.045	−0.526	0.645	−0.082
L. acuta	−0.683	0.456	0.384	0.754	−0.181	−0.439	−0.697	0.426	−0.134
L. pavo	−0.675	0.401	0.315	0.647	−0.119	−0.366	−0.669	0.458	−0.173
L. minuta	−0.558	0.608	0.161	0.368	−0.277	−0.126	−0.611	0.050	−0.414
L. bengalensis	−0.618	0.246	0.446	0.666	−0.123	−0.401	−0.523	0.678	−0.401
C. minor	−0.625	0.255	0.465	0.536	−0.578	−0.422	−0.723	0.219	−0.635
C. aurivilli	−0.520	0.416	0.389	0.515	−0.522	−0.364	−0.653	0.174	−0.585
C. elliptica	−0.529	0.202	0.221	0.649	0.0486	−0.026	−0.507	0.412	0.0114
P. danae	0.115	−0.016	0.022	0.422	−0.214	−0.017	−0.285	−0.373	−0.089
P. scotti	−0.377	−0.237	0.412	0.286	−0.499	−0.270	−0.602	0.141	−0.570
P. herdmani	−0.155	0.0097	−0.061	0.234	−0.642	−0.205	−0.131	−0.370	−0.313
Total pontellid	−0.749	0.360	0.303	0.732	−0.183	−0.285	−0.782	0.451	−0.502

Table 4. Diversity indices of pontellid copepods from Covelong coast during the prelockdown and postlockdown periods.

	Number of species		Shannon index (H)	
Months	**2019**	**2021**	**2019**	**2021**
January	4	6	1.29	1.759
February	**5**	**8**	**1.468**	**2.012**
March	4	5	1.205	1.345
April	1	2	-	0.6719
May	1	1	-	-
June	0	1	-	-
July	1	1	-	-
August	1	3	-	1.14
September	1	1	-	-
October	1	1	-	-
November	2	2	0.6345	0.6088
December	4	3	1.377	1.105

4. Discussion

The Government of India considers the Covelong coast to be a suitable location for the deployment of artificial reefs because of the diverse range of life forms (Kumar et al., 2021). Many previous studies claim that COVID lockdown has improved water quality in the aquatic ecosystem (Shah, 2020; Edward et al., 2021). In the present study, comparatively low amounts of nitrite, phosphate, and ammonia in postlockdown period compared to prelockdown period were observed. Inorganic phosphate, ammonia, and nitrites are brought into the aquatic ecosystem by both natural and anthropogenic activities (Toetz, 1981; Shanmugam et al., 2007). High phosphate, nitrite, and nitrate levels in the water will promote the rapid growth of phytoplankton, which cause algal bloom and the various toxins produced by algae result in a low copepod population (Fadiran et al., 2008; Hong et al., 2012; Umer et al., 2020). Magnesium is required for various biological functions such as protein synthesis, enzyme activity, energy transfer, and cellular homeostasis. They can be toxic to aquatic organisms at high concentrations; however, the toxicity of magnesium depends on the concentration of calcium in the water (Van Dam et al., 2010).

Recent studies indicated that the COVID lockdown reduces the nutrient concentration of water, consequently improving the population of marine fish (Edward et al., 2021). In the current study, the diversity of pontellid copepods was significantly high when there was a decrease in the nutrient content of the water during the postlockdown phase. Pontellid copepods showed high diversity and density during winter (Jan-Mar) from both periods and their population declined for the rest of the season. This is because temperature and nutrient content of the water was relatively low during these months compared to the rest of the season. This clearly shows that pontellid copepods are extremely sensitive to

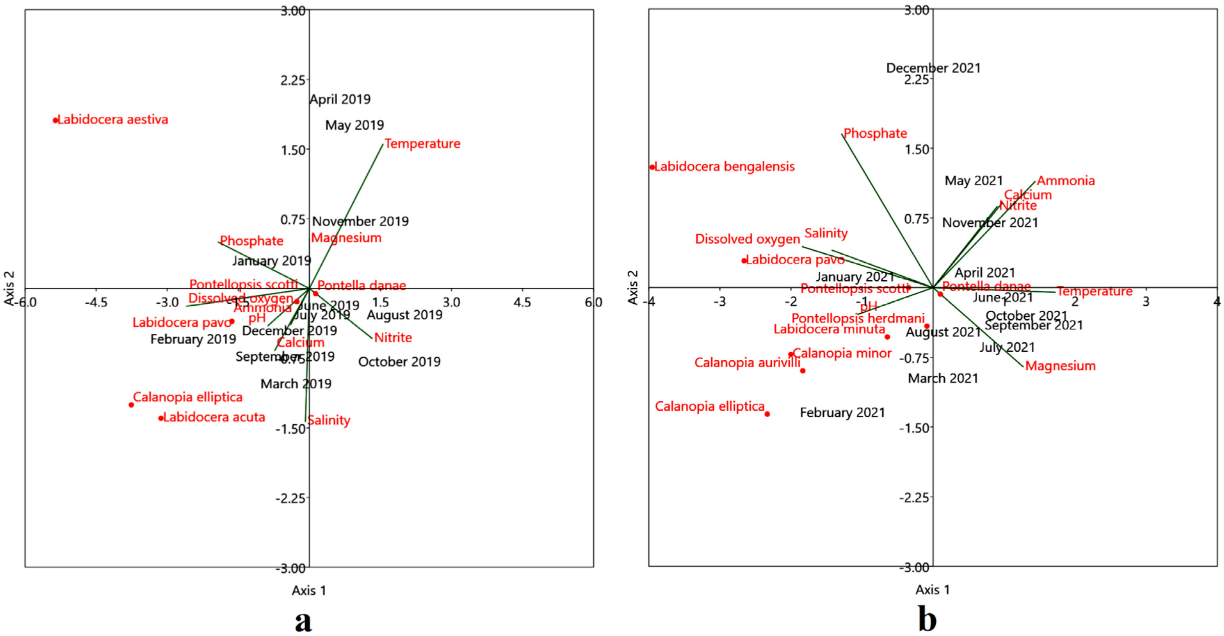

Figure 4. RDA (redundancy analysis) of pontellid copepods and physicochemical parameters in (a) prelockdown period and (b) postlockdown period.

Table 3. The regression (R^2) coefficient of various calanoid copepod species with physico-chemical parameters.

Species	Temperature	pH	Salinity	DO	Calcium	Magnesium	Nitrite	Phosphate	Ammonia
L. aestiva	0.198	0.056	0.016	0.621	0.022	0.002	0.277	0.304	0.044
L. acuta	0.467	0.209	0.148	0.569	0.033	0.193	0.522	0.115	0.155
L. pavo	0.455	0.161	0.099	0.419	0.014	0.134	0.463	0.027	0.102
L. minuta	0.328	0.37	0.026	0.136	0.077	0.016	0.383	0.556	0.14
L. bengalensis	0.468	0.061	0.199	0.444	0.015	0.161	0.285	0.107	0.268
C. minor	0.409	0.065	0.217	0.288	0.334	0.178	0.773	0.119	0.424
C. aurivilli	0.271	0.174	0.152	0.266	0.273	0.133	0.72	0.266	0.412
C .elliptica	0.28	0.041	0.049	0.422	0.002	0.001	0.585	0.253	0.144
P. danae	0.013	0	0	0.278	0.046	0	0.025	0	0.003
P. scotti	0.119	0.002	0.128	0.125	0.106	0.051	0.374	0.025	0.039
P. herdmani	0.054	0	0.004	0.055	0.413	0.042	0.018	0.039	0.132
Total pontellid	0.571	0.13	0.092	0.636	0.033	0.081	0.682	0.177	0.257

changes in environmental temperature. Temperature is the governing factor that determines the diversity and density of various zooplankton communities including copepods (Peck et al., 2015; García et al., 2018; Rugebregt and Nurhati, 2020). There has to be a constant migration pattern in pontellid copepods during unfavorable environmental conditions. However, seasonal variation and circadian migration in pontellid copepods are also supported by various studies (Jeong et al., 2014; Smith et al., 2019).

In the present study, we can see a significantly high dissolved oxygen level in water after the lockdown period. Wang (2022) reported decreased calanoid copepod diversity and density in low dissolved oxygen environment from Taiwan. Dissolved oxygen is the most essential parameter, which is responsible for the survival of the aquatic organism (Kulkarni, 2016; Song et al., 2019). During lockdown, the water quality of Covelong beach improved but the nutrient level fluctuated throughout the research period. However, the ammonia level was significantly low during the postlockdown period compared to the prelockdown period. Nitrite and nitrate are naturally occurring components of the nitrogen cycle that cause a variety of physiological problems in aquatic organisms, even at low concentrations. They are known to convert oxygen-transporting pigments into an ineffective form. As a result, aquatic organisms take up less oxygen (Jensen, 2003). Ammonia is naturally present in the aquatic environment as an excretory product of aquatic animals, but human activities have triggered an increase in the level of ammonia in the aquatic ecosystem in the past few decades (Eddy, 2005). High ammonia levels in water are considered hazardous to many aquatic organisms, particularly copepods as it reduces the success of hatching eggs in copepods (Buttino, 1994; Jepsen et al., 2015; Kennedy et al., 2019). However, most calanoid copepods especially the pontellid copepods are known for producing diapause eggs, which only hatch when the environmental conditions are favorable for their survival (Marcus, 1984; Hairston and Bohonak, 1998; Wu et al., 2007). This could be another reason for the appearance of more pontellid copepods after the lockdown period as the water quality was significantly improved. *L. bengalensis*, a species first described from the Madras coast (old name of Chennai) almost 70 years ago (Krishnaswamy, 1951) has not been reported again from the Chennai coast, but its members were often cited from Indonesian waters (Mulyadi 2002, 2020). There is also disappearance of *L. aestiva* after the prelockdown period. The reappearance of *L. bengalensis* in the present study after the lockdown period strongly indicates the migratory pattern of this copepod. However, there is not enough literature available regarding the disappearance and reappearance of these copepods in this region.

5. Conclusions

Copepods play a vital role in the aquatic food chain and serve as bioindicators since they respond quickly to changes in the environment. However, because of their unique characteristics, pontellid copepods have attracted the attention of many researchers worldwide. In the current study, we observed improved water quality parameters in the coastal ecosystem after the COVID-19 lockdown period. The coastal zone after lockdown showed significantly reduced levels of nitrite, phosphate, and ammonia, which are all known to cause rapid growth of phytoplankton thereby significantly lowering copepod productivity. This could be the reason for the high diversity of pontellid copepods after the lockdown period. However, temperature and dissolved oxygen are also observed to play an important role in governing the population composition of pontellid copepods throughout the study period. The appearance of more pontellid copepods after the lockdown period indicates that pontellid copepods either migrate or produce diapause eggs and reappear when the conditions are favorable. Since it is not easy to study the community structure and factors affecting the pontellid copepods in a laboratory, this study will provide a useful reference in understanding the population structure of copepods belonging to the family Pontellidae from the Covelong coast, India.

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Conflict of interest statement

The authors declare that they have no financial or personal ties that could appear to have affected the work presented in this study.

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