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Original Article

A Principal Component Analysis (PCA) Approach to Seasonal and Zooplankton Diversity Relationships in Fishing Grounds of Mannar Gulf, India

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Abstract

Principal component analysis (PCA) is a technique used to emphasize variation and bring out strong patterns in a dataset. It is often used to make data easy to explore and visualize. The primary objective of the present study was to record information of zooplankton diversity in a systematic way and to study the variability and relationships among seasons prevailed in Gulf of Mannar. The PCA for the zooplankton seasonal diversity was investigated using the four seasonal datasets to understand the statistical significance among the four seasons. Two different principal components (PC) were segregated in all the seasons homogeneously. PCA analyses revealed that *Temora turbinata* is an opportunistic species and zooplankton diversity was significantly different from season to season and principally, the zooplankton abundance and its dynamics in Gulf of Mannar is structured by seasonal current patterns. The factor loadings of zooplankton for different seasons in Tiruchendur coastal water (GOM) is different compared with the Southwest coast of India; particularly, routine and opportunistic species were found within the positive and negative factors. The copepods *Acrocalanus gracilis* and *Acartia erythrea* were dominant in summer and Southwest monsoon due to the rainfall and freshwater discharge during the summer season; however, these species were replaced by *Temora turbinata* during Northeast monsoon season.

Keywords: Gulf of Mannar, principal component analysis, Tiruchendur and copepods, zooplankton diversity

Introduction

Zooplankton inhabits oceans at all the depths and occupies every ecological niche that is considered as the chief index of utilizing aquatic biotope at the secondary trophic level (Pitchaikani and Lipton, 2015). Sea surface temperature, salinity and inorganic nutrients are some of the important factors that are reported to cause spatial changes among zooplankton population (Lawrence *et al.*, 2004). Among the zooplankton groups, copepods are the important grazers of phytoplankton and micro zooplankton, and hence they form a major trophic link to many predatory invertebrates and fish (Atkinson, 1996). Studies related to seasonal variation and zooplankton diversity in offshore waters, particularly in fishing grounds of Gulf of Mannar, is meager; hence, the present study was established to investigate the relationship between seasons and zooplankton diversity.

Pelagic copepods are a key trophic group in the marine plankton, where they play important roles in both the transfer of energy from primary producers to higher trophic levels and biogeochemical cycles (Roemmich *et al.*, 1995; Beaugrand *et al.*, 2009). Principal component analysis (PCA) is a technique used to emphasize variation and bring out strong patterns in a dataset. It is often used to make data easy to explore and visualize. The primary objective of the present study was to record information of zooplankton diversity in a systematic way and to study the variability and relationships among seasons prevailed, which in turn should be useful for an understanding of highly variable aquatic environments in general, besides Gulf of Mannar.

Materials and Methods

The present investigations of principal component analyses (PCA) on zooplankton diversity was carried out and in the coastal waters off Tiruchendur, Southeast coast of Tamil Nadu (Gulf of Mannar), India. The study was carried out at three different fishing grounds (Fig. 1): Station-1 (Lat: 8°.27'.28.48"N, Long: 78°.8'.18.48"E), Station-2 (Lat: 8°.27'.23.32"N and Long: 78°.14'.57.06" E), Station-3 (Lat: 8°.30'.46.2" N and Long: 78°.16'.48.15" E), for a period of two years, extending from January 2009 to December 2010. The area located between the Southeast coast of India and West coast of Sri Lanka is a unique

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marine environment, and rich in biodiversity (Pitchaikani and Lipton, 2015).

The zooplankton diversity data used in the present study was obtained from the published data of the first author of this paper (Pitchaikani and Lipton, 2015). To examine the relationship among the four seasonal data sets, Principal Component Analyses (PCA) was performed on the zooplankton species diversity using program PAST ver. 2.01 (Hammer, 2001). This program makes PCA of the correlation matrix of two sets of data (environmental data and zooplankton counts) and also calculates the correlations between the components of the two sets.

Results and Discussion

A total of 49 species of zooplankton have been recorded during the study. The PCA for the zooplankton seasonal diversity was investigated using the four seasonal datasets to understand the statistical significance among the four seasons viz. post monsoon (January-March), summer season (April-June), southwest monsoon (July-September) and northeast monsoon (October-December). Two different principal components (PC) were segregated in all the seasons homogeneously. The component matrix which is exceeding 0.6 could be taken for interpretation in the present study (Udayakumar *et al*., 2009; Jose *et al*., 2012). The correlation matrix loadings of the significant principal components for the four seasons are given in Tables 1 to 4.

For a few coastal areas, it has been suggested that protists occasionally constitute the main food source for calanoid and cyclopoid copepods (Kleppel *et al*., 1991; Pierce *et al*., 1992; Levinsen *et al*., 2000), which would have important implications for food web dynamics. In order to provide an insight into this idea, the present study was aimed to attempt statistically the feeding of small copepods on the full food size-spectrum (phytoplankton) and predation on juvenile appendicularians.

Principal component analyses (PCA)

In the post monsoon season, two different components of the principal component analyses explained 100% of total variance with eigene values exceeding 1 as could be boted from Table 1. The total variance observed in the study was directly linked with zooplankton forage predicting the routine (PC1) and opportunistic grazers (PC2). The extracted principal component 1 (PC1) explained 74.9% of the total variability and this could be used to differentiate the zooplankton groups present within the extracted fishing grounds. Earlier studies also emphasized similar findings in Gulf of Manine (Pershing *et al*., 2005).

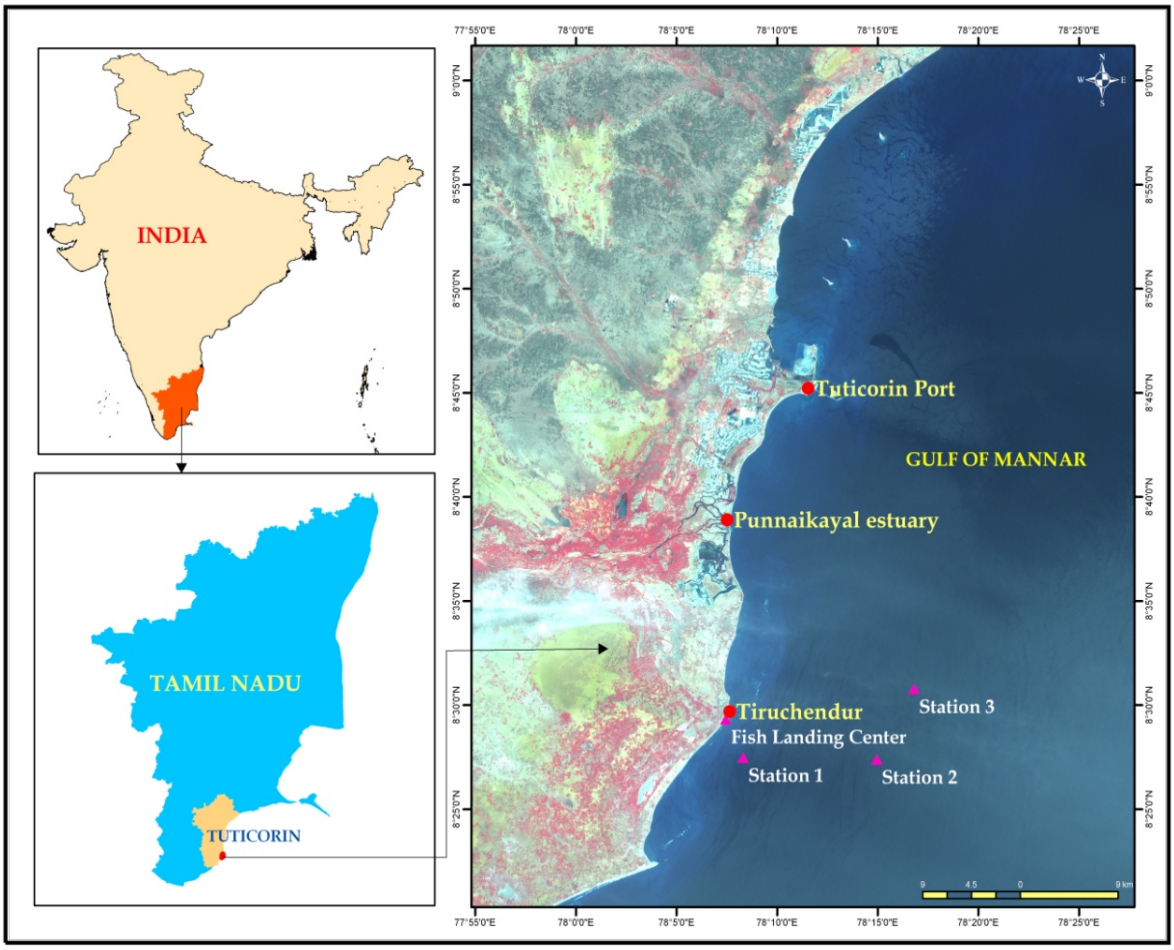

Fig. 1. Study area, Tiruchendur, Southeast coast of Tamil Nadu, Gulf of Mannar

Table 1. Eigene analyses of the correlation matrix loadings of the significant principal components in post-monsoon season

Post monsoon season	PCA 1	PCA 2
Eigene values	9.11943	3.05
Variability (%)	74.924	25.08
Cumulative %	74.924	100
Factor loadings		
Acartia erythrea	0.8992	-0.4376
Acartia spinicauda	0.6569	-0.754
Acrocalanus gibber	-0.93	0.3676
Acrocalanus gracilis	-0.9352	0.354
Eucalanus elongates	-0.7085	0.7057
Eucalanus subcrassus	-0.9194	0.3934
Paracalanus parvus	0.947	-0.3213
Paracalanus simplex	0.9806	0.1959
Calanopia elliptica	0.8666	-0.499
Temora turbinate	0.6814	0.7319
Copepodite labidoceropavo	0.5965	-0.8026
Oncaea venusta	0.8782	0.4782
Oncaea conifera	-0.9224	0.3863
Clausocalanus arcuicornis	-0.9901	-0.1402
Nannocalanus minor	0.5221	-0.8529
Pseudodiaptomus sp.	0.5877	-0.8091
Metacalanus aurivillii	-0.9879	0.1553
Metacalanus sp.	-0.3739	0.9275
Temora discaudata	-0.3466	0.938
Temora stylifera	0.8024	-0.5968
Calanopia minor	0.9643	-0.2648
Euchaeta marina	0.1402	-0.9901
Euterpina acutiferons	0.999	0.04473
Oithona brevicornis	0.2083	-0.9781
Oithona rigida	0.9848	0.1737
Oithona similis	-0.9958	-0.0911
Oithona nana	-0.8252	0.5649
Oithona spinirostris	0.9434	0.3315
Corycaeus sp.	0.3736	0.9276
Corycaeus danae	0.03712	-0.9993
Favella brevis	0.9024	-0.4309
Tintinnopsis cylindrica	-0.7874	-0.6165
Tintinnopsis cynensis	0.8403	-0.5422
Sagita enflata	-0.9368	0.3499
Lucifer sp.	-0.2493	0.9684
Gastropod larvae	0.8227	0.5685
Gastropod veliger	0.9733	0.2295
Bivalve veliger	-0.8107	0.5855
Crab zoea	0.5648	-0.8252
Euphasid zoea	0.882	-0.4713
Labidocera acuta	0.5258	-0.8506
Leucosiidae zoea	0.4646	-0.8855
Porcellidium spp.	0.8532	0.5216
Portunidae spp.	-0.6165	0.7874
Dotilla fenestrate	0.9979	0.06547
Mysis larvae	0.3104	-0.9506
Nauplius of balanus	0.9688	-0.2479
Cypris of balanus	0.5444	-0.8388
Globigerina spp	-0.9996	0.02752

Table 2. Eigene analyses of the correlation matrix loadings of the significant principal components in summer

Summer	PCA 1	PCA 2
Eigene values	4.76	0.90
Variability (%)	84.18	15.82
Cumulative %	84.18	100
Factor loadings		
Acartia erythrea	0.9812	-0.1932
Acartia spinicauda	0.9883	-0.1526
Acrocalanus gibber	-0.7704	0.6375
Acrocalanus gracilis	-0.7379	0.6749
Eucalanus elongatus	-0.4334	0.9012
Eucalanus subcrassus	-0.421	0.9071
Paracalanus parvus	0.989	0.1477
Paracalanus simplex	0.8955	0.4452
Calanopia elliptica	0.8096	-0.587
Temora turbinata	-0.3788	0.9255
Copepodite labidoceropavo	0.9227	-0.3855
Oncaea venusta	0.9919	0.1266
Oncaea conifera	-0.8506	0.5258
Clausocalanus arcuicornis	-0.6187	0.7856
Nannocalanus minor	-0.9603	0.279
Pseudodiaptomus sp.	0.9883	-0.1526
Metacalanus aurivillii	-0.7796	0.6263
Metacalanus sp.	-0.9765	0.2155
Temora discaudata	-0.4266	0.9044
Temora stylifera	0.9417	-0.3366
Calanopia minor	0.5971	-0.8022
Euchaeta marina	-0.9131	-0.4077
Euterpina acutiferons	0.8675	0.4974
Oithona brevicornis	-.07791	-0.997
Oithona rigida	0.06002	-0.9982
Oithona similis	-0.9812	0.1932
Oithona nana	0.7856	0.6187
Oithona spinirostris	0.8608	0.5089
Corycaeus sp.	0.1963	0.9806
Corycaeus danae	0.5658	-0.8245
Favella brevis	0.9995	-.03129
Tintinnopsis cylindrica	-0.9227	0.3855
Tintinnopsis cynensis	0.07086	-0.9975
Sagita enflata	-0.7292	0.6843
Lucifer sp.	0.7289	0.6847
Gastropod larvae	0.7623	0.6472
Gastropod veliger	0.9993	0.03696
Bivalve veliger	0.5415	0.8407
Crab zoea	0.889	-0.458

Euphasid zoea	0.05175	-0.9987
Labidocera acuta	-0.5243	-0.8515
Leucosiidae zoea	-0.9322	-0.362
Porcellidium spp.	0.9985	0.05463
Portunidae spp.	-0.7623	-0.6472
Dotilla fenestrate	0.491	0.8711
Mysis larvae	0.08929	-0.996
Nauplius of balanus	0.9691	-0.2465
Cypris of balanus	-0.3044	-0.9525
Globigerina spp.	0.3666	0.9304

In the PC1 of the post monsoon, species such as *Acartia erythrea*, *A. spinicauda*, *Paracalanus parvus*, *P. simplex*, *Calanopia elliptica*, *Temora turbinata*, *Oncaea venusta*, *T. stylifera*, *Calanopia minor*, *Euterpina acutiferons*, *Oithona rigida*, O. *spinirostris*, *Favella brevis*, *Tintinnopsis cynensis*, *Gastropod larvae*, *Gastropod veliger*, *Euphasid zoea*, *Porcellidium* spp., *Dotilla fenestrate* and *Nauplius of balanus* were showed with positive significant correlation, which indicated their preference for sharing the same feeding habitat devoid of antagonism as suggested by Jose *et al.* (2012). However, the positive loadings in the PC1, most of the copepods species were herbivores, except that of *Oithona rigida* and *O. spinirostris* as similarly reported by Madupradap *et al.* (2003). Carnivore species also congregated in the same ground along with herbivores though they limit their feeding habit. This result therefore suggests that different feeding habituated zooplankton species gathered in the fishing grounds during the post monsoon season.

However, the PC1 components showed negative correlation with *Acrocalanus gibber*, *A. gracilis*, *Eucalanus elongatu*s, *E. subcrassus*, *Oncaea conifer*, *Clausocalanus arcuicornis*, *Metacalanus aurivillii*, *Oithona similis*, *O. nana*, *Tintinnopsis cylindrical*, *Sagita enflata*, *Bivalve veliger*, *Portunidae* spp. and *Globigerina* spp. It was thus clearly noticed that, the significant positive loading species of copepods, which were also dominant exerted grazing pressure, which in turn depressed the remaining copepods by the way of squeezing them away from their feeding grounds (Jose *et al.*, 2012). However, during the post monsoon season, most of the copepods remain there and only a few opportunistic species invade the fishing grounds with respect to the seasonal current pattern, as well as grazing pressure. In the Arabian Sea, upwelling and down welling are the prime factors that control the invading species along with grazing pressure. But in the case of Gulf of Mannar, seasonal current patterns are playing a major role on zooplankton species abundance (Jagadeesan *et al.*, 2013).

The results of the present study clearly demonstrated the following species as opportunistic invaders: *Acartia erythrea, Paracalanus simplex, Temora turbinate, Clausocalanus arcuicornis, Metacalanus aurivillii, Calanopia minor, Euchaeta marina, Euterpina acutiferons, Oithona nana, O. spinirostris, Crab zoea, Globigerina* spp. These opportunistic invaders could have possibly entered from northern part of the Gulf of Mannar and Palk Bay due to the monsoon induced water circulation pattern. From the PCA analyses, results reinforced the idea that the zooplanktonic community of Gulf of Mannar could be strongly influenced by hydrological circulation patterns. Similar inference could be noted from earlier studies in Gulf of Mannar and in Gulf of Maine (Pershing *et al.*, 2005). The results of the present study thus agreed with findings in other regions and explained that copepods constituted the major taxa in Catalan Sea (Jyothibabu *et al.*, 2013), in Arabian Sea (Madhupratap *et al.*, 2001; Jose *et al.*, 2012), and in Mondego estuary (Marques *et al.*, 2007).

PC2 represented the following species viz. *Eucalanus elongatus*, *Temora turbinata*, *Metacalanus* sp., *Temora discaudata*, Corycaeus sp., *Corycaeus* sp., *Lucifer* sp., *Portunidae* spp., with positive significant correlation. Most of the species were herbivores and preferred to grazing phytoplankton. Thus the PCA analyses tend to conclude that *Portunidae* spp. was the only opportunistic species available during the post monsoon season. This may be due to the coastal water circulation pattern in Gulf of Mannar. Increased abundance of both herbivores and carnivores in the fishing grounds could thus lead to sequential community development, subsequent to the start of nutrient supply either by current pattern or upwelling as recorded by Madhupratap and Haridas (1990).

However, the following species viz. *Acartia spinicauda, Copepodite labidoceropavo, Nannocalanus minor, Pseudodiaptomus* sp., *Euchaeta marina, Oithona brevicornis, Corycaeus danae, Tintinnopsis cylindrical, Crab zoea, Labidocera acuta, Leucosiidae zoea*, *Mysis larvae*, *Cypris of balanus* were negatively correlated at significant level due to the grazing pressure from the positive significant zooplankton groups, suppressing the species of negatively significant zooplankon species by the way of dragging away from their feeding ground (Jose *et al.*, 2012).

In the summer season also, PCA separated two different principal components explained 100% of total variance with eigene values exceeding 1 (Table 2). The extracted principal component 1 (PC1) explained 84.18% of the total variability and PC2 explained about 15.82% of variability. The following species viz. *Acartia erythrea, A. spinicauda, Paracalanus simplex, Calanopia elliptica, Copepodite labidoceropavo, Oncaea venusta, Pseudodiaptomus sp., Temora stylifera, Euterpina acutiferons, Oithona nana, O. spinirostris, Favella brevis, Lucifer* sp., *Gastropod larvae, Gastropod veliger, Crab zoea, Porcellidium* spp. *and Nauplius of balanus* showed positive significant correlation.

Similar to the post monsoon season, the herbivores and carnivores zooplankton species were abundantly observed in PC1 during summer season. Among the recorded zooplankton, the herbivores dominated in terms of biomass, which suggested that the richest areas of zooplankton production in turn are associated with areas of high primary productivity (Padmakumar *et al.*, 2010). In PC1, the following species identified as opportunistic species, invaded the fishing grounds based on the seasonal current pattern and grazing pressure: *Acartia erythrea, Paracalanus simplex, Oncaea venusta, Temora turbinata, T. stylifera, Clausocalanus arcuicornis, Favella brevis, Tintinnopsis cynensis, Metacalanus aurivillii, Calanopia minor, Labidocera acuta, Euchaeta marina, Porcellidium* spp.,

Table 3. Eigene analyses of the correlation matrix loadings of the significant principal components in SW monsoon

SW monsoon	PC1	PC 2
Eigene values	4.83531	1.66589
Variability (%)	74.376	25.624
Cumulative %	74.376	100
Factor loadings		
Acartia erythrea	0.8365	-0.5479
Acartia spinicauda	0.9755	0.2201
Acrocalanus gibber	-0.7782	0.6281
Acrocalanus gracilis	-0.6003	0.7998
Eucalanus elongatus	-0.3332	0.9429
Eucalanus subcrassus	-0.7529	0.6582
Paracalanus parvus	0.8582	-0.5134
Paracalanus simplex	0.9241	-0.3822
Calanopia elliptica	-0.279	0.9603
Temora turbinate	-0.2642	0.9645
Copepodite labidoceropavo	0.9985	-0.0542
Oncaea venusta	0.9825	0.1861
Oncaea conifera	-0.9917	0.1287
Clausocalanus arcuicornis	-0.7442	0.6679
Nannocalanus minor	-0.7632	0.6461
Pseudodiaptomus sp.	-0.1951	0.9808
Metacalanus aurivillii	-0.0062	1
Metacalanus sp.	-0.0845	-0.9964
Temora discaudata	0.5021	0.8648
Temora stylifera	0.9052	0.4249
Calanopia minor	0.7217	-0.6922
Euchaeta marina	-0.2101	-0.9777
Euterpina acutiferons	0.7297	0.6838
Oithona brevicornis	-0.0845	-0.9964
Oithona rigida	-0.3491	0.9371
Oithona similis	-0.6673	0.7448
Oithona nana	0.966	0.2586
Oithona spinirostris	0.8213	0.5705
Corycaeus sp.	-0.215	0.9766
Corycaeus danae	0.3587	-0.9335
Favella brevis	0.793	-0.6092
Tintinnopsis cylindrica	0.6436	0.7654
Tintinnopsis cynensis	0.394	-0.9191
Sagita enflata	-0.8228	0.5683
Lucifer sp.	0.1064	0.9943
Gastropod larvae	0.9808	0.1951
Gastropod veliger	0.9944	0.1052
Bivalve veliger	-0.6772	0.7358
Crab zoea	0.9711	-0.2386
Euphasid zoea	-0.9801	0.1983
Labidocera acuta	-0.2714	-0.9625
Leucosiidae zoea	-0.3969	-0.9179
Porcellidium spp.	0.9223	0.3866
Portunidae spp.	-0.6793	-0.7339
Dotilla fenestrate	0.6487	-0.7611
Mysis larvae	-0.0845	-0.9964
Nauplius of balanus	0.599	0.8008
Cypris of balanus	0.4249	-0.9052
Globigerina spp.	-0.9237	-0.3831

Euterpina acutiferons, Crab zoea, Portunidae spp., *Globigerina* spp., *Mysis larvae* and *Cypris of balanus.* While comparing post monsoon, more opportunistic species have invaded the fishing area in the summer season, due to the favorable environmental conditions such as salinity, sea surface temperature and coastal current pattern along the western boundary of Gulf of Mannar. Most of the studies on zooplankton in the Indian coastal waters with respect to the physical oceanographic factors mostly limited to the upwelling and eddies (Madhupratap, 1987; Jagadeesan *et al*., 2013).

The positively correlated PC1 species showed negative correlation with *Acrocalanus gibber, A. gracilis, Oncaea conifer, Clausocalanus arcuicornis, Nannocalanus minor, Metacalanus aurivillii, Metacalanus sp., Euchaeta marina, Oithona similis, Tintinnopsis cylindrical, Sagita enflata, Leucosiidae zoea, Portunidae* spp. Among these, *M. aurivillii, Euchaeta marina* and *Portunidae* spp. were identified as opportunistic species.

In summer season, PC2 represented the following species viz. *Acrocalanus gibber, Acrocalanus gracilis, Eucalanus elongatus, E. subcrassus, Temora turbinate, Clausocalanus arcuicornis, Metacalanus aurivillii, Temora discaudata, Oithona nana, Corycaeus* sp., *Sagita enflata, Lucifer* sp., *Gastropod larvae, Bivalve veliger, Dotilla fenestrata* and *Globigerina* spp., with significant positive correlation. Among these positive groups, the following species identified as opportunistic species*: Temora turbinata, Clausocalanus arcuicornis, Metacalanus aurivillii, Oithona nana, Globigerina* spp., while the rest of the species could be grouped as routine ones, being uniformly abundant throughout the year. From the factor analyses, it was derived that the grazing power of zooplankton on phytoplankton was in balanced condition (Verity and Smetacek, 1996) and development of algal bloom could be controlled by zooplankton. Since the grazing power of zooplankton over phytoplankton was in a balanced state, there was no algal bloom in the study area.

The second component of PC2 represented the routine and opportunistic groups. The routine group included species such as *Calanopia minor, Oithona brevicornis, O. rigida, Euphasid zoea* and *Cypris of balanus*. The grazing zooplanktons of opportunistic invaded species including herbivores and carnivores viz. *Tintinnopsis cynensis, Labidocera acuta, Portunidae* spp. and *Mysis larvae*.

In the southwest monsoon also, two different principal components PC1 and PC2 (Table 3) were extracted consisting 74.3% and 25.6% variability with eigene values exceeding 1. The first component showed strong positive loading on all *Acartia erythrea, A. spinicauda, Paracalanus parvus, P. simplex, Copepodite labidoceropavo, Oncaea venusta, Temora stylifera, Calanopia minor, Euterpina acutiferons, Oithona nana, O. spinirostris, Favella brevis, Tintinnopsis cylindrical, Gastropod larvae, Gastropod veliger,* *Crab zoea, Porcellidium* spp. and *Dotilla fenestrate.* Most of the species were herbivores except *Oithona nana, O. spinirostris* and *Porcellidium* spp. Similar to the post monsoon and summer, herbivore and carnivore groups were identified in the PC1 as positive loadings. Further, they were grouped as routine and opportunistic species. The routine group included *A. erythrea, A. spinicauda, Copepodite labidoceropavo, Oncaea venusta, Temora stylifera, Euterpina acutiferons, O. nana, O. spinirostris, Favella brevis, Tintinnopsis cylindrical, Gastropod larvae, Gastropod veliger, Crab zoea, Porcellidium* spp. and *Dotilla fenestrate.* The opportunistic group included *Paracalanus simplex, Calanopia minor, O. nana* and *O. spinirostris*. The opportunistic zooplankton observed during the southwest monsoon was similar with post monsoon species. Oithona was ubiquitous in the Gulf of Mannar, however, their large biological differences, in the community shift (eg. *O. nana*) had large proportional changes in their seasonal cycle. A similar trend was explained to occur along the Gulf of Maine (Pershing *et al.*, 2005). During the southwest monsoon season, phytoplankton population density had decreased gradually evidently due to the least availability of a few phytoplankton species: many of the zooplankton species which foraged in the food-rich surface layers would have possibly migrated to deeper waters form a direct source of flux of organic matter into the ocean interiors (Madhupratap and Parulekar, 1993).

Table 4. Eigene analyses of the correlation matrix loadings of the significant principal components in NE monsoon

NE monsoon	PC1	PC 2
Eigene values	5.67044	0.784322
Variability (%)	87.849	12.151
Cumulative %	87.849	100
Factor loadings		
Acartia erythrea	-0.2457	-0.9693
Acartia spinicauda	0.7644	-0.6448
Acrocalanus gibber	-0.6647	0.7472
Acrocalanus gracilis	-0.8181	-0.5751
Eucalanus elongatus	-0.5177	0.8555
Eucalanus subcrassus	-0.3344	0.9424
Paracalanus parvus	-0.5404	0.8414
Paracalanus simplex	0.786	-0.6182
Calanopia elliptica	0.9284	0.3716
Temora turbinate	-0.0883	0.9961
Copepodite labidoceropavo	0.119	-0.9929
Oncaea venusta	0.9958	-0.09195
Oncaea conifera	-0.938	0.3466
Clausocalanus arcuicornis	-0.4809	0.8768
Nannocalanus minor	0.2352	-0.972
Pseudodiaptomus sp.	0.9009	-0.4339
Metacalanus aurivillii	0.786	-0.6182
Metacalanus sp.	-0.9905	-0.1377
Temora discaudata	-0.3769	0.9263
Temora stylifera	0.9774	-0.2116
Calanopia minor	0.4146	-0.91
Euchaeta marina	-0.976	0.2179
Euterpina acutiferons	-0.5154	0.8569
Oithona brevicornis	-0.6431	-0.7658
Oithona rigida	-0.6182	-0.786
Oithona similis	-0.9115	0.4113
Oithona nana	0.4585	0.8887
Oithona spinirostris	-0.8203	0.5719
Corycaeus sp.	-0.2556	0.9668
Corycaeus danae	-0.9947	-0.1029
Favella brevis	0.676	-0.7369
Tintinnopsis cylindrica	-0.602	0.7985
Tintinnopsis cynensis	-0.2823	-0.9593
Sagita enflata	-0.5566	0.8308
Lucifer sp.	0.761	0.6487
Gastropod larvae	0.9613	0.2756
Gastropod veliger	0.7062	-0.708
Bivalve veliger	-0.9964	0.0851
Crab zoea	-0.0802	-0.9968
Euphasid zoea	-0.812	-0.5837
Labidocera acuta	-0.4955	0.8686
Leucosiidae zoea	-0.9522	-0.3055
Porcellidium spp.	0.9985	0.05517
Portunidae spp.	-0.6829	-0.7305
Dotilla fenestrate	0.9924	0.1232
Mysis larvae	-0.5226	-0.8526
Nauplius of balanus	-0.883	-0.4694
Cypris of balanus	-0.7658	-0.643
Globigerina spp.	-0.7266	0.687

The PC2 showed significant positive correlation among copepods assemblage such as *A. gibber, A. gracilis, E. elongates, E. subcrassus, Calanopia elliptica, Temora turbinate, Clausocalanus arcuicornis, Nannocalanus minor, Pseudodiaptomus* sp., *Metacalanus aurivillii, Temora discaudata, Euterpina acutiferons, O. rigida, O. similis, Corycaeus* sp., *Tintinnopsis cylindrical, Lucifer* sp., *Bivalve veliger* and *Nauplius of Balanus.* Similar to the post monsoon season and summer season, herbivores and carnivores species were recorded in southwest monsoon as well. However, there was a sharp declining in *Leucosiidae zoea, Porcellidium* spp., *Portunidae* spp., *Calanopia elliptica, Oithona nana, Calanopia elliptica* and *Sagita enflata* in the fishing grounds. Particularly, temporal and spatial variation in *Lucifer* sp. abundance was noticed during the study. During the first year of study, density of Lucifer sp. showed slight declining trend in southwest monsoon, and Lucifer sp. was not observed at station 3, in the second year of the study. Jacob *et al.* (1981) reported sharp declining trend of Lucifer sp. during southwest monsoon season in Vizhinjam coastal waters.

In the PC2, the following strong negative correlation were noticed viz. *Metacalanus* sp., *Calanopia minor, Euchaeta marina, Oithona brevicornis, Corycaeus danae, Favella brevis, Tintinnopsis cynensis, Labidocera acuta, Leucosiidae zoea, Portunidae* spp., *Dotilla fenestrate, Mysis larvae* and *Cypris of Balanus.*

In the northeast monsoon PC1 and PC2 (Table 4) were extracted with 87.8% and 12.1% variability with eigene values exceeding 1. PC1 species viz. *Acartia erythrea, Acartia spinicauda, Acartia spinicauda, Calanopia elliptica, Oncaea venusta, Pseudodiaptomus* sp., *Metacalanus aurivillii, Temora stylifera, Favella brevis, Dotilla fenestrate* were identified as opportunistic invader species, followed by *Paracalanus simplex, Lucifer* sp., *Gastropod larvae, Gastropod veliger, Porcellidium* spp. Similar to the summer season, herbivores and carnivores species were emerging together in northeast monsoon to share their food. The overall composition of copepods, harpacticoida and cyclopoida abundance were more or less the same throughout year in the fishing grounds of Gulf of Mannar. Similar findings were reported in Arabian Sea by Madhupratap *et al.* (2003). In the PC1, *Acrocalanus gibber, Acrocalanus gracilis, Oncaea conifer, Metacalanus* sp., *Euchaeta marina, Oithona brevicornis, Oithona rigida, Oithona similis, Oithona spinirostris, Corycaeus danae, Tintinnopsis cylindrical, Bivalve veliger, Euphasid zoea, Leucosiidae zoea, Portunidae* spp., *Cypris of balanus* and *Globigerina* spp. exhibited negative correlation. As implied by the principal component analyses, the routine species and opportunistic species were obliquely appearing in the study area as reported by Pershing *et al.* (2005).

The second component (PC2) of northeast monsoon showed strong positive loading on the species viz. *Acrocalanus gibber, Eucalanus elongatus, Eucalanus subcrassus, Paracalanus parvus, Temora turbinate, Clausocalanus arcuicornis, Temora discaudata, Euterpina acutiferons, Oithona nana, Corycaeus* sp., *Tintinnopsis cylindrical, Sagita enflata, Lucifer* sp., *Labidocera acuta, Globigerina* spp. and the negative correlations on the following species *Acartia erythrea, Acartia spinicauda, Paracalanus simplex, Copepodite labidoceropavo, Nannocalanus minor, Metacalanus aurivillii, Calanopia minor, Oithona brevicornis, Oithona rigida, Favella brevis, Tintinnopsis cynensis, Gastropod veliger, Crab* zoea, Portunidae spp., *Mysis larvae, Cypris of balanus.*

As implied by PCA, the zooplankton diversity was high in northeast monsoon. The factor loadings of zooplankton for different seasons in Tiruchendur coastal water (GOM) was differed from the study carried out by Jose *et al.* (2012) along the southwest coast of India, particularly, routine and opportunistic species were found within the positive and negative factors. The copepods *Acrocalanus gracilis* and *Acartia erythrea* were dominant in summer and southwest monsoon due to the rainfall and freshwater discharge during the summer season; however, these species were replaced by *Temora turbinata* during northeast monsoon season. The *Temora turbinata* was found abundantly during southwest monsoon and northeast monsoon. *Temora turbinata* is an important copepod group, which acts as indicator species of coastal upwelling. Jagadeesan *et al.* (2013) reported *Temora turbinata* in Gulf of Mannar (northern part) during the southwest monsoon only, but in the present study, this species was recorded during southwest monsoon and northeast monsoon as well.

From the results of PCA analyses, it was found that *Temora turbinata* is an opportunistic species, and also evidenced by Jagadeesan *et al.* (2013) in to northern Gulf of Mannar. *Temora turbinata* species showed positive loading during post monsoon only and this species did not show any significant loadings in other seasons. Further, *Temora turbinata* is capable of exploiting upwelling induced high phytoplankton stock prevailing along the west coast of India during the southwest monsoon (Madhupratap and Haridas, 1990; Jagadeesan *et al.*, 2013).

From the principal component analyses, it was understood that zooplankton diversity was significantly different from season to season and principally, the zooplankton structure and its dynamics in Gulf of Mannar was structured by seasonal current patterns.

Conclusions

From the results of PCA analyses, it was found that *Temora turbinata* is an opportunistic species in to northern Gulf of Mannar. Further, PCA revealed that zooplankton diversity was significantly different among studied seasons and principally, the zooplankton abundance and its dynamics in Gulf of Mannar was structured by seasonal current patterns. The factor loadings of zooplankton for different seasons in Tiruchendur coastal water (GOM) was different from the southwest coast of India, particularly, routine and opportunistic species were found within the positive and negative factors. The copepods *Acrocalanus gracilis* and *Acartia erythrea* were dominant in summer and southwest monsoon due to the rainfall and freshwater discharge during the summer season; however, these species were replaced by *Temora turbinata* during northeast monsoon season.

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