A study on zooplankton composition and their potentiality as bio indicators in selected coastal habitats, Sri Lanka

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Abstract

The present study carried out in order to understand the composition of zooplankton and their potentiality as bio indicators in Sri Lankan coastal waters. The study was carried out during the day time in a six months period in 2012. Samples were collected at major ports, fishery harbours and certain important native coastal habitats of Galle, Hambanthota and Trincomalee. A total of 79 zooplankton varieties, representing nine major phyla; Protozoa, Cnidaria, Rotifera, Mollusca, Annelida, Arthropoda, Echinodermata, Chaetognatha and Chordata, were identified in the study. Of these, majority of them are Copepods belonging to four major orders; Calanoida, Cyclopoida, Poecilostomatoida and Harpacticoida and they represented more than 50% of the total species identified. The presence of small sized Poecilostomatoids in higher densities and the presence of large sized Calanoids and Harpacticoids in low numbers may indicate the prey-predator relationship among these orders. Zooplankton diversity indices in all the studied locations were below 3.00. In majority of habitats higher BOD values were reported, few habitats recorded with high amounts of Ammonia and low dissolved oxygen, confirms that these habitats were moderately or highly polluted. Further, presence of few number of Calanoid species with minimum of their densities can be considered as an indicator of water pollution.

Keywords: Marine zooplankton, Bio indicators, Diversity

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Introduction

Zooplankton constitutes an important component of secondary production in aquatic ecosystems. They play a key role in energy transfer from primary to higher trophic levels. The most significant feature of zooplankton is its immense diversity over space and time (Sehgal *et al.*, 2013). Zooplanktons are globally recognized as pollution indicator organisms in the aquatic environment. A change in the physico-chemical aspect of a water body brings about a corresponding change in the relative composition and abundance of the organisms in that water. Non-polluted waters are often characterized by high diversity, with large number of species and no single species dominating in numbers over others (Thakur *et al.*, 2013). In Sri Lanka only a limited number of studies have focused on the marine zooplankton availability (Jayasiri and Priyadarshani, 2007; Jayasiri, 2007) and none with their potentiality as bio indicators. This reveals the importance of having the knowledge on their present distribution and abundance. Since Sri Lanka is located at the middle of the trans-oceanic route, connecting East and West of Indian Ocean, there is a huge potential of alien plankton being introduced into the Sri Lankan coastal zone via ballast water of the ships (Chandrasekera and Fernando, 2009). Therefore, studies on zooplankton are fundamental to controlling and managing the introduction and spread of introduced marine species via ballast water. The present study can be considered as a preliminary attempt to understand spatial variation of composition, abundance and diversity of zooplankton communities in selected coastal habitats and their potentiality to use as bio indicators.

Study Area

Study was carried out during the day time from June to December 2012. Sampling locations were selected to cover mainly the three major ports; Galle, Hambanthota and Trincomalee and all the fishery harbours and certain important native habitats (Arugam Bay, Panama Sea, Pigeon Island) (Fig. 1). Several locations representing each area were investigated for their species composition and abundance of zooplankton.

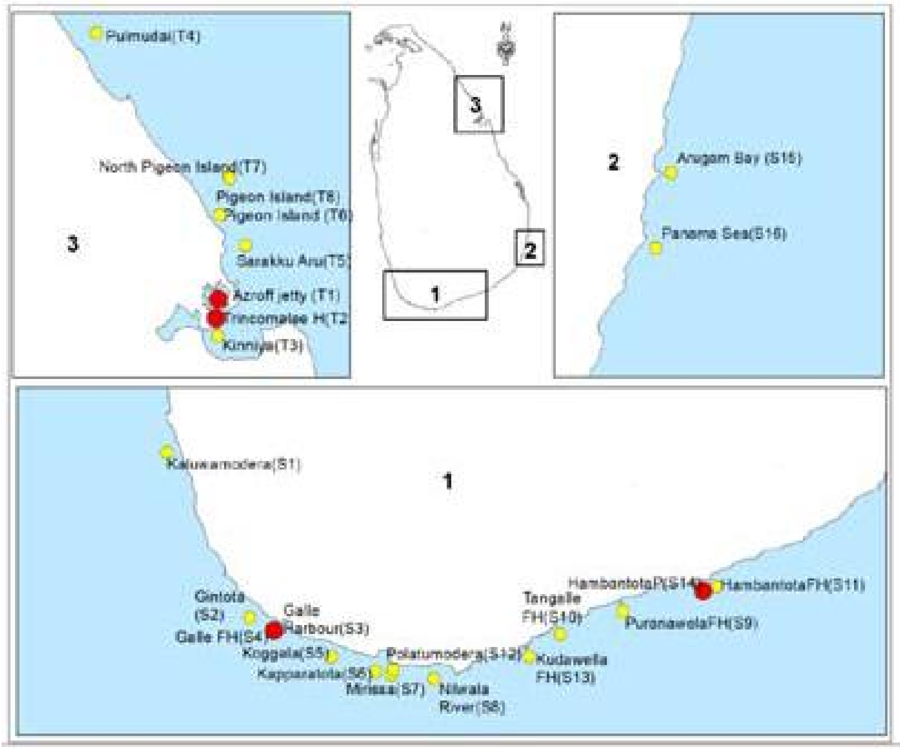

Fig. 1. Study area including Galle, Hambanthota and Trincomalee major ports

Materials and Methods

Plankton samples were collected from each location by filtering 50 L subsurface water through a 55 µm mesh size plankton net. At each location, three random samples were obtained to describe the spatial variation of the zooplankton composition. All the filtered samples were collected into plastic bottles and preserved using 5% formaldehyde solution. Each quantitative sample was concentrated to 10 ml and from this; 1 ml of sample was taken and all individual zooplankton taxa present were counted (APHA, 1998). They were identified to the nearest taxonomic group using standard identification keys (Conway *et al*., 2003; Jayasiri, 2009; Kasturirangan, 1963) and analyzed for their composition and density. Abundance (density) of zooplankton was calculated as the number of individuals per cubic meter of water filtered through the net. The zooplankton diversity was investigated using the Shannon-Wiener diversity index (H). The pollution status indicated by the diversity indices was further confirmed with the physico-chemical parameters (Annex. 1) obtained from Environmental Studies Division, NARA. All water quality analyses were carried out in accordance with the standard methods for examination of water and waste water (APHA, 1998).

Results

A total of 79 zooplankton groups including the developmental stages such as eggs, larvae and nauplii were encountered in the study. They mainly represented nine major phyla namely Protozoa, Cnidaria, Rotifera, Mollusca, Annelida, Arthropoda, Echinodermata, Chaetognatha and Chordata. Of them, forty one species were copepods (including two unknown calanoids and one unknown harpacticoid) representing more than 50% of the total groups identified (Table 1).

Table 1. Overall percentage composition of zooplankton groups found in the study

Zooplankton Group	Number of species/groups	Percentage frequency
Adult copepods		
Calanoida	19	24.05
Poecilostomatoida	7	08.86
Cyclopoida	7	08.86
Harpacticoida	8	10.13
Nauplii stages	5	06.33
Other crustaceans	9	11.39
Protozoans	2	02.53
Cnidarians	1	01.27
Rotifers	4	05.06
Molluscs	1	01.27
Polychetes	3	03.80
Echinoderms	3	03.80
Chaetognaths	1	01.27
Chordates	2	02.53
Unidentified	7	08.86

The abundance of zooplankton varied from 100-34,000 numbers/m^3 in the Southern stretch from Kaluwamodara up to Arugam Bay and 100 to 13,000 numbers/m^3 in locations at Trincomalee. The highest abundance of copepods along the Southern coastal belt was recorded at Hambanthota fishery harbour followed by Galle inner harbour and Koggala free trade zone area. The respective values were 20,533, 19,200 and 14,733 numbers/m^3. In Trincomalee, the highest copepod abundance of 12,133 numbers/m^{3}was observed at pigeon Island Sea (Fig. 2 and Fig. 3).

The most abundant group of copepods were represented by four major orders; calanoida, cyclopoida, poecilostomatoida and harpacticoida. *Acrocalanus* spp., *Acartia* spp., *Pontella* spp., *Temora* spp., *Canthocalanus* spp., *Paracalanus* spp., *Calocalanus* spp., *Cosmocalanus* spp., *Calusocalanus* spp. and *Isias* spp. were the Calanoids observed during the study. A number of Cyclopoids comprising of *Oithona nana, O. oculata, O. similis, O. attenuata* and *O. simplex* were identified. Poecilostomatoids were mainly composed of *Oncaea* spp., *Sapphirina* spp., *Corycaeus* spp. and *Copilia* spp. Harpacticoids included *Euterpina acutifrons, Microsetella rosea, Microsetella norvegica, Miracia efferata, Oculosetella gracilis, Distioculus minor* and *Clymenestra* spp.. All the above species were identified up to the lowest possible taxonomic category using standard identification keys.

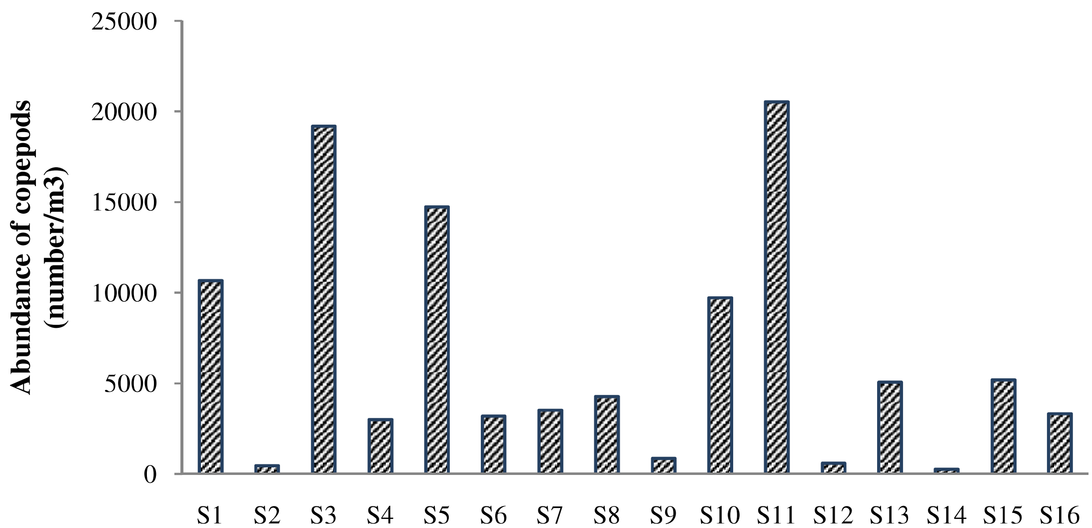

Fig. 2. Copepod abundance (including nauplii and adults) along Southern coastal stretch up to Arugam Bay

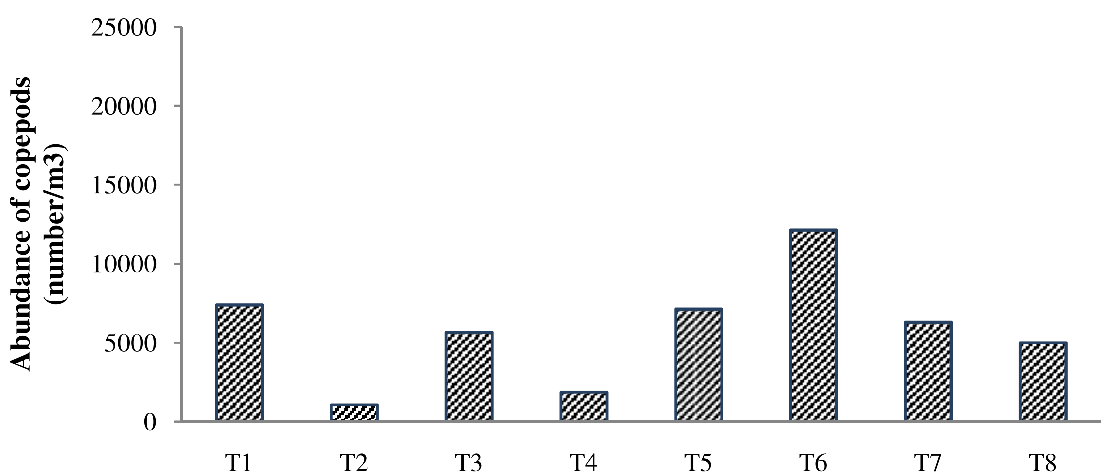

Fig. 3. Copepod abundance (including nauplii and adults) in Trincomalee coastal habitats

Relative abundance of copepods by their orders showed the presence of poecilostomatoids in high abundance only at the low abundance values of calanoids and harpacticoids (Fig. 4).

The Shannon Wiener Indices of all the studied locations were below 3.00, which is an indication of deviation from clean and healthy status of the water bodies. Comparing the data on the species diversity indices of the different locations along the Southern coast line, the maximum value of Shannon Wiener Index (2.45) was observed in Kaluwamodara followed by Arugam Bay (2.39) and Panama Sea (2.38) that can be considered as native habitats.

In Trincomalee, the same result was obtained for North Pigeon Island Sea, where the diversity index was 2.77 and at close proximity to the Pigeon Island, the value has been dropped to 2.00. All the major ports Galle, Hambanthota and Trincomalee and majority of fishery harbours (except Galle, Tangalle and Hambanthota fishery harbours) showed diversity index values less than 2.00 (Table 2).

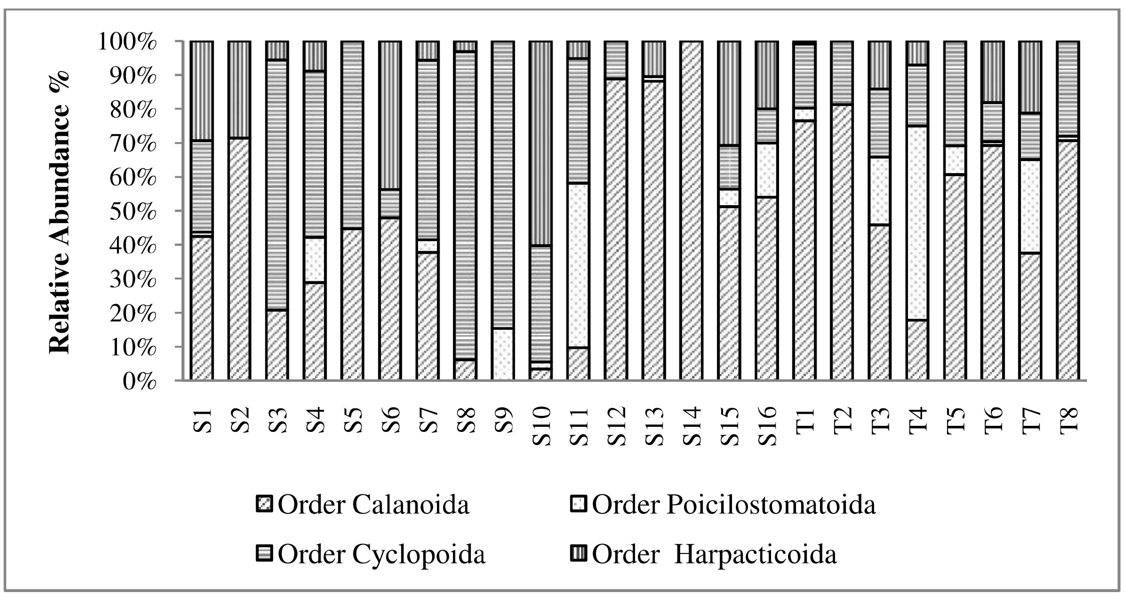

Fig. 4: Relative abundance of copepods and their nauplii by the orders

Results in the bivariate analysis showed that there is a significant linear correlation between zooplankton abundance with phosphate ($r = 0.41$, P-Value = 0.045). None of the other physico-chemical parameters significantly correlated with zooplankton abundance or diversity index values (Table 3).

Location	H	Location	H
S1-Kaluwamodara	2.45	T1-Azroff jetty	1.36
S2- Ginthota	1.77	T2-Trinco inner harbor	1.04
S3- Galle inner harbour	1.74	T3-Kinniya	2.3
S4- Galle FH	2.24	T4-Pulmudei	1.53
S5- Koggala	2	T5-Sarukku aru	2.42
S6- Kapparathota	1.75	T6-Pigeon island sea	2.09
S7- Mirissa FH	1.79	T7-North pigeon island	2.77
S8- Nilwala river mouth	1.31	T8-Pigeon island	2
S9- Puranawella FH	1.34		
S10- Tangalle FH	2.23		
S11- Hambanthota FH	2.31		
S12- Polathumodara	0.82		
S13- Kudawella FH	1.42		
S14- Hambanthota port	1.49		
S15- Arugambay	2.39		
S16- Panama sea	2.38		

Majority of the locations with Shannon Wiener Index< 2 were characterized by higher BOD values (>15 mg/L), some locations with high turbidities (>30 NTU), some with high phosphate levels or low amounts of dissolved oxygen (<4 mg/L). Based on the species found in the different locations, most of the poecilostomatoid, cyclopoid and harpacticoid species were found in both moderately as well as heavily polluted areas while only few species of calanoid were observed in comparatively higher polluted areas (Shannon Wiener Index< 2). Also it was interesting to note that the abundance of adult calanoids were poor in the locations with species diversity index < 2 (average density= 72 numbers/m^3) while the respective value was recorded as 1647 numbers/m^3 in the areas where diversity index ≥2.

Among the poecilostomatoids; *Saphirrina* spp. and *Copillia* spp. were found only in the moderately polluted areas with Shannon Wiener Index ≥2 while absent in highly polluted areas with Shannon Wiener Index< 2. The same consequence was observed with cyclopoids; *Oithona similis, Oithona attenuate* and *Oithona simplex.* Most of the harpacticoids were present in coastal waters in the Shannon index range 1-3, except *Oculosetella gracilis,* present only in waters where diversity index was ≥2 (Table 4).

Table 3. Correlation coefficients among zooplankton abundance, diversity indices and water quality parameters (n=24).

	pH	Temp	EC	TDS	Sal	TUR	DO	BOD	NO_3^-	PO_4^{3-}	NH_3
Temp	0.14										
EC	-0.23	-0.25									
TDS	0.31	0.1	-.83**								
Sal	-0.29	-0.2	.85**	-0.92**							
TUR	-0.28	0.02	-0.32	-0.06	0.11						
DO	0.32	0.1	0.06	-0.05	0.01	-0.23					
BOD	-0.1	-0.21	-0.12	0.15	-0.03	0.24	-0.06				
NO_3^-	-0.17	-0.31	-.41*	0.62**	-0.51*	-0.03	0.01	0.45*			
PO_4^{3-}	-0.01	-0.22	0.19	-0.08	0.16	0.05	-0.15	0.46*	0.19		
NH_3	0.18	0.26	-.70**	0.88**	-.86**	-0.06	0.03	0.18	0.57**	-0.05	
Total Abundance	-0.21	-0.3	0.31	-0.11	0.17	-0.17	0.02	0.26	0.11	0.41*	-0.08
Copepod Abundance	-0.14	-0.3	0.29	-0.09	0.16	-0.26	0.05	0.15	0.11	0.18	-0.14
Diversity Index	-0.08	-0.14	0.35	-0.24	0.31	-0.08	0.09	-0.08	-0.16	-0.1	-0.25

**- Correlation is significant at the 0.01 level (2-tailed)

* - Correlation is significant at the 0.05 level (2-tailed)

Table 4. Copepod species found at different locations based on their Shannon Wiener Index

Species	*≥2*	*< 2*
Order Calanoida		
Acrocalanus gracilis	+	+
Acrocalanus gibber	+	+
Acrocalanus longicornis	+	-
Paracalanus spp.	+	+
Canthocalanus spp.	+	-
Calocalanus pavo	+	-
Acartia erythraea	+	-
Acartia spp. 1	+	-
Acratia spp. 2	+	-
Acartiella spp.	+	-
Cosmocalanus spp.	+	-
Calanus spp.	+	-
Clausocalanus spp.	+	-

Temora spp.	+	+
Isias tropica	+	-
Metacanus spp.	+	-
Order Poecilostomatoida		
Sapphirina spp. 1	+	-
Sapphirina spp. 2	+	-
Corycaeus spp.	+	+
Oncaea spp. 1	+	+
Oncaea spp. 2	+	+
Oncaea spp. 3	+	+
Copilia spp.	+	-
Order Cyclopoida		
Cyclops spp. 1	+	+
Cyclops spp. 2	+	+
Oithona nana	+	+
Oithona oculata	+	+
Oithona similis	+	-
Oithona attenuata	+	-
Oithona simplex	+	-
Order Harpacticoida		
Euterpina acutifrons	+	+
Microsetella rosea	+	+
Miracia efferata	+	+
Microsetella norvegica	+	+
Oculosetella gracilis	+	-
Distioculus minor	+	+
Clymenestra spp.	+	+

Presence (+) /Absence (-) of Taxa

Discussion

In the present study, the abundance of zooplankton ranged between 100-34,000 numbers/m^3 where copepods have been identified as the most dominant group followed by other crustacean larval stages. According to Jayasiri (2007), the abundance of zooplankton in the Palk Strait has varied from 30-244 numbers/L with the same dominant group of copepods (38.78%) followed by crustacean larvae (28.5%). In Gulf of Mannar and Palk Bay, zooplankton density consequently dominated by copepods and their nauplii, other crustacean larvae and bivalve larvae within the range of 78-1,005 numbers/L (Jayasiri and Priyadarshani, 2007). The reported range of zooplankton abundance in the present study is lower than the above Northern areas. Remarkably higher abundance of zooplanktons in Palk Strait, Palk Bay and Gulf of Mannar is obvious since those areas were found to be more productive (Anon, 2005) than the rest of the coastal areas in Sri Lanka.

David (2009) stated that some of the larger copepod species are predators of their smaller relatives. In the present study, the relative abundance of copepods and nauplii by the orders; indicates the highest abundance of poecilostomatoids that are small in size occur only at lower abundance of calanoids and harpacticoids that are large in size. This may indicate the prey-predator relationship of these orders or the size dependent grazing of higher trophic levels. However, more ecological studies have to be carried out to confirm this argument.

The plankton population on which the whole aquatic life depends directly or indirectly is governed by the interaction of a number of physical, chemical and biological conditions and the tolerance of the organisms to variations in one or more of these conditions. In the present study, positive linear corelation was obtained between phosphate and total zooplankton abundance only. Amy *et al*., (2008) reported that there is a positive correlation between total phosphorus and chlorophyll-a. Hence, the above obtained relationship in the present study may be indicating the presence of high amount of phytoplankton containing chlorophyll-a at high phosphate levels and the presence of zooplankton as grazers.

Diversity indices can be served as a good indicator of overall pollution status of the habitat. In the present study, the Shannon Wiener Indices of all the studied locations were below 3.00 indicating the moderately or highly polluted status of the habitats. The recommended water quality standards for coastal waters in Sri Lanka proposed by the Central Environmental Authority (CEA,1992); is as BOD < 4 mg/L, ammonia < 0.4 mg/L, and pH 7-8.5. According to Palanisamy *et al*., (2006), general coastal water quality standards for rest of the parameters studied are as turbidity < 10 NTU, DO> 4 mg/L, nitrate ≤ 10 mg/L and phosphate < 0.1 mg/L. Therefore, highly or moderately polluted status of sites were further confirmed with higher BOD values (BOD > 4 mg/L) in the majority of habitats and high amounts of ammonia in few habitats. However, clarifications are needed to be sought for the sites of Polathumodara, Hambanthota fishery harbour and Tangalle fishery harbour; where in Polathumodara, physicochemical parameters were at the range of standard levels but Shannon Wiener Index was at the minimum level while the case is vice versa for other two locations.

The deviation of Shannon Wiener index value of 2.00 near the Pigeon Island from the maximum value of 2.77 in the Pigeon island sea can be an alarming signal reflecting the ecosystem changes due to various anthropogenic activities. Meanwhile, comparatively higher polluted status (Shannon Wiener Index < 2.00) of all the major ports and majority of fishery harbours also indicates the need for comprehensive monitoring for proper management decisions to conserve their water quality.

The present study was restricted to the period of Southwest Monsoon and Inter Monsoon period only. In spite of other similarities, zooplankton species have different types of life histories influenced by seasonal variations of abiotic factors, feeding ecology and predation pressure (Sakhare, 2007). Therefore, it is recommended to carry out studies on temporal variations of zooplankton communities in the future for the same habitats.

With pollution causing stress, sensitive species are eliminated from a habitat while tolerant species increase in numbers to become dominant. Based on the present observations; *Saphirrina* spp., *Copillia* spp., *O. similis, O. attenuata, O. simplex* and *Oculosetella gracilis* were identified as the sensitive species since they only appeared in the moderately polluted waters where Shannon Wiener Index ≥ 2. But, further confirmation of these species as key indicators of pollution is essential for a proper conclusion. Also, the presence of few calanoid species may be another indicator of heavy water pollution. In addition to the lesser number of species, the density of adult calanoids was also at a minimum level in heavily polluted water. Nimbalkar *et al*., (2013) stated that the low number of adults of calanoida in polluted water may be related to their very low feeding rates on bacteria and picoplankton in the more eutrophic lakes.

The number of zooplankton species present today and their distribution pattern is a result of both their evolutionary history and present day environmental circumstances. Information on environmental conditions and the structure and functioning of plankton communities is used in preparing management plans for minimizing adverse effects of unsustainable developments and pollution. Conservation of aquatic ecosystem is fundamentally more difficult than land because of much greater degree of interconnectedness and lack of clear boundaries. So this type of work will help to formalize the management plans in the aspects of conservation.

Conclusions

Zooplankton communities in the study areas were mainly comprised of copepods and their nauplii stages, other crustacean larval stages, polychete larvae, echinodermata developing stages, rotifers, cnidarians, protozoans, mollusc developing stages and chordates. The abundance, diversity and species richness of these zooplankton community concluded that there would be a potentiality of using them as bio indicators of water quality.

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Annex 1: Average water quality results in the studied locations

Location	Water quality Parameters										
	pH	Temperature/°C	EC ms/cm	TDS g/L	Salinity (ppt)	Turbidity NTU	DO mg/L	BOD mg/L	NO_3^- mg/L	PO_4^{3-} mg/L	Ammonia mg/L
Kaluwamodara	8.05±0.20	29.3 ± 0.73	45.8 ± 0.78	28.5 ± 1.32	30 ± 0.11	3.2 ± 0.65	6.59±0.79	22 ± 5.33	0.02 ± 0.01	0.02 ± 0.01	0.15 ± 0.02
Ginthota	8.04 ± 0.24	28.1 ± 0.65	28.1 ± 0.52	51.8 ± 1.55	33 ± 0.60	34.1 ± 16.23	7.49 ± 0.85	11 ± 3.97	0.32 ± 0.09	0.22 ± 0.01	0.04 ± 0.00
Galle inner harbor	8.18 ± 0.11	29.4 ± 0.74	50.1 ± 1.51	31.6 ± 1.29	33 ± 0.60	4.2 ± 1.75	7 .00± 0.81	07 ± 1.87	0.15 ± 0.05	0.0 ± 0.00	0.20 ± 0.00
Galle FH	8.04 ± 0.21	29.9 ± 0.81	45.1 ± 0.77	28.0 ± 2.61	29 ± 0.56	2.7 ± 0.95	4.30 ± 0.55	09 ± 1.99	0.14 ± 0.05	0.02 ± 0.01	0.19 ± 0.00
Koggala	8.16 ± 0.12	29.1 ± 0.71	51.6 ± 1.53	32.6 ± 1.49	34 ± 0.62	3.4 ± 0.99	8.10 ± 1.11	14 ± 2.83	0.24 ± 0.07	0.02 ± 0.01	0.30 ± 0.05
Kapparathota	8.08 ± 0.21	29.6 ± 0.75	52.7 ± 1.57	33.4 ± 1.59	35 ± 0.68	6.3 ± 4.01	10.2 ± 1.56	25 ± 6.23	0.35± 0.19	0.03 ± 0.02	0.21 ± 0.03
Mirissa FH	8.29 ± 0.32	29 ± 0.70	46.1 ± 0.99	28.8 ± 1.45	30 ± 0.52	3.9 ± 1.56	6.90 ± 0.79	27 ± 6.35	0.22 ± 0.06	0.02 ± 0.01	0.35± 0.06
Nilwala river mouth	8.4 ± 0.55	29.6 ± 0.76	1.2 ± 0.33	613 ± 0.21	0.6 ± 0.003	2.3 ± 1.69	5.50 ± 0.68	22 ± 6.11	0.92 ± 0.04	0.02± 0.00	1.26 ± 0.07
Puranawella FH	7.75 ± 0.15	29.8 ± 0.79	50 .0± 1.50	31.5 ± 1.36	33 ± 0.62	1.7 ± 0.87	5.6 0± 0.66	16 ± 2.85	0.66 ± 0.03	0.03 ± 0.01	0.28 ± 0.04
Tangalle FH	7.72 ± 0.14	26.4 ± 0.55	53.5 ± 1.61	34 ± 1.58	35 ± 0.69	24.6 ± 10.63	3.40 ± 0.57	27 ± 6.01	0.57± 0.03	0.05 ± 0.11	0.24± 0.04
Hambanthota FH	7.92 ± 0. 21	27.3 ± 0.64	53.9 ± 1.67	34.3 ± 1.62	36 ± 0.78	2.8 ± 1.55	4.40 ± 0.59	35 ± 7.81	0.60 ± 0.03	4.95 ± 1.21	0.05 ± 0.00
Polathumodara	8.1 ± 0.13	30.0 ± 0.86	39.7 ± 0.92	24.3 ± 0.55	25 ± 0.45	4.4 ± 1.80	5.60 ± 0.67	01 ± 0.11	0.06 ± 0.01	0.00 ± 0.00	0.18 ± 0.03
Kudawella FH	7.82 ± 0.33	28.5 ± 0.71	54.2 ± 1.71	34.5 ± 1.63	36 ± 0.89	2.6 ± 1.61	2.60 ± 0.22	08 ± 1.94	0.06 ± 0.01	0.06 ± 0.00	0.19 ± 0.04
Hambanthota Port	8.15 ± 0.12	31.3 ± 0.89	31.3 ± 0.87	53.3 ± 1.33	35 ± 0.87	33.8 ± 15.69	2.78 ± 0.29	30 ± 6.39	0.01 ± 0.00	0.37 ± 0.05	0.17 ± 0.22
Arugambay	8.16 ± 0.15	30.2 ± 0.87	52.5 ± 1.65	33.3 ± 1.94	35 ± 0.85	1.9 ± 0.55	7.40 ± 0.86	08 ± 1.93	0.05 ± 0.01	0.01 ± 0.00	0.28 ± 0.06
Panama sea	8.21 ± 0.21	29.5 ± 0.75	52.4 ± 1.63	33.2 ± 1.54	35 ± 0.86	0.6 ± 0.11	6.60 ± 0.75	14 ± 2.55	0.27 ± 0.05	0.01 ± 0.00	0.29 ± 0.09
Azroff Jetty	8.31 ± 0.25	28.1 ± 0.69	53.5 ± 1.68	34.0 ± 1.60	35.4 ± 0.89	0.3 ± 0.07	5.70 ± 0.67	21 ± 5.64	0.20 ± 0.11	0.17 ± 0.01	0.04 ± 0.01
Trinco inner harbor	8.38 ± 0.51	27.9 ± 0.56	53.2 ± 1.66	33.7 ± 1.58	35.1 ± 0.79	0.7 ± 0.01	5.70 ± 0.66	20 ± 5.61	0.30 ± 0.13	2.78 ± 0.09	0.04 ± 0.13
Kinniya	8.22 ± 0.31	29.4 ± 0.81	53.1 ± 1.66	35.0 ± 1.70	33.7 ± 0.68	6.9 ± 3.17	4.2 0± 0.57	02 ± 0.13	0.10 ± 0.10	0.11 ± 0.01	0.06 ± 0.14
Pulmudei	8.17 ± 0.22	30.0 ± 0.85	53.4 ± 1.67	35.3 ± 1.73	33.9 ± 0.67	15.8 ± 5.61	5.90 ± 0.68	23 ± 5.67	0.20 ± 0.12	4.55 ± 0.11	0.46 ± 0.51
Sarukku aru	8.11 ± 0.12	29.9 ± 0.82	53.1 ± 1.65	33.7 ± 1.62	35.1 ± 0.78	9.0 ± 3.97	5.60 ± 0.67	07 ± 1.91	0.12 ± 0.10	0.20 ± 0.01	0.17 ± 0.23
Pigeon island sea	8.12 ± 0.13	30.2 ± 0.87	53.1 ± 1.66	33.7 ± 1.62	35.1 ± 0.76	0.5 ± 2.99	6.00 ± 0.76	17 ± 2.89	0.30 ± 0.13	0.08 ± 0.01	0.065 ± 0.13
North pigeon island	8.28 ± 0. 32	28.0 ± 0.68	53.2 ± 1.67	33.8 ± 1.32	35.1 ± 0.78	0.6 ± 3.07	6.20 ± 0.77	09 ± 1.97	0.19± 0.11	0.15 ± 0.01	0.04 ± 0.11
Pigeon island	8.39 ± 0.61	27.8 ± 0.54	53.2 ± 1.67	33.8 ± 1.81	35.2 ± 0.81	0.2 ± 0.89	6.30 ± 0.77	12 ± 0.45	0.14 ± 0.10	0.16 ± 0.01	0.03 ± 0.11

Source: Environmental Studies Division, NARA