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Zooplankton composition and distribution in the Lembeh Strait of North Sulawesi, Indonesia

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Abstract

Based on oceanographic survey data in June 2012 in the Lembeh Strait, the zooplankton ecological characteristics such as species composition, individual abundance, dominant species and distribution were analyzed. The results showed that 183 species (including 4 sp.) had been recognized, most of them belonged to copepoda. Cnidaria followed with 43 species (including 1 sp.) were identified. The average abundance of zooplankton was (150.47±58.91) ind./m^3. As to the horizontal distribution, the abundance of the zooplankton was higher in the southern waters than in the northern waters. The dominant species in the study area were *Lensia subtiloides*, *Sagitta enflata*, *Lucifer intermedius*, *Oikopleura rufescens*, *Diphyes chamissoni*, *Creseis acicula*, *Subeucalanus subcrassus*, *Temora discaudata*, *Aglaura hemistoma*, *Doliolum denticulatum*, *Canthocalanus pauper*, *Oikopleura longicauda* and *Nanomia bijuga*. Zooplankton biodiversity indexes were higher in study area than previous study in the other regions. The findings from this study provide important baseline information for future research and monitoring programs.

Key words: zooplankton, species composition, dominant species, distribution, Lembeh Strait

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1 Introduction

Coral reef ecosystems were composed by several interdependent communities and habitat niches. Zooplankton, which was an important community in the coral reef ecosystems, was a necessary food source for corals and other reef organisms. (Tada et al., 2003; Ferrier-Pagès et al., 2011). Zooplankton also plays a key role in marine food web dynamics, biogeochemical cycling and fish recruitment (Alcaraz et al., 2010). They also play an important role in the biomagnifications of pollutants of food webs (Gray, 2002). Zooplankton affected the health, growth, and survival of corals by several ways. They can be able to influence the physicochemical characteristics of the water column by absorption, transformation and elimination (Fisk et al., 2001). Disturbances such as a decrease of corals and increase of nutrients from human activities may influence the structure of zooplankton communities by changing the quantity and composition of food sources (Houlbrèque and Ferrier-Pages, 2009). At the same time, as to the sensitivity to water conditions such as food supply, water temperature, and salinity, some species have long been employed as indicators of different water masses (Hwang and Wong, 2005; Dur et al., 2007; Tseng et al., 2011; Chou et al., 2012). Extensively studies had been carried out in recent years focus on zooplankton in coral reef (Nakajima et al., 2006, 2008, 2009). Researches revealed that greater availability of zooplankton prey may also mitigate coral bleaching (Palardy et al., 2008). Also when impaired autotrophy some coral species can be able to increase feeding rates and supplement their metabolic requirements by means of zooplanktivory (Towle et al., 2014). Palardy et al.'s (2005, 2006) researches in Pacific Panama have quantified the important role of zooplankton as a source of food for corals. This work pointed out that coral feeding is facultative and those rates can vary widely.

The Lembeh Strait, located in the east of the North Sulawesi, is one of the busiest straits in the Indonesia's island of Sulawesi. The strait is the only gate to the Bitung Sea Port which is the hub of ocean transportation in the eastern part of Indonesia. Besides being one of the busiest seaports in East Indonesia, several industries and economic activities are allocated around Bitung. These include fish processing, ship building, sea transportation, and notably marine tourism. The Lembeh Strait, which is the migratory area for fish, connect the Malucca Sea and Sulawesi Sea. The Lembeh Strait is endowed with rich marine biodiversity which makes it one of the favorite diving spots. The Lembeh Strait also contains enormous abundance of plankton which supports the life of surrounding marine biota (Rumengan et al., 2011).

The increasing industrialization of Bitung has led to threat to the existing biodiversity of plankton. Recently the Lembeh Strait

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has attracted the interest of marine scientists. Notwithstanding the ecological interest in this area, the literature on its pelagic biological domain is limited (Rumengan, 2012). This study gives a general picture of zooplankton of the Lembeh Strait based mainly on samples collected in June 2012. The objectives of the present study were to determine the composition and species diversity of zooplankton along the Lembeh Strait and to examine their spatial distributions along the strait. This investigation forms part of a multidisciplinary research project on the Lembeh Strait. This work also is essential for the conservation of coral reef ecosystems in the Bitung Strait.

2 Materials and methods

2.1 *Study area*

The Lembeh Strait is a narrow strait located at the northeast of the North Sulawesi of Indonesia (Fig. 1). It is a relatively shallow sea (the depth range from 5 to 20 m) and is about 15 km long and 2 km width stretch of water which separates the Lembeh Island and the mainland. The tides in this area are mixed and mainly semidiurnal, which fluctuate slightly with an annual tidal range of 2.4 m. The strait is strongly influenced by wet northwest monsoon from November to March and from May to September it was influenced by dry southeast monsoon (Aldrian and Susanto, 2003).

2.2 *Sampling program*

Cruise was carried out in June 2012. Zooplankton samples were collected at 19 sites in the Lembeh Strait (Fig. 1) using a hand net (0.2 m² aperture, 0.505 mm mesh) (Table 1). The net was hand-towed vertically. When the depth of the station was ⩽16 m, samples were collected from near bottom to the surface; when the depth of station was >16 m, samples were collected from 16 m to the surface. All samples were removed from the nets and immediately fixed and preserved in 4%–5% formaldehyde seawater solutions.

2.3 *Identification and measurement of zooplankton*

In the laboratory, zooplankton were sorted and identified from the entire sample. Only adult individuals were identified as species, while juveniles were counted as larva by a Nikon SMZ-1500 stereomicroscope. A high quality imaging system (Axio Imager M2, Zeiss, Germany) was used to observe zooplankton appendages. For identification many guides and manuscripts were consulted (Sars, 1903; Huys and Boxshall, 1991; Boxshall and Halsey, 2004). The abundance of zooplankton was computed on the basis of the volume filtered, as estimated from the flowmeter mounted on the equipment. All samples were deposited into the Biodiversity Collections of the Third Institute of Oceanography, Ministry of Natural Resources, Xiamen.

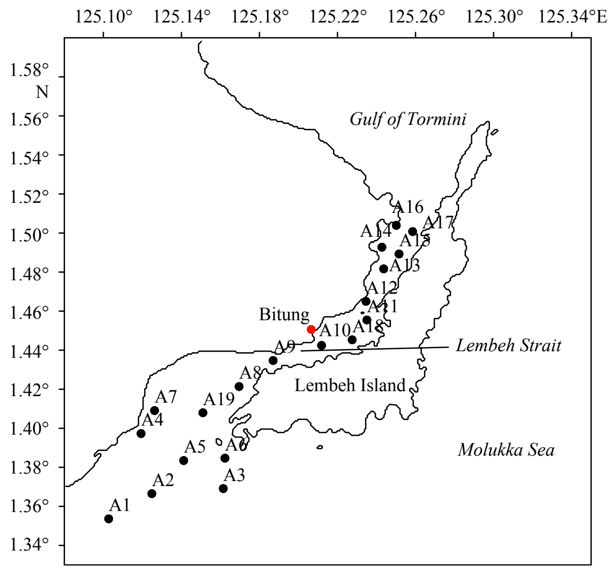

Fig. 1. Map of the study area and location of sampling station in the Lembeh Strait.

2.4 *Statistical analyses*

To evaluate the distribution pattern of zooplankton, the data from 19 samples of 183 zooplankton species were computed using a cluster analysis to elucidate the relative similarities among

Table 1. Geographical coordinates of sampling stations with the date, time, and sampling depth at each station

Station	North latitude	East longitude	Date	Sampling depth/m
A1	1°21′13.20″	125°06′09.90″	2012/06/09/10:33:00	16
A2	1°21′59.58″	125°07′29.52″	2012/06/11/10:11:00	16
A3	1°22′09.00″	125°09′41.28″	2012/06/11/09:43:00	16
A4	1°23′50.40″	125°07′09.66″	2012/06/09/11:25:00	8
A5	1°23′00.60″	125°08′28.26″	2012/06/11/10:36:00	16
A6	1°23′04.96″	125°09′44.34″	2012/06/11/10:53:00	16
A7	1°24′32.76″	125°07′34.56″	2012/06/11/11:23:00	16
A8	1°25′17.04″	125°10′10.44″	2012/06/11/11:23:00	16
A9	1°26′05.04″	125°11′13.26″	2012/06/11/11:48:00	16
A10	1°26′32.89″	125°12′42.60″	2012/06/11/12:53:00	16
A11	1°27′19.68″	125°14′06.18″	2012/06/09/14:24:00	16
A12	1°27′54.00″	125°14′04.50″	2012/06/11/13:49:00	16
A13	1°28′53.94″	125°14′37.20″	2012/06/11/13:30:00	16
A14	1°29′33.84″	125°14′33.90″	2012/06/12/10:11:00	16
A15	1°29′21.30″	125°15′05.52″	2012/06/12/09:55:00	16
A16	1°30′14.10″	125°15′00.42″	2012/06/12/09:33:00	16
A17	1°30′02.64″	125°15′30.60″	2012/06/12/09:41:00	16
A18	1°26′43.14″	125°13′39.06″	2012/06/13/11:29:00	16
A19	1°24′28.70″	125°09′03.74″	2012/06/13/11:10:00	16

samples. The abundance of species in each sample was used to calculate Bray–Curtis similarities before the clustering analyses. The functional test of Box and Cox (1964) for data transformation was applied before the similarity analysis. The value (λ) of the power transformation for the zooplankton was 0.75. Therefore, lg(x+1) was applied to the logarithmic transformation of the individual abundance of the zooplankton. Similarity analysis programs in the Paleontological Statistics (PAST) software package were used to evaluate the significance level of differences among zooplankton assemblages (Hammer et al., 2001). The zooplankton species characterizing each cluster were further identified using the indicator value index (IndVal) proposed by Dufrêne and Legendre (1997). This index was obtained by multiplying the product of two independently computed values by 100:

$$IndVal\,(j,s) = 100 \times SP\,(j,s) \times FI\,(j,s)\,, \tag{1}$$

where $SP(j, s)$ is the specificity and $FI(j, s)$ is the fidelity of a species (s) toward a group of samples (j). These value were calculated by

$$SP\,(j,s) = \frac{NI\,(j,s)}{\sum NI\,(s)}\,, \tag{2}$$

$$FI\,(j,s) = \frac{NS\,(j,s)}{\sum NS\,(s)}\,, \tag{3}$$

where $NI(j, s)$ is the mean abundance of species s across samples pertaining to j, $\sum NI\,(s)$ is the sum of the mean abundances of species s within the various groups in the partition, $NI(j, s)$ is the number of samples in j in which species s is present, and $\sum NS\,(s)$ is the total number of samples in that group.

The Pielou evenness indexes (J') were used to estimate the community composition, and the Shannon–Wiener diversity indexes (H') was used to evaluate the species diversity of each sample.

$$J' = \frac{H'}{\log_2 S}\,, \tag{4}$$

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i, \tag{5}$$

$$P_i = n_i / N, \tag{6}$$

where S is the total species of the samples, p_i means the percentage of the ith species individual to the all individual, n_i means the individual of the ith species, and N means the number of all species.

3 Results

3.1 *Zooplankton community structure*

From a total of 19 samples in the Lembeh Strait obtained in June 2012, a total of 183 zooplankton species (including 4 sp.) were identified (Table 2). The most dominant were copepod, ac-

Table 2. Average abundance (ind./m^3), relative abundance (RA, %) and occurrence ratio (OR, %) recorded from the survey

Scientific classification	Mean±SD	RA	OR
Cnidaria			
Aglaura hemistoma	3.17±4.07	2.72	84.21
Geryonia proboscidalis	0.03±0.14	0.03	5.26
Liriope tetraphylla	1.07±1.04	0.92	78.95
Petasiella asymmetrica	0.18±0.72	0.16	10.53
Obelia spp.	0.10±0.36	0.08	10.53
Cirrholovenia tetranema	0.10±0.21	0.08	21.05
Clytia folleata	0.44±0.79	0.38	47.37
Clytia hemisphaerica	0.02±0.07	0.01	5.26
Clytia macrogonia	0.02±0.07	0.01	5.26
Eirene brevistylus	0.07±0.20	0.06	10.53
Eirene pentanemalis	0.26±0.85	0.23	10.53
Eucheilota menoni	0.08±0.36	0.07	5.26
Eucheilota multicirris	0.03±0.14	0.03	5.26
Helgicirrha gemmifera	0.02±0.07	0.01	5.26
Laodicea indica	0.03±0.14	0.03	5.26
Lovenella assimilis	0.15±0.37	0.13	26.32
Lovenella polyconcretus	0.03±0.10	0.03	10.53
Pseudoclytia pentata	0.03±0.14	0.03	5.26
Cunina octonaria	0.02±0.07	0.01	5.26
Cunina peregrine	0.02±0.07	0.01	5.26
Solmundella bitentaculata	0.36±0.83	0.31	26.32
Euphysora bigelowi	0.05±0.16	0.04	10.53
Euphysora knides	0.02±0.07	0.01	5.26
Halitiara knides	0.08±0.18	0.07	21.05
Proboscidactyla flavicirrata	0.13±0.38	0.11	15.79
Vannuccia forbesi	0.05±0.16	0.04	10.53
Zanclea costata	0.08±0.36	0.07	5.26
Abylopsis eschscholtzi	0.44±0.51	0.38	63.16
Abylopsis tetragona	0.05±0.16	0.04	10.53
Bassia bassensis	0.21±0.33	0.18	42.11
Chelophyes appendiculata	1.58±2.19	1.35	57.89
Chelophyes contorta	0.49±0.66	0.42	47.37
Diphyes bojani	0.08±0.20	0.07	15.79
Diphyes chamissoni	3.87±3.72	3.32	94.74
Diphyes dispar	0.21±0.45	0.18	26.32
Lensia campanella	0.03±0.14	0.03	5.26
Lensia hotspur	0.02±0.07	0.01	5.26
Lensia subtilis	0.07±0.20	0.06	10.53
Lensia subtiloides	30.48±21.42	26.14	100.00
Nanomia bijuga	2.96±4.85	2.54	68.42
Sphaeronectes gracilis	0.08±0.36	0.07	5.26
Sulculeolaria chuni	0.51±0.94	0.44	36.84
Rhopalonema velatum	0.10±0.21	0.08	21.05
Ctenophora			
Cestum veneris	0.02±0.07	0.01	5.26
Haeckelia rubra	0.03±0.10	0.03	10.53
Hormiphora palmate	0.07±0.22	0.06	10.53
Pleurobrachia globosa	0.64±0.56	0.55	78.95
Prosobranchia			
Atlanta sp.	0.13±0.24	0.11	26.32
Atlanta depressa	0.16±0.34	0.14	26.32
Atlanta fusca	0.07±0.17	0.06	15.79
Atlanta lesueuri	0.43±0.51	0.37	57.89
Atlanta peroni	0.13±0.32	0.11	21.05

to be continued

Continued from Table 2

Scientific classification	Mean±SD	RA	OR
Atlanta rosea	0.05±0.12	0.04	15.79
Atlanta turriculata	0.10±0.26	0.08	15.79
Opisthobranchia			
Diacria sp.	0.03±0.10	0.03	10.53
Cavolinia longirostris v. *angulata*	0.02±0.07	0.01	5.26
Corolla ovata	0.03±0.10	0.03	10.53
Creseis acicula	3.60±3.04	3.09	94.74
Creseis chierchiae	0.05±0.12	0.04	15.79
Creseis clava	0.48±0.74	0.41	47.37
Creseis virgula	0.03±0.14	0.03	5.26
Creseis virgula v. *conica*	0.05±0.16	0.04	10.53
Diacria quadridentata	0.02±0.07	0.01	5.26
Diacria quadridentata v. *costata*	0.03±0.10	0.03	10.53
Limacina inflata	0.02±0.07	0.01	5.26
Limacina trochiformis	0.03±0.10	0.03	10.53
Cladocera			
Evadne tergestina	0.03±0.10	0.03	10.53
Ostracoda			
Euconchoecia bifurata	0.02±0.07	0.01	5.26
Euconchoecia elongata	1.88±2.29	1.61	78.95
Copepoda			
Acartia erythraea	0.38±0.41	0.32	57.89
Acartia negligens	0.36±0.46	0.31	57.89
Acartia pacifica	0.02±0.07	0.01	5.26
Acartia spinicauda	0.02±0.07	0.01	5.26
Acrocalanus gibber	0.36±0.64	0.31	47.37
Acrocalanus gracilis	0.25±0.41	0.21	36.84
Acrocalanus longicornis	0.02±0.07	0.01	5.26
Bestiolina amoyensis	0.02±0.07	0.01	5.26
Bestiolina zeylonica	0.16±0.30	0.14	36.84
Calanopia elliptica	0.59±1.09	0.51	63.16
Calanopia minor	0.05±0.16	0.04	10.53
Calocalanus pavo	0.12±0.24	0.10	26.32
Candacia bradyi	1.10±1.72	0.95	52.63
Candacia catula	0.99±0.92	0.85	78.95
Candacia discaudata	0.59±0.77	0.51	63.16
Canthocalanus pauper	2.14±2.69	1.83	84.21
Centropages calaninus	0.02±0.07	0.01	5.26
Centropages furcatus	0.53±0.74	0.45	57.89
Centropages gracilis	0.02±0.07	0.01	5.26
Centropages orsinii	0.56±0.89	0.48	47.37
Clausocalanus furcatus	0.10±0.15	0.08	31.58
Clausocalanus mastigophorus	0.05±0.12	0.04	15.79
Clausocalanus minor	0.07±0.17	0.06	15.79
Copilia lata	0.03±0.14	0.03	5.26
Copilia mirabilis	1.04±0.79	0.89	94.74
Corycaeus agilis	0.12±0.19	0.10	31.58
Corycaeus andrewsi	0.08±0.29	0.07	10.53
Corycaeus asiaticus	0.08±0.29	0.07	10.53
Corycaeus catus	0.05±0.22	0.04	5.26
Corycaeus crassiusculus	0.08±0.18	0.07	21.05
Corycaeus dahli	0.02±0.07	0.01	5.26
Corycaeus giesbrechti	0.08±0.20	0.07	15.79
Corycaeus pacificus	0.02±0.07	0.01	5.26
Corycaeus pumilus	0.02±0.07	0.01	5.26
Corycaeus speciosus	0.41±0.50	0.35	63.16

to be continued

Continued from Table 2

Scientific classification	Mean±SD	RA	OR
Corycaeus subtilis	0.02±0.07	0.01	5.26
Corycaeus typicus	0.03±0.10	0.03	10.53
Cosmocalanus darwinii	0.97±1.18	0.83	78.95
Euchaeta concinna	0.03±0.14	0.03	5.26
Euchaeta indica	0.02±0.07	0.01	5.26
Euchaeta rimana	0.03±0.10	0.03	10.53
Euterpina acutifrons	0.03±0.10	0.03	10.53
Farranula carinata	0.05±0.16	0.04	10.53
Farranula gibbula	0.08±0.18	0.07	21.05
Labidocera acuta	0.07±0.13	0.06	21.05
Labidocera bataviae	1.71±5.08	1.47	42.11
Labidocera minuta	0.25±0.34	0.21	47.37
Nannocalanus minor	0.05±0.16	0.04	10.53
Oithona plumifera	0.48±0.51	0.41	68.42
Oithona setigera	0.05±0.12	0.04	15.79
Oithona simplex	0.02±0.07	0.01	5.26
Oncaea clevei	0.02±0.07	0.01	5.26
Oncaea media	0.07±0.17	0.06	15.79
Oncaea mediterranea	0.07±0.13	0.06	21.05
Oncaea venusta	0.18±0.39	0.16	26.32
Paracalanus aculeatus	0.46±1.18	0.39	31.58
Paracalanus crassirostris	0.02±0.07	0.01	5.26
Paracalanus denudatus	0.30±0.28	0.25	63.16
Paracalanus elegans	0.02±0.07	0.01	5.26
Paracalanus parvus	0.08±0.36	0.07	5.26
Paracandacia truncata	0.02±0.07	0.01	5.26
Pontella denticauda	0.05±0.16	0.04	10.53
Pontellina plumata	0.02±0.07	0.01	5.26
Rhincalanus cornutus	0.03±0.10	0.03	10.53
Sapphirina angusta	0.02±0.07	0.01	5.26
Sapphirina auronitens	0.07±0.17	0.06	15.79
Sapphirina gastrica	0.05±0.22	0.04	5.26
Sapphirina gemma	0.03±0.14	0.03	5.26
Sapphirina intestinata	0.03±0.14	0.03	5.26
Sapphirina nigromaculata	0.02±0.07	0.01	5.26
Sapphirina ovatolanceolata	0.05±0.12	0.04	15.79
Sapphirina sinuicauda	0.05±0.12	0.04	15.79
Sapphirina stellata	0.05±0.12	0.04	15.79
Subeucalanus crassus	0.21±0.72	0.18	15.79
Subeucalanus dentatus	0.25±0.44	0.21	31.58
Subeucalanus mucronatus	0.28±0.42	0.24	42.11
Subeucalanus pileatus	0.25±0.46	0.21	31.58
Subeucalanus subcrassus	1.88±1.88	1.61	94.74
Subeucalanus subtenuis	0.28±0.36	0.24	52.63
Temora discaudata	1.99±1.44	1.71	89.47
Temora turbinata	0.02±0.07	0.01	5.26
Tortanus forcipatus	0.02±0.07	0.01	5.26
Tortanus gracilis	0.02±0.07	0.01	5.26
Undinula vulgaris	2.52±4.60	2.16	68.42
Mysidacea			
Promysis orientalis	0.03±0.14	0.03	5.26
Amphipoda			
Vibilia viatrix	0.02±0.07	0.01	5.26
Decapoda			
Lucifer intermedius	7.67±12.00	6.57	94.74
Lucifer typus	0.02±0.07	0.01	5.26

to be continued

Continued from Table 2

Scientific classification	Mean±SD	RA	OR
Lucifet hanseni	1.55±4.62	1.33	36.84
Chaetognatha			
Krohnitta pacifica	0.54±0.50	0.47	78.95
Sagitta bedoti	0.20±0.38	0.17	36.84
Sagitta enflata	8.44±7.11	7.24	94.74
Sagitta ferox	0.30±0.51	0.25	36.84
Sagitta minima	0.02±0.07	0.01	5.26
Sagitta nagae	0.15±0.32	0.13	21.05
Sagitta neglecta	0.69±1.49	0.59	42.11
Sagitta pacifica	0.02±0.07	0.01	5.26
Sagitta pulchra	0.05±0.16	0.04	10.53
Sagitta regularis	0.05±0.12	0.04	15.79
Appendiculata			
Oikopleura spp.	0.39±1.03	0.34	15.79
Fritillaria formica	0.18±0.35	0.16	26.32
Fritillaria haplostoma	0.03±0.14	0.03	5.26
Fritillaria pellucida	0.03±0.14	0.03	5.26
Oikopleura albicans	0.07±0.29	0.06	5.26
Oikopleura fusiformis	1.12±1.80	0.96	36.84
Oikopleura longicauda	2.78±4.37	2.38	73.68
Oikopleura megastoma	0.63±1.02	0.54	47.37
Oikopleura rufescens	6.32±5.63	5.42	94.74
Stegosoma magnum	1.20±4.71	1.03	21.05
Thaliacea			
Dolioletta gegenbauri	0.05±0.16	0.04	10.53
Doliolina separata	0.28±1.00	0.24	15.79
Doliolum denticulatum	2.52±2.80	2.16	84.21
Thalia democratica	1.51±2.49	1.30	78.95
Weelia cylindrica	0.03±0.14	0.03	5.26
Total abundance	150.47±58.91		

counting for 45.90% of the total zooplankton species, respectively. Cnidaria followed with 23.50% of the total species (Fig. 2a). When it comes to abundance, Cnidaria was the most dominant group with 31.92% of the total zooplankton abundance. The second group was copepod accounting for 22.09% of the total abundance (Fig. 2b).

Zooplankton abundance and the number of species recorded over 19 sampling stations are shown in Fig. 3. Integrating the data from all stations (19 samples), the maximum zooplankton abundance was recorded at Sta. A4 (252.52 ind./m^3), followed by a sample at Sta. A19 (246.56 ind./m^3), whereas the minimum abundance was recorded in a sample at Sta. A14 (51.24 ind./m^3). The number of copepods species identified in each sample ranged from 27 (Sta. A4) to 64 (Sta. A17) (Fig. 3).

Among all samples, the six most abundant species were *Lensia subtiloides* (relative abundance (RA): 26.14%), *Sagitta enflata* (RA: 7.24%), *Lucifer intermedius* (RA: 6.57%), *Oikopleura rufescens* (RA: 5.42%), *Diphyes chamissoni* (RA: 3.32%) and *Creseis acicula* (RA: 3.09%). In terms of frequency of occurrence, the following 12 species occurred in >80% samples: *Lensia subtiloides* (100%), *Copilia mirabilis*, *Creseis acicula*, *Diphyes chamissoni*, *Lucifer intermedius*, *Oikopleura rufescens*, *Sagitta enflata* and *Subeucalanus subcrassus* (94.74%), *Temora disaudata* (89.47%), *Aglaura hemistoma*, *Canthocalanus pauper* and *Doliolum denticulatum* (84.21%) (Table 2).

The rank of RAs of the dominant species at each sampling station showed geospatial variation (Fig. 4). The occurrence ratio of

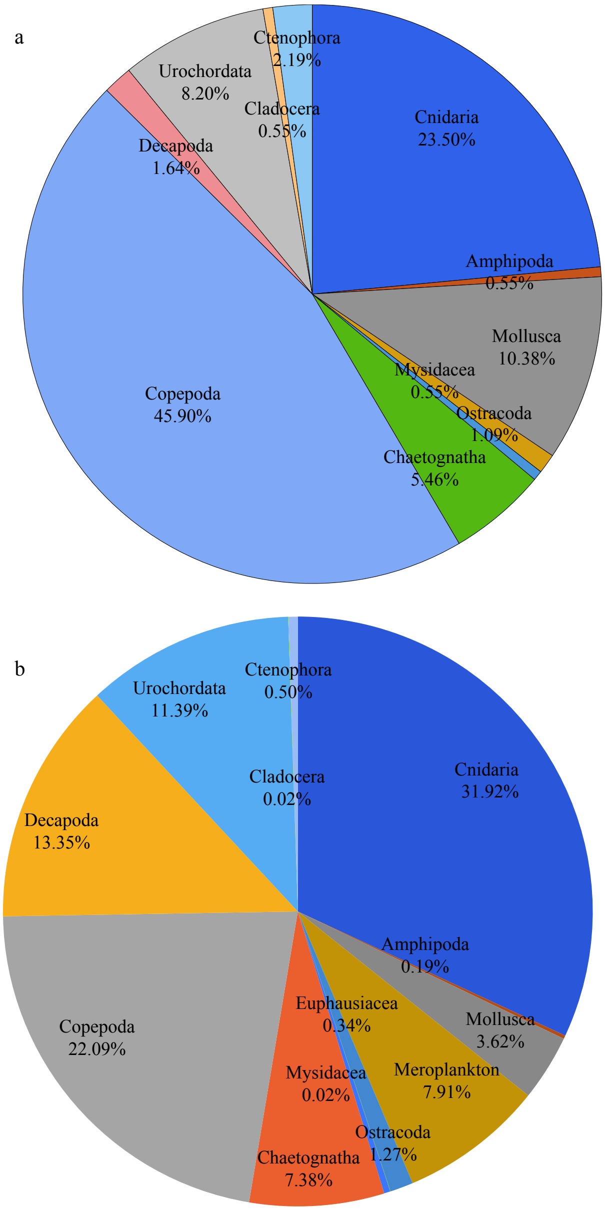

Fig. 2. Percentage of species number (a) and abundance (b).

the dominant species *Lensia subtiloides* was 100%. The highest RA of this species was recorded at Sta. A11 with 52.14%, followed by Stas A12 (43.74%) and A4 (39.91%). The highest RA of *Sagitta enflata* was recorded at Sta. A6, (16.28%) followed by A10 (15.70%). *Lucifer intermedius* was dominant at Stas A7 (43.11%), A16 (10.76%), A12 (10.16%) and A9 (10.11%). At Stas A17 and A6, *Oikopleura rufescens* was dominant with the RA 19.31% and 13.44%. *Doliolum denticulatum* exhibited relatively high RA values at Sta. A15 (11.51%). A higher RA of *Nanomia bijuga* was recorded at Sta. A2 with 13.42%. The remaining zooplankton RA varies between 19.35% (Sta. A19) to 50.00% (Sta. A15).

3.2 *Hierarchical classification*

Zooplankton assemblage analysis based on Bray–Curtis similarities showed that the station variations in community structure were separated (Fig. 5). Table 3 provided the zooplankton composition and distribution for the 19 samples at the sampling station. At the highest grouping level, two samples with a relative

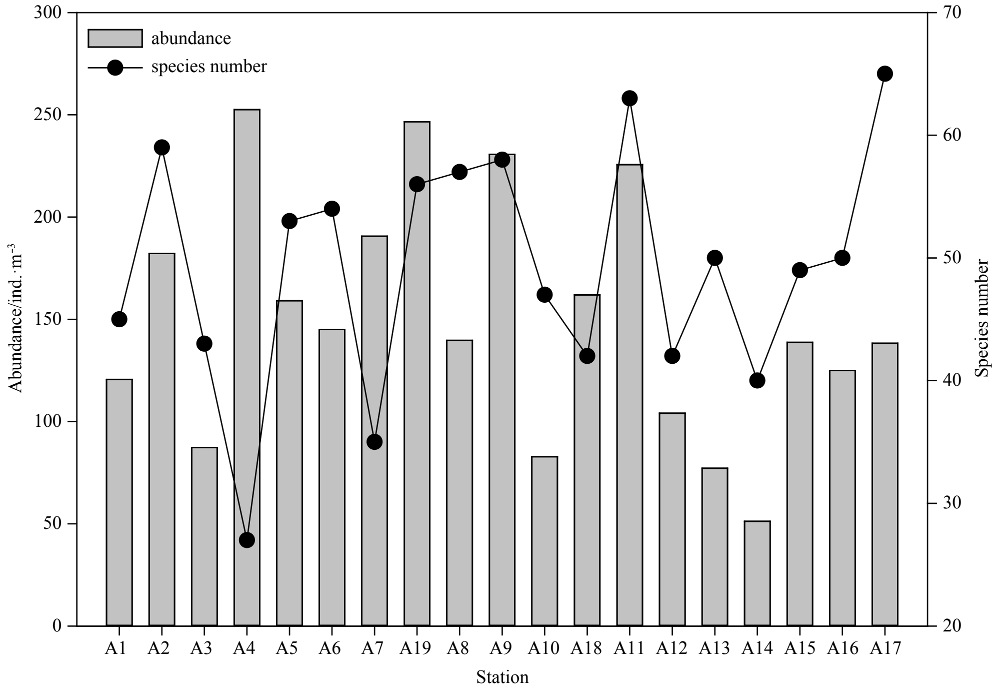

Fig. 3. Variations of the zooplankton abundance and species composition.

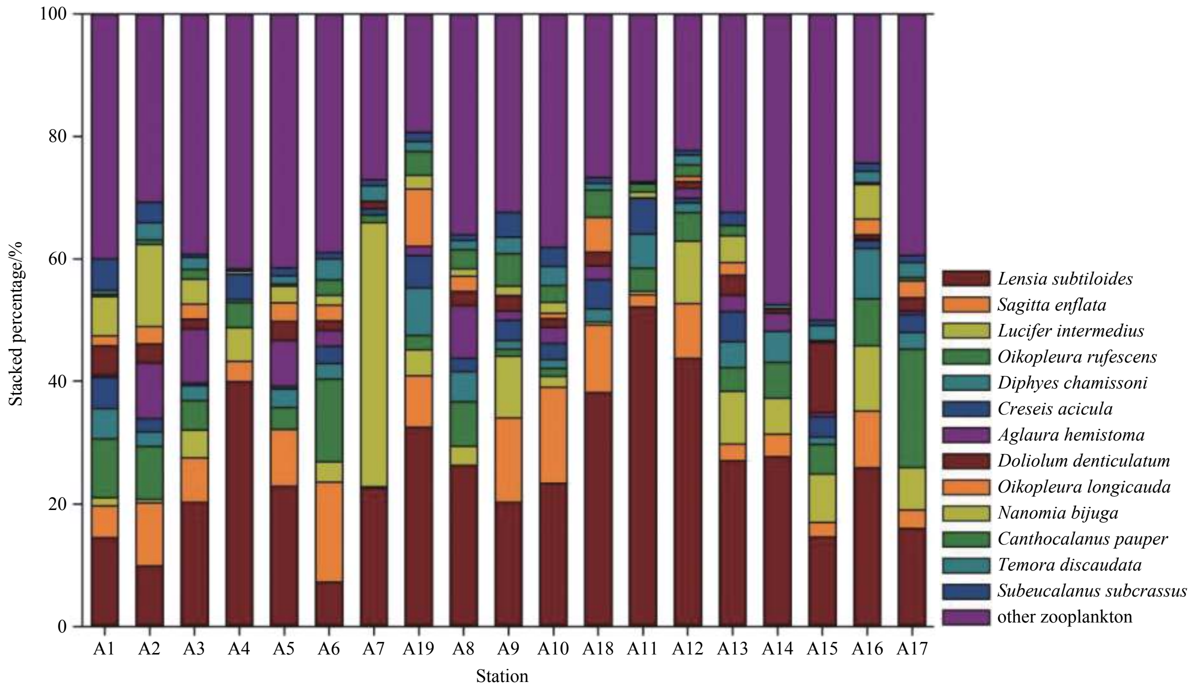

Fig. 4. Relative abundances of the dominant zooplankton species found at different sampling stations.

higher abundance of zooplankton collected along the coast line at the southern part of the strait were separated into Group I (Fig. 5). The major species of Group I were *Lensia subtiloides* (IndVal: 32.00%), *Lucifer intermedius* (IndVal: 22.63%), *Labidocera bataviae* (IndVal: 10.74%), and *Lucifer hanseni* (IndVal: 9.72%) (Table 3). The second hierarchical level separated the samples collected at station located at the northern area of the strait (Group II). The major zooplankton species of Group II were *Lensia subtiloides* (IndVal: 20.74%), *Oikopleura rufescens* (IndVal: 9.39%), and *Lucifer intermedius* (IndVal: 8.19%) (Table 3). Stations, which located at the center of the strait, were grouped into Group IIIA. *Lensia subtiloides* (IndVal: 30.31%) and *Sagitta enflata* (IndVal: 8.06%) were the major dominant species in this group. The other stations were grouped into Group IIIB except Sta. A11. In Group IIIB, the major dominant species were *Lensia subtiloides* (IndVal: 14.54%), *Sagitta enflata* (IndVal: 10.03%), *Oikopleura rufescens* (IndVal: 8.08%) and *Nanomia bijuga* (IndVal: 6.09%). There were 63 zooplankton species at Sta. A11 which located at the center of

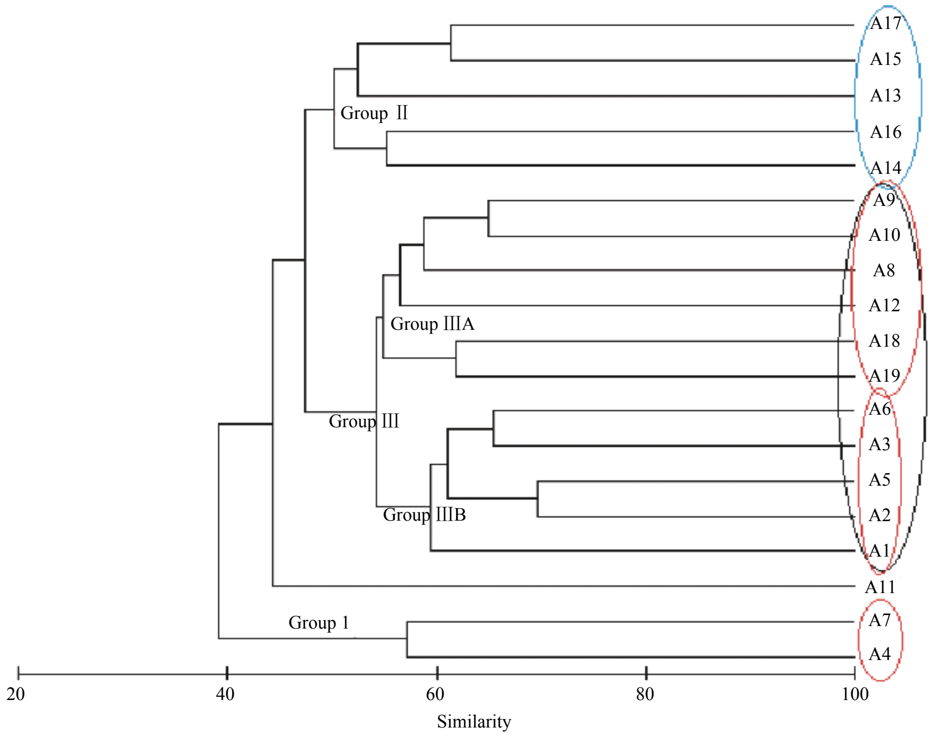

Fig. 5. Clustering of different samples using Bray-Curtis similarity of the zooplankton.

Table 3. Indicator species and index values (%) of each species with a value exceeding 1% for each cluster identified using Bray–Curtis cluster analysis (Fig. 5)

Indicator species	Cluster Group			
	I	II	IIIA	IIIB
Lensia subtiloides	32.00	20.74	30.31	14.54
Sagitta enflata	1.94	4.36	8.06	10.03
Oikopleura rufescens	2.86	9.39	2.05	8.08
Nanomia bijuga				6.09
Aglaura hemistoma		1.05	2.70	5.93
Undinula vulgaris			1.60	5.14
Chelophyes appendiculata				3.73
Diphyes chamissoni		4.13	3.73	2.99
Doliolum denticulatum		4.13	1.30	2.89
Oikopleura longicauda			3.31	2.57
Subeucalanus subcrassus			1.97	2.31
Creseis acicula	2.74	2.08	3.61	2.15
Temora discaudata		1.44	1.88	2.10
Oikopleura fusiformis				1.85
Thalia democratica		3.38		1.84
Copilia mirabilis		1.05		1.63
Candacia bradyi			1.02	1.51
Cosmocalanus darwinii		1.38		1.36
Lucifer intermedius	22.63	8.19	5.12	1.30
Euconchoecia elongata			2.87	1.26
Canthocalanus pauper			3.89	1.10
Candacia catula			1.13	1.05
Oikopleura megastoma		1.62		
Liriope tetraphylla		1.73		
Labidocera bataviae	10.74			
Centropages orsinii	1.71			
Clytia folleata		1.43		
Lucifer hanseni	9.72			
Stegosoma magnum		2.07		
Cumulative contribution/%	84.34	68.20	74.56	81.46

the strait with the dominant species of *Lensia subtiloides* (RA: 52.15%). Followed by *Creseis acicula* (RA: 5.78%), *Diphyes chamissoni* (RA: 5.59%), *Oikopleura rufescens* (RA: 3.73%) and *Sagitta enflata* (RA: 2.05%) (Table 3).

3.3 *Statistical analysis*

A rank abundance (%) analysis of zooplankton composition among the 19 sampling stations demonstrated geospatial variability in the structure (Fig. 6). The patterns of the rank abundance curves were relatively similar for most sampling stations. The result was similar with hierarchical classification. Station A11 was dominant by *Lensia subtiloides* with the abundance of 87.50 ind./m^3 at Sta. A7, *Lucifer intermedius* was the most dominant specie with the abundance 53.75 ind./m^3, and *Lensia subtiloides* followed with 28.13 ind./m^3.

Indexes of evenness and Shannon-Wiener diversity were shown in Fig. 7. The average of the evenness index was 0.92, with the maximum 0.95 at Sta. A6. The evenness index minimum was also recorded at Sta. A7 with 0.90. The average of Shannon-Wiener diversity was 5.16. The maximum of Shannon-Wiener diversity was recorded at Sta. A11 with the value 5.53. The secondary high value of Shannon-Wiener diversity was recorded at Sta. A17 with 5.50. The minimum was also recorded at Sta. A4 with 4.36. The Shannon-Wiener diversity was 4.60 at Sta. A7, which matched with the minimum of the richness index and evenness index.

4 Discussion

Several methods were used for the study of zooplankton associated with coral reefs, including nets, benthic traps, core samplers, bags, video footage and suction devices (Heidelberg et al., 2004). All the different methods made a better understanding of zooplankton dynamics. Coral reef zooplankton abundance was affected greatly by both biological and environmental cycles (Heid-

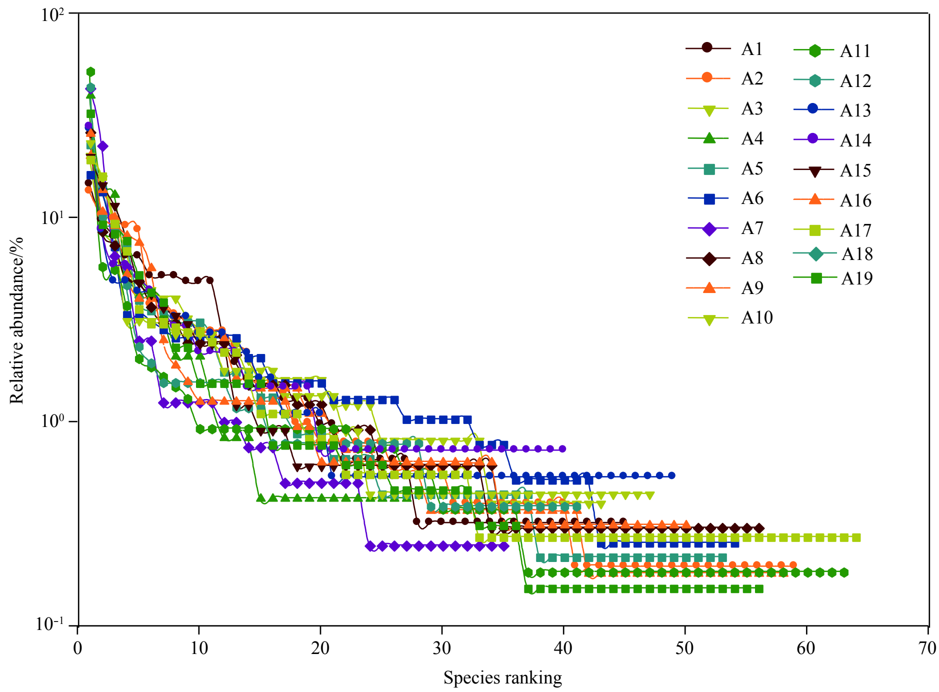

Fig. 6. Rank abundance diagrams of zooplankton sampled at 19 stations.

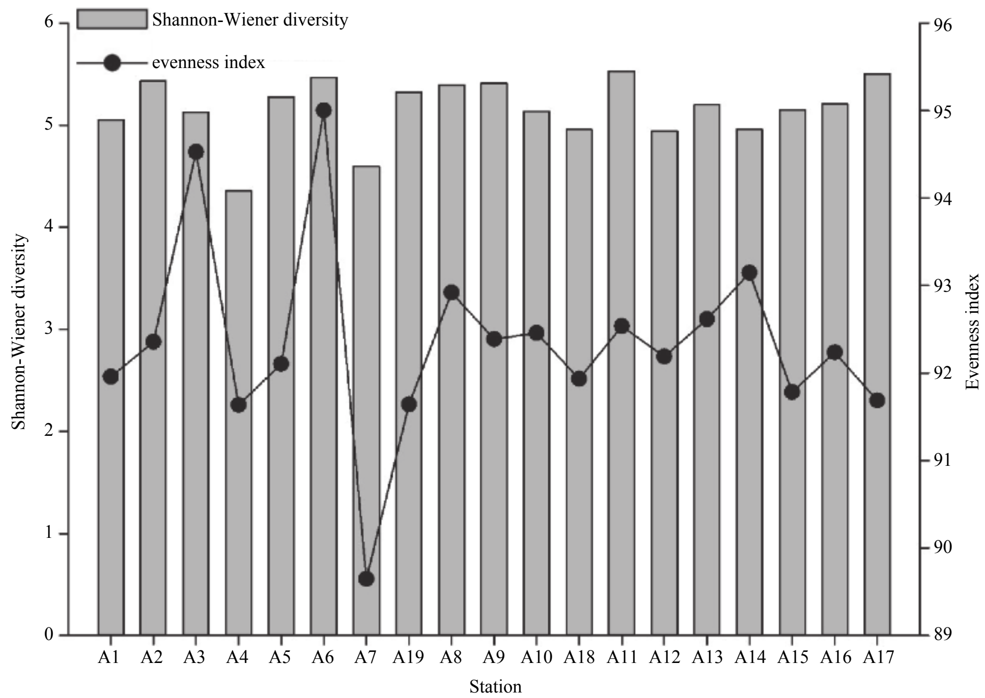

Fig. 7. Variations of the Pielou's evenness index and Shannon-Wiener diversity.

elberg et al., 2004). Abundance was generally one to two times greater at night than during the day. Coral reef zooplankton abundance varied geographically from highs of 3 000–4 000 ind./m^3 in Jamaica and Panama, to <100 ind./m^3 on the Great Barrier Reef (Heidelberg et al., 2004). The water mass in the Lembeh Strait with a relatively strong current provided a favorable condition for zooplankton to grow (Rumengan, 2012). Strong currents together with the characteristic of mixing water provide relative abundance of most zooplankton taxa (Coyle and Pinchuk, 2003). In our research, zooplankton abundance ranged from 51.24 ind./m^3 to 252.52 ind./m^3 with average (150.47±58.91) ind./m^3. Samples were collected using a net of 300 μm mesh size with abundance of 3 100 ind./m^3 to 33 750 ind./m^3 (Rumengan, 2012). Different net mesh size was used in our research and Rumengan's and in Rumengan's research, Ciliata was counted also result in difference of the abundance.

Study area was located in the center of the global convection and was affected by the Indonesian Through Flow (ITF) (Gordon et al., 2010, Schiller et al., 2010). There exists a southward flow delivered warm and fresh water in north to the south of Lembeh Strait. In the southern coast of the strait, Stas A4 and A7 were classified into Group I. This area was affected by coconut oil industry and fish processing on land. Lower indexes of evenness and Shannon-Wiener diversity were recorded at Stas A4 and A7, which was similar with previous study (Rumengan et al., 2011). Group II located at the northern part of the strait where the water mass were affected by the NPTW (North Pacific Tropical Water) significant than southern (Nagai and Hibiya, 2015). Group III contains the other station which located at the center and southern part of the strait. Group IIIA was located at the center of the strait with relatively high diversity and abundance, which was similar with Rumengan et al. (2011). The result in our research showed that zooplankton distribution was observably affected by different water mass in the strait.

In our research 183 zooplankton species were identified with the average of Shannon-Wiener diversity 5.16 and the evenness index 0.92. Both Shannon-Wiener diversity and evenness index were much higher than Rumengan et al. (2011). Du et al. (2015) showed that zooplankton Shannon-Wiener diversity only 3.33 in the Meiji coral reef. Copepod diversity was very poor with the index 1.17 in Hainan coast line (Sun et al., 2014). Copepod species were much higher than the coastline of northern of the Taiwan Strait, where the plankton copepod showed low biodiversity index with remarkable dominant species (Wang et al., 2012). Diversity index confirmed that the zooplankton diversity in the Lembeh Strati was very rich based on the classification from Mcintyre (1982). The result maybe signing that the abundance and composition of the zooplankton in research area were steadier, which was conflicting with Rumengan's (2012) result.

The species composition and abundance of zooplankton are known to change seasonally in coral reef waters (Sammarco and Crenshaw, 1984). This study was conducted only during dry season. A long-term investigation is needed to clarify the details of zooplankton community structure in this coral reef environment. Also, considering the anthropogenic input into the coastal water, more extensive studies concerning zooplankton are required to understand plankton biodiversity and distribution in the Lembeh Strait.

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