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Zooplankton researches in Indonesian waters: A historical review

MULYADI[1*] and Inneke F. M. RUMENGAN[2]

[1] *Research Center for Biology, Indonesian Institute of Sciences, Jl. Raya Bogor Km. 46, Cibinong 16911, Indonesia*
**E-mail: mulyadi_08@yahoo.com*
[2] *Faculty of Fisheries and Marine Science, Sam Ratulangi University, Kampus Unsrat, Manado, Indonesia*

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Abstract—The taxonomic study of Indonesian marine zooplankton was initiated by the U.S. Exploring Expedition in 1849, followed by Challenger (1874) and other expeditions. Long term studies of Delsman (1921–1939) have made inventory of fish eggs and larvae in Java Sea. Some copepod taxa from Indonesian waters, in particular, have been reported, such as *Rhincalanus*, *Pleurommama*, some genera of Calanoida, *Labidocera pectinata* group and *Pontella alata* group. Studies of Mulyadi (1994–2011) have listed about 300 species of copepods, including 55 new records and 13 new species. Zooplankton production-related surveys have been conducted during the Baruna Jaya Expedition I in 1964. The findings of higher zooplankton abundances in the Java Sea than in the Indian Ocean are consistent with the results of more recent studies. Similar tendency of temporal zooplankton distribution in the waters around Seribu Islands and that in Jakarta Bay has been found by the Research Center for Oceanography, Jakarta. The studies on effects of environmental factors on copepods and rotifers are also reviewed. Constraints in taxonomic studies due to the lack of taxonomic skills and insufficient facilities need to be addressed for future elaboration of zooplankton research.

Key words: zooplankton, biodiversity, Indonesia, copepods, expeditions

Introduction

The Indonesian archipelago stretches from 6°N to 10°S and from 95°E to 142°E and comprises about 18,110 islands with coastlines totaling 108,920 km. About 78% of the Indonesian territory is covered by waters with shallow seas in the western and eastern regions, the Sunda and Sahul plates separated by the deep Banda Sea connected with other deep seas such as Sulawesi and Maluku Seas in the north and Bali and Flores Seas in the south. The northern seas are connected to the Pacific Ocean while the southern seas to the Indian Ocean. The assemblage of marine habitats in Indonesia, therefore, is among the most diverse in the world. The diversity of Indonesian marine life is hard to be precisely reported, new species are still being described and many more are still unknown.

Because of their importance in the marine ecosystem, the existing body of knowledge on the biology of zooplankton is considerable, but comparatively much fewer studies on the taxonomy and biogeography of Indonesian marine zooplankton have been carried out previously, and mostly were conducted by foreign scientists.

This review addresses a progress of the researches on zooplankton in Indonesian waters. The historical expeditions in Indonesian waters regarding zooplankton are firstly reviewed, followed by studies on the distribution and abundance of zooplankton, mainly in the eastern Indonesian waters. More recent taxonomic studies on copepods covering nearly the whole Indonesian waters are reviewed. Limited information on biological characteristics and life cycles of major zooplankton taxa and those on fisheries-oriented studies are also provided. Implications to fisheries science and zooplankton monitoring in general are discussed with the intent to inspire relevant experts for more researches for assessment of zooplankton as indicators of environmental change in the future.

Taxonomic studies

Plankton research in Indonesia started in the mid-19th as parts of the earliest natural-history expeditions. For instance, Dana (1849, 1853) reported a number of zooplankton species collected by U.S. Exploring Expedition from Bangka region and Malacca Strait in his monographs, representing the first taxonomic studies of zooplankton in Indonesian waters. Although many of the young specimens mentioned by Dana can not be recognized and several of the adult specimens are insufficiently characterized, Dana's papers undoubtedly are of fundamental value, as a comprehensive treatise on the various groups of Crustacea. In 1874 the Challenger Expedition (1872–1876) visited Arafura, Banda, Buru and Sulawesi Seas. The copepods collected during the cruise were studied by Brady (1883), who identified a number of calanoid species. Collections of zooplankton were also taken by ships of other expeditions, such as Valdivia (1898–1899) from the west coast of Sumatra. Several reports on the Indonesian zooplankton were also published, such as that by Cleve (1901) which, disappointingly, does not indicate accurate sampling localities. Next report was that of Carl (1907) for copepods from Ambon Bay, followed by Scott (1909) who reported the copepods collected in the eastern part of Indonesian waters during the Siboga Expedition (1898–1900), including 338 species, of which 83 were new to science. Although descriptions and references to localities are short and notes on the variability are almost completely lacking, Scott's article is still among the most important papers and the first dealing with bathypelagic species collected in the Indonesian waters. Snellius Expedition (1929) brought home about 800 plankton samples from 350 localities in the eastern Indonesian waters. Vervoort (1946) reported the families Calanidae, Eucalanidae, Paracalanidae and Pseudocalanidae from this expedition, but observation on the other families of the Calanoida was far from complete.

Collections of copepods were also taken from the Indian Ocean side of West Sumatra by ships such as Valdivia (1898). Monographical papers on various groups from this expedition were published by Schmaus and Lehnhofer (1927) on *Rhincalanus* and Steuer (1932) on *Pleurommama*. Additional zooplankton species from Indonesian waters were reported by Früchtl (1923, 1924) who published papers on pelagic copepods of the Aru Islands. Dammerman (1929) reported three copepod species from brackish waters in Verlaten Island near Krakatau, which were identified by Sewell. Sewell (1933) also described copepods from Malacca Strait, mainly from Penang and Perak regions. Zooplankton from Java Sea and Sunda Strait were also reported by Delsman (1939, 1949).

More recent studies on zooplankton from Indonesian waters include those by Fleminger and Hulsemann (1973) on the genus *Eucalanus*, Fleminger et al. (1982) on *Labidocera pectinata*-group, Fleminger (1986) on the family Pontellidae, Ohtsuka et al. (1987) on *Pontella alata*-group. Fleminger et al. (1982) and Fleminger (1986) recognized 6 species-groups among the Indo-West Pacific *Labidocera* and *Pontella*, i.e, the *L. detruncata*, *L. kroyeri, L. pectinata, P. alata, P. andersoni* and *P. fera* groups, but they did not give any definition for these groups. In the meantime Grigore Antipa Expedition (1991) visited North Sulawesi and adjacent waters. Gutu et al. (1997) reported on Amphipoda, Cumacea, Isopoda, and Mysidacea collected during this expedition. The occurrence of the mysid, *Doxomysis quadrispinosa* in the Indian ocean which probably from the Banda Sea was reported by Taniguchi (1974). Other species, *Pseodoxomysis caudaensis* collected from the northern coast of the Central Java (Tegal) and *P. incisa*, from Sahul Shelf, Timor Sea, as a new species, were described by Murano (2001).

More recent extensive studies on the taxonomy and biogeography of copepods in Indonesian waters (Fig. 1) were conducted by Mulyadi (1997a, 1997b, 2002, 2003, 2004, 2005, 2009), and he found about 300 species including 55 new records and 13 new species, *Calanopia asymmetrica*, *Labidocera javaensis, L. muranoi, Pontella bonei, P. kleini, P. labuanensis, P. vervoorti, Candacia ishimarui*, *Hemicyclops javaensis, H. minuta*, *Paramacrochiron amboinensis, Kelleria indonesiana* and *K. javaensis*. In his studies from 1994 to 2010, the copepod samples were collected from several areas of Java Sea, Cilacap Bay (1994, 1997, 2009), off Bengkulu (2006), Derawan Strait, East Kalimantan (2003-2004), Lembeh Strait, North Sulawesi (2003-2004), Labuan Tobelo, Buton (2004), Togean Islands (2004), Ombai Strait (2005), Ambon Bay (1994), and Manyailibit Bay, West Papua (2008), Ujung Kulon National Park (2008), Bali Strait (2009) and Sempu Island, East Java (2010). Zooplankton data in these areas have also been contributed by Ahadi (2005) and Heriyanto (2008) in Lembeh Strait, Bitung connected to Maluku Sea. A new species of copepod, *Pseudodiaptomus sulawesiensis* (Calanoida, Pseudodiaptomidae) in Likupang water of northern tip of Sulawesi which is connected to Sulawesi Sea was described by Nishida and Rumengan (2005).

Very limited data is available on meroplankton taxonomy. The earliest body of knowledge on the ichtyoplankton in the Java Sea was provided by Delsman who conducted a 17-year study and found more than 20 taxa of ichtyoplankton, such as *Fistularia serrate* Cuv., *Chirocentrus dorab* (Forsk), *Dussumieria hasseltii* Blkr, *Caranx kurra, C. marosoma, C. cromenophthalmus, Clupea* spp., *Dorosoma chacunda* (H.B), *Scomber kanagurta* C.V., *Trichiurus* spp., *Engraulis, Chanos chanos*, *Pellona, Chirocentrus hipaelososma, Amphiprion percula* C.V., *Stolephorus*, *Cybium, Setipinne* and *Coila*. He annually reported it from 1921 to 1939, as shown in the reference list of Praseno (1979).

Distributional studies

Zooplankton studies dealing with distribution including composition and abundance have been started in the early 1960's (Nontji 1993). Relevant information has also been resulted from the sample collections of the Cooperative Study of the Kuroshio and Adjacent Regions (1965–1970 and 1971–1973). Praseno (1979) reported the average density of zooplankton in the Java Sea being 226 inds m^{-3}. A similar pattern of temporal zooplankton distribution around Seribu Islands has been found by Arinardi et al. (1977). They reported the average density of zooplankton being 695 inds m^{-3} during rainy season (west monsoon) and 689 inds m^{-3} in dry season (east monsoon). During the rainy season the distribution was more or less homogeneous, while during the dry season the plankton were concentrated near the coast. Montly observations from June 1974 to May 1975 by Sutomo et al. (1977) reported higher plankton concentration in April (4451 inds m^{-3}) than in October (366 inds m^{-3}), while an opposite pattern was found in the next survey by Sutomo (1978) where the maximum number of zooplankton (1689 inds m^{-3}) was in November and the minimum (1309 inds m^{-3}) in May. Copepoda, Luciferidae and Larvacea were found mainly during rainy seasons, while Ostracoda were found mainly during dry seasons. According to Sutomo et al. (1977) low zooplankton concentrations in October were caused by blooming of *Noctiluca* and Thaliacea, or by the high turbidity of sea water due to heavy rainfall. In the rainy season the nitrate content in sea water was low, corresponding with the low zooplankton abundance. The highest zooplankton densites were found during the east monsoons ($>$1000 inds m^{-3}), while in the west monsoon the plankton abundance decreased to a half. Yusuf (1979) found that zooplankton density in Ambon Bay from May 1974 to April 1975 varied with the range of 230–1153 inds m^{-3} and 181–980 inds m^{-3} in the inner and outer bays, respectively.

One of the most significant contributions to the distributional ecology of Indonesian zooplankton has resulted from the Snellius II Expedition (1985) in the northern Arafura Sea and the eastern Banda Sea (Arinardi et al. 1990, Baars et al. 1990, Schalk et al. 1990, Soewito and Schalk 1990). Vertical distribution has been investigated during the expedition, not only for holoplankton, such as copepods (Baars et al. 1990, Arinardi et al. 1990), but also for the meroplankton such as fish larvae (Soewito and Schalk 1990) and micronekton (Schalk et al. 1990). Baars et al. (1990) described the seasonal variation in vertical distribution of zooplankton biomass in Banda Sea with reference to the physical ocean dynamics. In this area, upwelling occurs in the eastern region during the southeast monsoon. They found that in the upwelling area 77% of the zooplankton biomass in the 0–500 m layer was present in the upper 150 m both day and night. In contrast, in the stations downstream of the upwelling, a pronounced vertical migration occurred, with only 37% of the 0–500 m population present in 0–150 m by day versus 75% at night. Soewito and Schalk (1990) found no significant seasonal differences in abundance and biomass. At night on average two-thirds of the fish larvae occurred in the upper 100 m of the water column. During the day the larvae exhibited vertical migration, down to the depths of 400–500 m.

In their review, Tomascik et al. (1997) discussed the variation in migration of the major species of calanoid copepods based on Arinardi's (1991) description. Among the 8 species studied (*Calanoides philippinensis, Rhincalanus nasutus, Subeucalanus dentatus, S. mucronatus, Scolecithrix danae, Candacia pachydactyla, Euchaeta marina*, and *Pleurommama abdominalis*), *C. philippinensis* was regarded as a typical upwelling species. During the upwelling period, when the upper water was cooler and more nutrient-rich, this species was confined to the upper layer (0–50 m) during the day and night. In less nutrient-rich water downstream of the upwelling area, however, it stayed in a deeper layer (250 m). This species appears to migrate ontogenetically and seasonally between the surface and below 500 m. Another copepod, *Pleurommama abdominalis*, was considered as a strong vertical migrant. It was distributed in 50–500 m in the daytime and migrated to the surface at night in both seasons. Based on the distributional pattern, copepod species of Indonesian waters may be divided into two groups: one that occurs in coastal waters with low salinity and a wide range of water temperature, such as *Parvocalanus crassirostris*, and the other that inhabits offshore water of high salinity and a narrower range of water temperature, e.g., *Pleurommama gracilis* and *Rhincalanus cornutus*.

The abundance of each species varied with areas and seasons. *Acrocalanus gibber, Parvocalanaus crassirostris*, and *Acartia erythraea* were most abundant in the Java Sea throughout the year, and *Undinula vulgaris* and *Cosmocalanus darwini* from June to September. The patterns of vertical distribution of copepods seemed to be relatively stable throughout the year. In deep water stations, the center of abundance both in biomass and in species diversity was usually in the upper 100 m layer, frequently associated with an aggregation of copepods within 40–60 m. Some copepod species performed diel vertical migration. The general pattern of this diel migration varied from species to species and from one stage to another in the life history of the same species. In general four patterns were recognized: (1) descending at midnight and ascending at dawn as in *Pareucalanus attenuatus*, *Euchaeta concinna*, and *Pseudodiaptomus annandalei*; (2) ascending during the day and descending at night as in *Corycaeus*; (3) irregular migration as in *Temora discaudata, Centropages gracilis*, and *Calanopia australica*; and (4) weak vertical migration as in *Calocalanus pavo, Pontella fera,* and *Labidocera detruncata* (Tomascik et al. 1997).

Zooplankton abundance and biomass data (1970–1985) are available in the online database (the Global Plankton Database: http://www.st.nmfs.noaa.gov/plankton/), including those of Snellius II Expeditions, especially on the zooplankton production in the Arafura Sea.

Production-oriented studies

Feeding habits of several species of cpepods have been reported from the Indonesian waters. *Paracalanus aculeatus* and *Temora turbinata* are non-selective plant feeders, while *Centropages tenuiremis* and *Acartia pacifica* are ominivores with preference for plant rather than animal diet and *Euchaeta concinna* and *Tortanus discaudatus* are carnivores. A close relationship between feeding habits and the structure of mouth-parts has been found in these species (Chen 1986). Ingestion and absorption of food by copepods have been studied applying ^{14}C (NH^{14}CO$_3$) or ^{35}S (^{35}S-Methionine) isotope labeling techniques. In their study on *Calanoides philip-*

pinensis and *Rhincalanus nasutus* Arinardi and Baars (1986) found that the filtering rate, feeding rate, and absorption rate increased markedly with development of the animals. The absorption efficiency decreased as the food density increased, and remained at a lower level with a further increase of the food density. It seems that superfluous feeding may have been encountered in higher level of food density.

Based on the collections from the Aru Archipelago, Arinardi (1986) studied the breeding periods, sex ratio, and variation in body size of a common upwelling calanoid species, *Calanoides philippnensis*. This species breeds once a year in the eastern part of Indonesian waters in August in the early upwelling period. The ratio of female to male in copepodite V was 1 : 1, but females were much more abundant than males in the adult stage throughout the year. The size of adults varied with area and season but was apparently related to the temperature. They also found that the three species, *Labidocera acuta*, *Temora turbinata*, and *Centropages tenuiremis* involved 9, 6, and 5 generations per year, respectively. The life cycles of some common zooplankton such as rotifers and cyclopoids of North Sulawesi waters were studied in the laboratory with different salinities and microalgae as diet by Rumengan et al. (1998) and Wullur et al. (2004). The effects of temperature on the development of copepods have also been studied by Sutomo (2004) for the coastal copepods, *Euterpina acutifrons*.

Romimohtarto & Yuana (1987) studied the effects of heavy metals on the fecundity of *Acartia pacifica* under controlled laboratory conditions. The number of eggs produced by each female was inversely proportional to the concentration of the heavy metals in the medium. It was indicated that the copepod *Apocyclops* sp. from Sulawesi, Indonesia, is highly sensitive to acute toxicity of tributyltin, suggesting its potential usefulness in environmental assessment (Rumengan et al. 2009). Biological traits of local zooplankton originated from certain estuaries in North Sulawesi, mainly copepods and rotifers reared in the laboratory, have also been studied (Rumengan et al. 1998; Wullur et al. 2004).

Fisheries-oriented studies

Copepod studies concerning their impacts on the fisheries have been limited to some particular areas. Ambon Bay is an important area for fishing of live bait fishes for tuna and skipjack. Yusuf (1979) has shown that zooplankton biomass and composition affects the stock of live bait fishes such as *Stolephorus* spp., *Rastrelliger* sp. and *Sardinella* spp. in Ambon Bay. The occurrence of abundant fish eggs indicates that this area is their spawning ground. There has been much concern on the relationships between the abrupt seasonal increase of certain bait-fish populations, changing zooplankton species diversity, and the impact of climatic change on the zooplankton.

Copepods are the dominant group of zoolankton in the fishing grounds in Indonesia, mainly consisting of *Acrocalanus gibber, Calanopia australica, Parvocalanus crassirostris*, *Acartia erythraea* in the Java Sea, and *Undinula vulgaris, Cosmocalanus darwini Calanopia minor, Calanopia elliptica, Acartia pacifica,* and *Subeucalanus subcrassus* in the eastern Indonesian waters. These copepodes are major foods of the fish such as, sardine (*Sardinella longiceps*), japuh (*Dussumiera acuta*), puri (*Stolepholus indicus*) and anchovy (*S. waitei*) (Arinardi 1998). The abundance of copepods and the productivity of these fishes are positively related. For instance, schooling of fishes takes place in northern and eastern parts of Indonesia waters in August when upwelling occurs and brings in a large quantity of warm water copepods to this area (Arinardi et al. 1990). Some Indonesian scientists studied the feeding habits of several planktivorous fishes, such as *Sardinella longiceps* in Bali Strait. They found this fish fed mainly on planktonic crustaceans that were dominated by copepods with high percentage (85-95%: Soerjodinoto 1960). A similar condition was found in the gut contents of anchovy (*Stolepholus waitei*) in Jakarta Bay; this fish feeds mainly on copepods and other crustaceans (Burhanuddin et al. 1975). *Sardinella fimbrata* feeds also plankton with preference in copepods (Hutomo & Martosewojo 1975). Skipjact also feeds zooplankton mainly copepods and decapod larvae (Sutomo & Arinardi 1978).

Edible giant jellyfishes are among important fisheries resources in Indonesia, as well as in other Asian countries (Omori and Nakano 2001). With the intent to synthesize the historical- and present status of jellyfish fisheries in Indonesia and to better understand the biology and ecology of these jellyfises and other gelatinous animals represented by cnidarians and ctenophores, several researches have been conducted under collaboration of Indonesian and Japanese scientists. These resulted in statistic summaries of jellyfish fisheries, reports on jellyfish processing in factories, taxonomic identification of the targeted species (Omori and Nakano 2001, Nishikawa et al. 2009, Kitamura and Omori 2010), and studies on the relationships between jelyfishes and their symbionts (Ohtsuka et al. 2009).

Future prospects

As reviewed in the previous sections, the zooplankton researches in Indonesia appear to have been conducted with a wide areal coverage, but still lacking comprehensive ecosystem-scale direction. The initial studies on zooplankton were conducted in the frame of international collaboration, but not much followed by national-level well-organized studies led by Indonesian scientists. The richness of biodiversity with the unique characteristics of these tropical seas of ASEAN countries has attracted relevant foreign scientists to develop international scientific collaboration which also inspired a few Indonesian scientists to biodiversity researches, including discovery and description of many new species. Apart from these studies, production-oriented studies were conducted mostly during the Snellius Expedition II in the eastern Indonesian waters.

Long-term monitoring program has not yet been conducted to address the issues related to global warming impacts and anthropogenic contamination in the Indonesian waters, which is among the most urgent researches. It is also noted that still there are numerous undecribed species which have a risk to disappear before being discovered due to their habitat loss as a result of the above environmental changes. With this circumstance, well-organized researches should be developed to generate integrated topics, including such as risk assessments of contaminants on zooplankton and species diversity, and search for indicator species for relevant contaminant.

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